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Research paper

Influence of the interaction between cysticercosis and obesity on rabbit behavior and productive parameters

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ABSTRACT

Parasites induce behavioral changes in the host and obesity is a health problem affecting different animal species. Cysticercosis caused by *Taenia pisiformis* affects some behavior of rabbits and reproductive behavior of does. Rabbits do not escape from metabolic disorders, being long-live animals useful in breeding, research and companion animals. Here, we addressed the interaction between parasitosis and obesity, and studied how these conditions or the comorbidity affect behavioral and productive parameters in bucks infected with 3000 *T. pisiformis* eggs. We found that the chronic infection reduced locomotor activity by 28.5% in obese, 18.5% in infected and 47% in obese-infected group (comorbid). The exploratory activity reduced by 42% in obese, 48% in infected and 68% in comorbid rabbits ($P \leq 0.001$). Chinning was not affected by obesity, while infection decreased it by 25%. Behavioral reproductive parameters like response time, the mount latency and number of ejaculates were affected by infection and obesity. Furthermore, obesity seems to increase the parasite load promoting the formation of liver granulomas (16% granulomas compared with normal weight), with a higher number of cysticerci in obese animals (86% more than normal weight). Infection decreases body weight, body mass index and the zoometric index BW/LV in obese and normal weight rabbits. In conclusion, infection with *T. pisiformis* altered behavioral and productive parameters, and obesity magnifies the impact caused by the infection. Also, obesity leads to major susceptibility to infection with *T. pisiformis*.

1. Introduction

The behavioral changes induced by parasites have been considered a strategy that favors the continuity of the parasitic cycle (Klein, 2003); they are also a tool that can help the presumptive diagnosis of parasitosis, with the advantage that changes are prior to clinical infection (Weary et al., 2009). In the domestic rabbit it has been reported that ectoparasites such as the mite *Psoroptes cuniculi* (Hallal-Calleros et al., 2013) and endoparasites such as *Taenia pisiformis* (*T. pisiformis*) (Betancourt-Alonso et al., 2011), induce behavioral changes in specific behaviors of rabbits, such as chinning and rearing in the case of the mite, and in the case of the cestode there was a decrease in the frequency of grooming and the number of visits to the feeder and the trough.

In rabbits, *T. pisiformis* is the most frequent cestode and one of the more frequent parasites. Its biological life cycle involves the dog or fox as carriers of the adult stage and the rabbit or hares as a host of the metacestode larval stage. This parasitosis can induce lesions in the liver and the formation of granulomas (Flatt and Moses, 1975; Pritt et al., 2012), in addition, it induces a reduction in prolificacy by approximately 40% in rabbit does, and it has been reported as a frequent, sex-associated parasite in wild rabbits (Hallal-Calleros et al., 2016; Domínguez-Roldan et al., 2018).

Behavioral changes in obesity have been scarcely studied, but it has been reported in rats that a cafeteria diet adversely affects reproduction by reducing the number of oocytes and prenatal follicles, besides

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altering the histoarchitecture in follicular layer thickness, while luteinizing hormone and progesterone were not detected in the pre-ovulatory stage in obese rats (Sagae et al., 2012). With respect to obesity on the behavior in rabbits, it has been reported that the males with greater weight have a decrease in the libido and the time that elapses between ejaculations is greater (Rodríguez-De Lara et al., 2015).

With regard to the relationship between obesity and parasites, it has been reported that parasites affect the metabolism of their hosts, specifically energetic metabolism, a condition that has been seen with interest because it represents a potential strategy of treatment and prevention against type two diabetes and obesity, besides proposing a change in the paradigm that parasites only cause negative effects in their guests (Shea-Donohue et al., 2017). Yang et al. (2013) reported that mice fed a high-fat diet and infected with *Nippostrongylus brasiliensis*, had a decrease in body weight (BW) gain and adipose tissue mass, associated with increased glucose metabolism. At the hepatic level, the parasitosis induced a decrease in steatosis, in the expression of lipogenic enzymes, and an improvement of the glucose metabolism. Moreover, in mice fed an obesogenic diet and experimentally infected with the helminth *Schistosoma mansoni*, authors concluded that chronic infection protects against metabolic disorders, since it reduces the size of adipocytes, promotes peripheral glucose absorption and improves sensitivity to insulin (Hussaarts et al., 2015).

It has also been speculated that parasites can protect against metabolic syndrome, based on the observation of an inverse correlation between the incidence of metabolic syndrome and helminth infections (Wiria et al., 2012).

In this paper, the interaction between cysticercosis and obesity is addressed, studying how these conditions affect the susceptibility to parasitic infection, behavioral, and productive parameters, in rabbits experimentally infected with eggs of *T. pisiformis*.

2. Material and methods

Animal care and experimentation practices were followed with adherence to official Mexican regulations (NOM-062-ZOO-1999), which are in strict accordance with all applicable international, national, and institutional guidelines for the care and use of animals.

2.1. Animals and diet

Twenty-eight male New Zealand rabbits, 4.5 month old with a weight of 3.2 ± 0.2 kg were kept in individual wire cages (60 × 90 × 40 cm) under farm conditions, with an average environmental temperature of 19 ± 3 °C. Food was provided according to the experimental design of each group, and water *ad libitum*.

The 28 rabbits were randomly allocated to one of four groups (n = 7). Two groups were kept normal, feeding them with a commercial pellet maintenance diet (Ganador®, Malta Cleyton, Mexico, minimum 16% protein, 3% fat and 17% fiber), providing 180 g of feed per day per rabbit (NRC, 1997). The other two groups were induced to obesity through providing a high-calorie diet high in fat (Antic et al., 1999), consisting of the commercial maintenance diet, to which 5% of soybean oil and 5% of lard were added. This diet was provided *ad libitum* for eight weeks prior to infection and throughout the experiment.

2.2. Infection

After eight weeks of diet, a normal-weight group and an obese group were infected with eggs of *T. pisiformis*. Proglottids of *T. pisiformis* were collected from the feces of an infected dog, washed, identified and maintained in accordance with the method described by Flatt and Moses (1975). Proglottids were mashed in saline solution using a scalpel. Viable eggs were quantified using a hemocytometer and rabbits were orally infected with 3000 eggs by esophageal administration using a sterile plastic tube (Betancourt-Alonso et al., 2011).

2.3. Open field test

Locomotor activity, rearing and chinning behaviors were recorded every other day during ten minutes in a 120 cm × 120 cm open field arena made of wire mesh, placed on the floor of a room contiguous to that in which the rabbits were housed. The arena was divided into 9 squares (40 × 40 cm) by lines painted on the floor. Locomotor activity (ambulation) was quantified as the number of times the rabbit crossed one of these lines during the observation period. Three stacked bricks previously scrubbed with water, were placed inside the arena, and the number of times the rabbit rubbed its chin against the bricks was quantified. Rearing behavior was quantified as the number of times the rabbit reared up on its hind legs (Hallal-Calleros et al., 2013).

2.4. Reproductive behavior

Fourteen ovariohysterectomized rabbits induced to estrus with 10 μg of estradiol propionate intramuscularly 7 days before (Hudson et al., 1990) were used. The does were placed in cages with the bucks for 6 min (Fuentes et al., 2004). The reaction time of males was evaluated as the time period that elapses between the entrance of the rabbit to the cage and the first mount or attempt to mount (Rodríguez-De Lara et al., 2015). Attempts to mount were counted as the times that the buck place himself on the hind quarter of the doe without achieving penetration or ejaculation. Ejaculations were defined as the times that the male place himself on the doe and had an ejaculation, manifested by the characteristic behavior that includes rapid pelvic movements with loss of balance, falling to the side or back (Contreras and Beyer, 1979). Latency was evaluated as the time interval between a mount with ejaculation and the next mount with or without ejaculation (Fuentes et al., 2004).

2.5. Semen collection

The semen of the rabbits was collected using an artificial vagina; a rabbit doe was introduced in the cage of the buck, the operator held the underneath the rabbit artificial vagina provided with a graduated collection tube at 39 °C, until obtaining the semen (IRRG, 2005). The volume of semen was determined directly in the graduated tube connected to the artificial vagina. The total number of spermatozoid per ejaculate was obtained by counting them in the fresh semen diluted 1:100 in 3% sodium chloride solution, in a Neubauer chamber (Fausto et al., 2001). Spermatozoid motility was determined by placing 10 μL of semen on a slide and observing 200 sperm under a microscope, assigning a value of 0 if the sperm had no mobility, 25 non-progressive mobility, 50 slow progressive mobility, 75 progressive mobility and 100 fast progressive mobility (WHO, 2010).

2.6. Body weight, body mass index and Zoometric index

Body weight (BW) was measured weekly with a digital scale during the entire experiment.

The body mass index (BMI) was obtained dividing the BW by the distance from the dorsal border of the arm to the distal phalanx of the thoracic limb (BW/DFL). The zoometric index (ZI) was obtained by dividing the BW between the vertebral length (VL), measured as the distance from the occiput to the sacral-caudal junction, following the curvature of the vertebral spine, according to previous studies in rabbits referred by Sweet et al. (2013).

2.7. Blood glucose

Every two weeks, after 12 h of fasting, a drop of blood was obtained from the marginal vein of the ear, immediately measuring blood glucose levels with a glucometer (Contour™TS®, Bayer).

2.8. Parasite load

At eight weeks post infection the peritoneal cavity, mesentery, liver and spleen were inspected and the number of cysticerci and granulomes found in humanely sacrificed rabbits were counted (Betancourt-Alonso et al., 2011). Sacrifice was carried out with a lethal dose of pentobarbital (100 mg/kg) in rabbits previously anesthetized with xylazine/ketamine (35/5 mg/kg) (AVMA 2001).

2.9. Statistical analysis

Prior to the infection, the effect of the diet over 8 weeks on the weight was compared with the Student *t*-test. For locomotor activity, chin marking behavior and exploratory activity the differences were established obtaining the total values of the analyzed variables and compared with an ANOVA test, while the weekly data was compared between groups using a 2-way repeated measures mixed model approach (groups as the treatment factor and weeks as the repeated factor), followed by a multiple Tukey's test; and for the comparison over time with respect to the beginning of the infection a multiple Student *t*-test was used. For the reproductive variables response time, mounting attempts, latency period, number of ejaculates and spermatobioscopy an ANOVA test was used. To establish differences during 8 weeks post infection on the variables BW, BMI and ZI, we used a 2-way repeated measures mixed model approach (groups as the treatment factor and weeks as the repeated factor), followed by a multiple Tukey's test; and for the comparison in time with respect to the beginning of the infection in the same group we used the multiple Student *t*-test. To establish differences between the number of granulomas the Mann Whitney test was used, and to compare the number of metacestodes the Student *t*-test. Blood glucose concentrations were compared in the post-infection period by comparing the control group *vs* the three groups with a 2-way repeated measures mixed model approach (groups as the treatment factor and weeks as the repeated factor), followed by a multiple Tukey's test. All data are presented as the mean ± SEM, and significance was considered with a $P \leq 0.05$ (Bate and Clarck, 2014). The statistical software *in vivo* stat 3.7 was used.

3. Results

3.1. Induction of obesity in rabbits

A batch of 28 males (3.2 ± 0.02) was randomly divided into two groups. One of the groups was fed with a maintenance diet, reaching a weight of 3.45 ± 0.03 after eight weeks, while the group fed with an obesogenic diet reached a weight of 4.2 ± 0.04 kg (****$P \leq 0.0001$).

3.2. Open field test

3.2.1. Locomotor activity

We observed that obesity induced a decrease of about 22% in the locomotor activity of obese rabbits, compared with normal weight rabbits (prior to infection, $P \leq 0.05$, Fig. 1a). Infection with *T. pisiformis* reduced locomotor activity by 18.5% compared with the control group ($P \leq 0.05$), with a significant decrease observed at weeks 15 and 16 post-infection (Fig. 1b, c). Obesity decreased locomotor activity by 28% *vs* the control group ($P \leq 0.01$); this decrease was observed from week 6 post-infection and until the end of the experiment, week 16 (Fig. 1b, d). In obese-infected rabbits, the decrease in locomotor activity was 47% *vs*. the control group (Fig. 1b, $P \leq 0.01$); the decrease was observed from week 5 and remained until week 16. The infection caused the decrease in locomotor activity late and to a lesser extent in relation to obesity and obesity-infection comorbidity. The co-morbid group presented a greater and earlier decrease in locomotor activity, and it was sustained over time (Fig. 1e).

3.2.2. Exploratory activity

Obesity induced a 29% reduction in exploratory behavior compared with the control group, previous to infection (Fig. 2a, $P \leq 0.05$), and the infection caused a 48% decrease (Fig. 2b, $P \leq 0.001$). The highest decrease was recorded at week 16 (Fig. 2c). After infection, obesity decreased a 42% in exploratory activity (Fig. 2b, $P \leq 0.01$), observed from week 8 and until week 16. At the end of the experiment, exploratory behavior decreased by 61% compared with the control group (Fig. 2d). With the comorbidity obesity-infection, the decrease of locomotor activity was similar (62%, $P \leq 0{,}0001$). The weekly mean of rearings in the obese-infected group ranged from 1.7 to 3.8, while in control group it was and from 5.5 to 9.5 (Fig. 2e).

3.2.3. Chin marking behavior

The behavior of chin marking was not affected by obesity (Fig. 3a and d, $P \geq 0.05$), however, the infection reduced chinning behavior by 28% (Fig. 3b, $P \leq 0.05$), practically from the beginning of the infection until week 16, in which a 33% decrease was observed compared with the control group (Fig. 3c). In the obese-infected group there was a 25% decrease in chinning behavior from the beginning of the infection (Fig. 3b, $P \leq 0.05$) and a 41% decrease at week 16, compared with the control group (Fig. 3e). Notably, the infection reduces the chinning behavior in a similar manner to the comorbidity infection-obesity, without a notorious effect of obesity.

3.3. Reproductive behavior

The reproductive parameters analyzed were affected by obesity and by infection (Fig. 4). In the response time (first mounting attempt) an additive effect of the infection and obesity was observed, since, while the infection itself induced an increase in the response time of 2.5 times (9.9 *vs* 24.8 s $P > 0.05$) and obesity itself induced an increase of 7 times (9.9 *vs* 71 s, $P \leq 0.0001$), the co-morbidly induced an increase of 10 times (9.9 *vs* 101.1 s, $P \leq 0.0001$) (Fig. 4a). Mount attempts were not affected by the infection itself, and although with obesity and the co-morbidity obesity-infection a significant decrease is observed, this change is modest (13 and 23% decrease, respectively $P \leq 0.05$) (Fig. 4b). The period of latency (time between one mount and another) is observed altered only in obese-infected animals, with an increase in time of 47 s compared with the control group (Fig. 4c, $P \leq 0.01$). In the number of ejaculates an impact of the infection is observed, decreasing by 42% (from 2.37 to 1.37 times, $P \leq 0.001$), whereas in the obese group it decreased 24% (from 2.37 to 1.8 times) and in obese-infected 47.3% (from 2.37 to 1.25 times, $P \leq$) (Fig. 4d).

Spermatobioscopic parameters at weeks 0, 4 and 8 post-infection did not show differences between groups (volume of ejaculate, sperm concentration and sperm motility). At week eight, the values of volume of semen were 0.63 ± 0.03 for control group, 0.67 ± 0.04 for infected, 0.70 ± 0.04 for obese and 0.70 ± 0.04 for infected-obese ($P = 0.710$). For sperm concentration, the values were 559 ± 7.8, 547 ± 10.4, 542 ± 8.3, 546 ± 7.9 for control, infected, obese and infected-obese, respectively ($P = 0.316$). Percentage of motility was 84.2 ± 2, 85.7 ± 1.9, 85.2 ± 2, 83.3 ± 1.9 for control, infected, obese and infected-obese, respectively ($P = 0.053$).

3.4. Body weight, body mass index and zoometric index

Comparing the weight gain dependent on the infection (control *vs* infected, and obese *vs* obese-infected), in the normal-weight animals it was observed a gain of 120 g less than control group in weeks 6, 7 and 8 (Cr *vs* infected, $P \leq 0.0001$). The obese-infected group, starting at week 1, had a lower weight compared with the obese group that was not infected ($P \leq 0.001$), observing that this difference was maintained in the subsequent weeks, with a gain of 230 g less in those infected at week 8 (Fig. 5a). Our results show an affectation in the weight gain induced by the infection that represents 3.3% of the total weight in

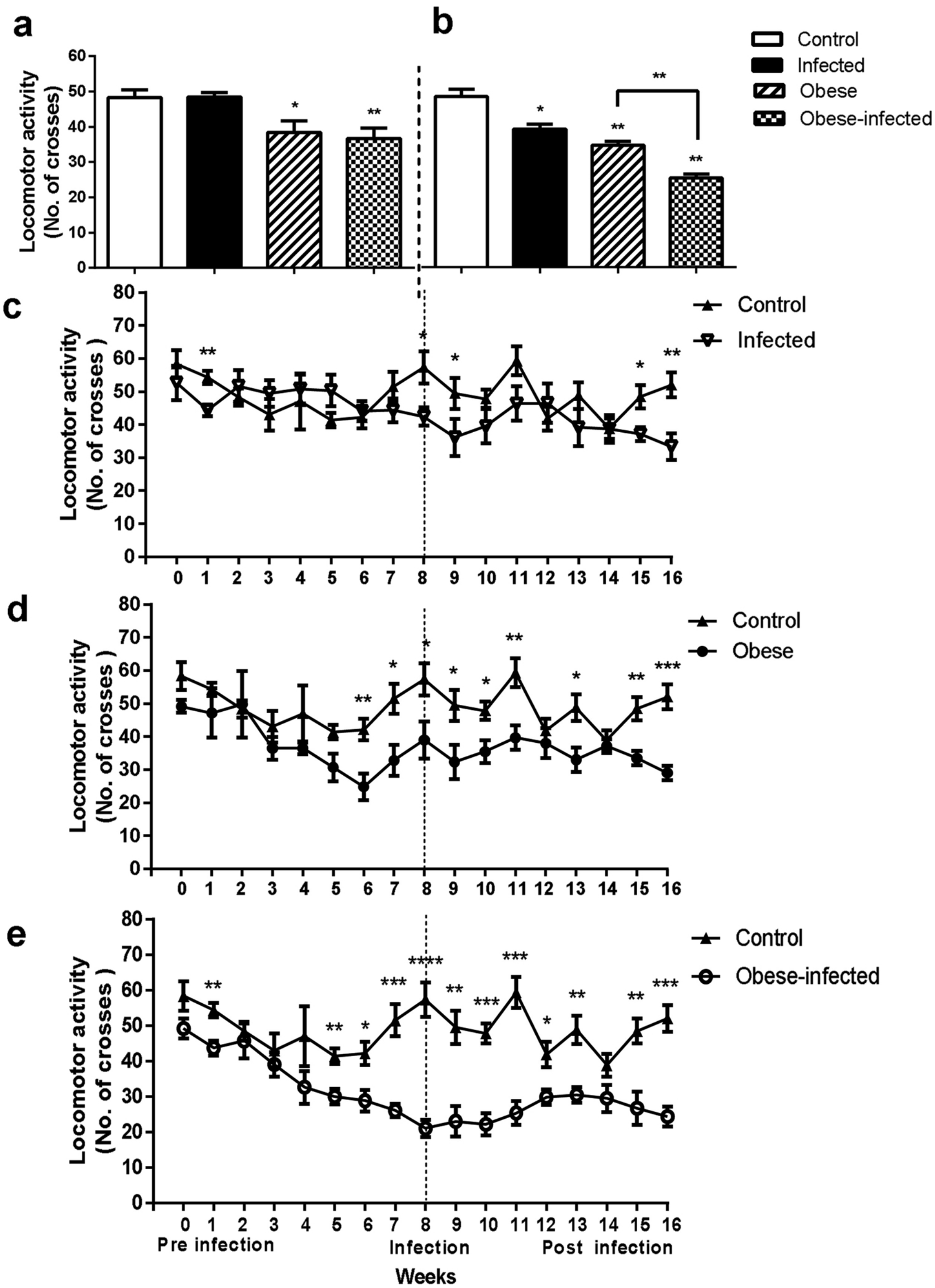

Fig. 1. Locomotor activity in rabbits is affected by obesity and by infection with *T. pisiformis* eggs. Total locomotor activity during 16 weeks, comparison Control *Vs* Infected, Obese and Obese-infected. Brackets indicate comparison between groups, mean ± SEM (**P* ≤ 0.05, ** *P* ≤ 0.01). Locomotor activity through eight weeks pre-infection (a) and eight weeks post-infection (b) in Control and Infected (c), Obese (d) or Obese-infected rabbits (e). Mean ± SEM (**P* ≤ 0.05, ** *P* ≤ 0.01, *** *P* ≤ 0.001).

normal animals and 4.7% in obese animals.

Analyzing the BW over time in a same group, it was noted that from the infection (week zero, Fig. 5a), in the control group there was an increase of weight since the second week (*P* ≤ 0. 05), achieving an increase of 6% at week 8 post infection (P ≤ 0.0001) compared with the initial weight (week zero). An increase in BW since week 3 (*P* ≤ 0.05) was observed in the infected group, and in week 8 they achieved an increase of just 3% compared with the initial weight (*P* ≤ 0.05), showing that infection induced a delay of a week in the weight gain and a 3% less regarding to the control group. The weight in the obese group increased since week 2 (*P* ≤ 0.01), reaching a 5% more at week 8 (*P* ≤ 0.0001) compared with the initial weight (week zero). In the obese-infected group, the weight gain was observed from week 6 (*P* > 0.05), and in week 8 it reached just 2% more compared with the initial weight (*P* ≤ 0.05) (Fig. 5a). Thus, the infection affects weight gain over time, both in normal weight and in obese animals, achieving an increase of 50% less than the observed in non-infected animals. The BMI (Fig. 5b) and the ZI (Fig. 5c) did not change through the time in any of the control, infected or obese-infected groups. In the obese group, both indices were higher in week 7 (P ≤ 0.001) and BMI increased also in week 8 (P ≤ 0.05) compared with the week zero. The differences between groups dependent on the infection (control *vs* Infected, and obese *vs* obese-infected) were observed at week three and all the subsequent weeks (Figs. 5b and c). Serum glucose was monitored, without alterations suggestive of diabetes induced by the diet (Fig. 6).

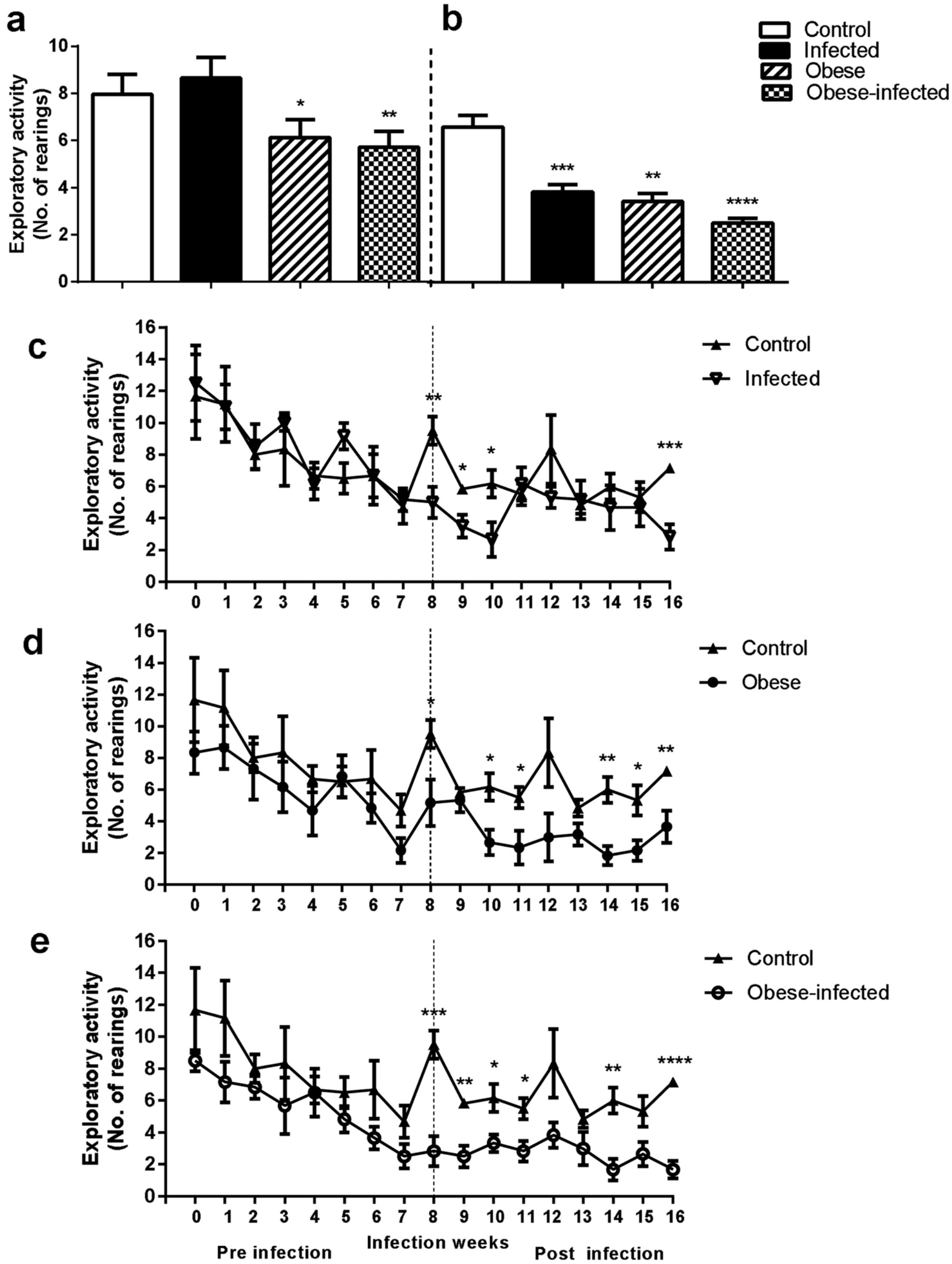

Fig. 2. Exploratory activity in rabbits is affected by obesity and by infection with *T. pisiformis* eggs. Total rearing during 16 weeks, Comparison Control *Vs* Infected, Obese and Obese-infected. Mean ± SEM (*$P \leq 0.05$, ** $P \leq 0.01$). Rearing through eight weeks pre-infection (a) and eight weeks post-infection (b) in Control and Infected (c), Obese (d) or Obese-infected rabbits (e). Mean ± SEM (*$P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

3.5. Parasite load

At necropsy (8 weeks post-infection), the number of metacestodes was increased by obesity (44 *vs* 82), being 6.28 ± 1.1 per rabbit compared with 11.7 ± 3.1 in non-obese rabbits ($P = 0.0231$). In contrast, the number of hepatic granulomes was reduced to 4 in the Obese-infected group compared with the 25 that were observed in the infected group ($P = 0.0361$). In the control and obese groups, no metacestodes were found. In conclusion, obese animals develop 86% more metacestodes of *T. pisiformis* than normal-weight animals and only 16% of granulomas with regard to normal weight animals.

4. Discussion

The behavioral changes observed coincide with others that have shown that when rabbits are infected by parasites, such as the mite *P. cuniculi*, ambulatory, exploratory and chinning activity behaviors are diminished (Hallal-Calleros et al., 2013) and when they are infected with cysticercosis by *T. pisiformis*, the percentage of time spent lying down, grooming and drinking water are altered (Betancourt-Alonso et al., 2011).

In the specific case of *T. pisiformis* it is important to consider that the metacestode are the infective stage, thus, a decrease in locomotor activity in the rabbit in a natural environment will favor the capture process by a dog, fox or coyote, increasing the chances of generating the adult phase or taenia in the intestine and the continuation of the parasitic cycle. Then, in rabbits with the comorbidity obesity and infection, where the locomotor activity decreases, the transmission of the parasite can be facilitated.

The decrease in the number of rearings through the time is probably

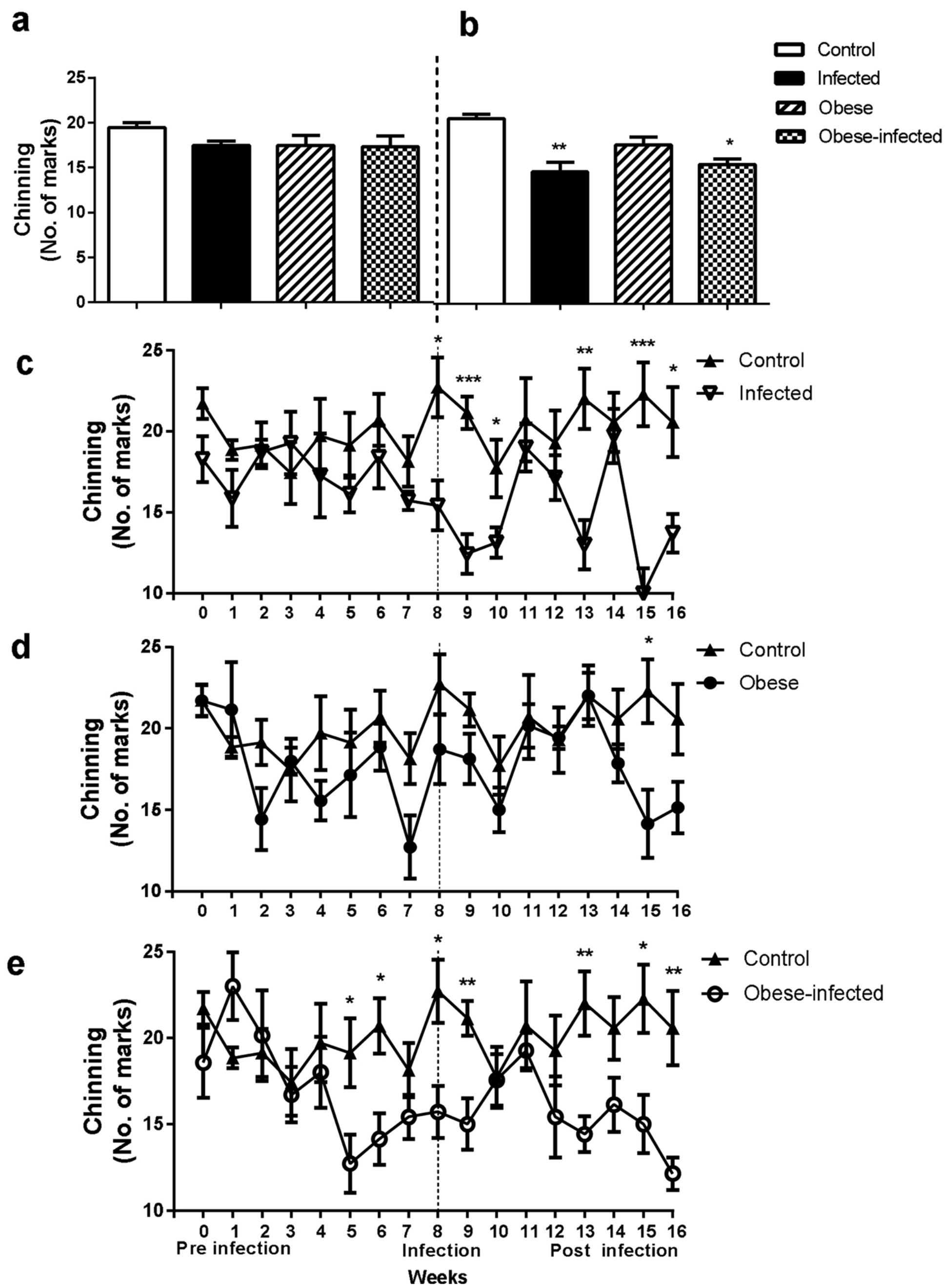

Fig. 3. Chin marking behavior is affected by obesity and by infection with *T. pisiformis* eggs. Total chinning during 16 weeks, Comparison Control *Vs* Infected, Obese and Obese-infected. Mean ± SEM (*$P \leq 0.05$, ** $P \leq 0.01$) (a). Chinning through eight weeks pre-infection (a) and eight weeks post-infection (b) in Control and Infected (c), Obese (d) or Obese-infected rabbits (e). Mean ± SEM (*$P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

due to the habituation of the rabbit to the arena where the behavioral tests are performed, having less need to explore the environment. However, despite the progressive habituation, there is a decrease on this behavior, caused both by obesity and infection.

The behavior of chin marking is associated with social rank and with sexual behavior, since it is related to changes in serum testosterone levels and with dominance (Mykytowycz, 1962; Arteaga et al., 2008). The observed decrease in chinning and altered sexual behavior in our work, coincides with diminution of sexual behavior reported in other cestode infections, specifically during infection with *T. crassiceps* cysticerci in mice, where testosterone levels are diminished (Larralde et al., 1995). Although testosterone levels were not measured in this study, alterations of this hormone could partially explain the fact that chinning and sexual behavior decreases to a greater degree in those rabbits that are infected, either normal weight or obese.

The decrease in the number of mounts coincides with a study in mice infected with *T. crassiceps* metacestodes. At 6 weeks after infection, they observed changes in the number of mounts and other sexual behaviors of the male, including disorders in the ejaculation and hormonal changes that resulted in a process of feminization (Morales et al., 1996). The spermatic alterations differ with our work, since we did not observe disorders in the ejaculate. These differences may be related to the experimental model, since infection with *T. crassiceps* is massive, representing a more severe infection model in which it is expected to observe more marked alterations, while in rabbits, our infection model is very similar to that occurring naturally. Another study in male rats infected with larvae of *T. taeniaeformis* reported a lower rate of mounts (29%) when compared with Control group at month five post-infection,

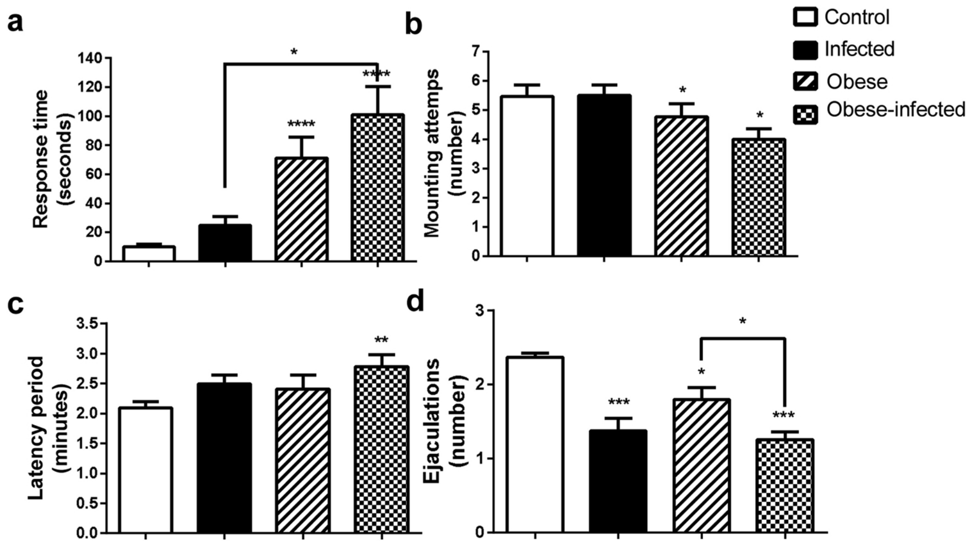

Fig. 4. Total sexual behavior in male rabbits for 8 weeks post-infection. Response time (a), Mounting attemps (b) Latency period (c) and Number of ejaculates (d). Mean ± SEM (*$P \le 0.05$, ** $P \le 0.01$, ***$P \le 0.001$).

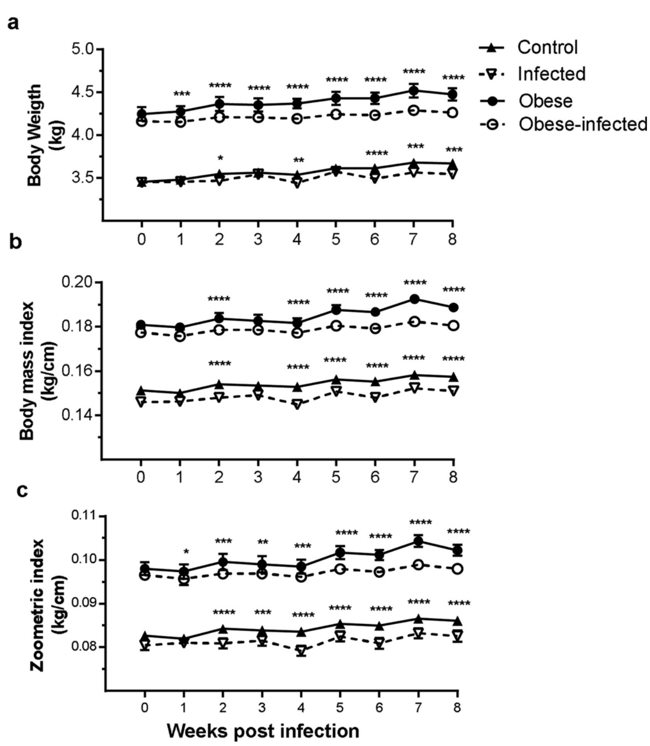

Fig. 5. *T. pisiformis* infection affects weight gain. Body weight (a) body mass index (BW/DFL) (b) and (c) zoometric index (BW/LW) through eight weeks post-infection. Mean ± SEM (*$P \le 0.05$, **$P \le 0.0001$, Infected *vs* Control and Obese *vs* Obese-infected).

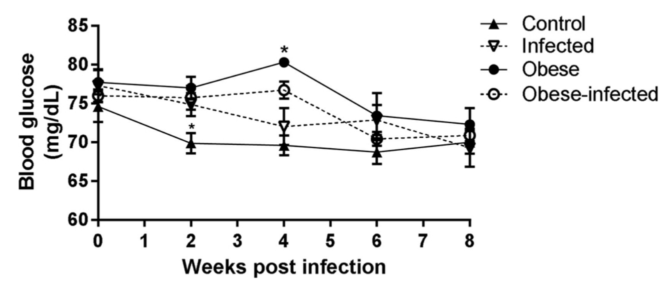

Fig. 6. Serum glucose. It was monitored weekly in male rabbits during 8 weeks post-infection. Mean ± SEM (*$P < 0.05$).

attributing it to a decrease in serum testosterone (Rikihisa et al., 1985). On the other hand, the reaction time is part of the libido behavior.

In obese rabbits the reaction time increased 7 times with infection and it was up to 10 times higher in obese-infected rabbits, also affecting the refractory time (latency period) in this group. Previously, it was reported that the BW increases the reaction time, therefore it was concluded that the weight affects the libido (Rodríguez-De Lara et al., 2015). Also it has been proposed in cattle that the natural infection with *Trypanosoma vivax* induces a decrease in libido (Bittar et al., 2015), however, in that work the reaction time of the animals was not quantified, but the libido was measured using a categorical scale. The infection with *T. pisiformis* did not modify the volume of the ejaculate, sperm concentration or percentage of motility. Similarly, *Trypanosoma vivax* infectection did not modified the sperm parameters such as sperm concentration, motility and sperm strength in cattle (Bittar et al., 2015). It was also mentioned that the spermatic volume increased in the infected animals.

The increased susceptibility to infection caused by obesity may be related to the diminished immune response (Hegde and Dhurandhar, 2013), thus, retaining less eggs *via* the portal circulation and allowing the development of more cysticerci. We observed a reduction of hepatic granulomas, and it has been proposed that the migration of the eggs into the host can be through three routes in the small intestine. The first is through the intestine reaching the peritoneal cavity and developing to cysticerci, the second is through the lymphatic vessels near the intestine to reach the peritoneum, and the third, the one proposing that has oncospheres pass through the wall of the intestine and reach the liver by portal circulation, where some of them can be encapsulated forming granulomas, but others can evade the immune response and they pass to the main circulation, establishing mainly in the peritoneal cavity (Heath, 1971). In humans and in obese mice there is a decrease in the cells associated with Th2 immune response and an increase in cells associated with Th1 response inducing the characteristic stage of low grade chronic inflammation (Guigas and Molofsky, 2015). Thus, if immunity at the local level in obese individuals is altered and the ability to generate granulomas is reduced, the development of a greater number of oncospheres maturing to metacestodes is allowed, as we observed.

In animal-oriented medicine, specifically in rabbits, there is no measure comparable to the IMC. However, recently Sweet et al. (2013)

proposed a ZI, similar to the BMI calculated through the formula BW/LV; in our work, it was observed that the BW, the BMI and the ZI behaved similarly in the experimental groups. Experimental infection with *T. pisiformis* eggs in normal weight individuals affects BW, while in obese individuals, the parameters that are affected with greater magnitude are the BMI and the ZI, in addition, this alteration is more early than in normal weight. Gastrointestinal parasites that infect children, induce a negative correlation between the hormone leptin and the body mass index, unlike what happens in non-infected patients where this correlation is positive (Yahya et al., 2018); an increase in leptin expression and a decrease in adiponectin were also observed in pediatric patients infected with *E. histolytica* and *Strongyloides*. In addition, the double infection with *E. histolytica* and *Giardia* caused the greatest increase in leptin, suggesting that the lack of regulation of these two hormones causes alteration in the intestinal absorption of some nutrients, thus altering the rate of body mass leading to anorexia. We did nor recorded the voluntary intake, but in rabbits infected with the mite *Psoroptes cuniculi*, it was observed a decrease in voluntary consumption and in BW (Hallal-Calleros et al., 2013). Future research should elucidate the mechanisms by which this phenomenon occurs. As well as the productive interest in animals, may be of interest in problems associated with overweight and obesity.

5. Conclusions

In this work we conclude that obesity magnifies altered behavior and increase parasite load and BW that are caused by infection with *T. pisiformis*.

Declaration of Competing Interest

The authors declare that they have no conflict of interest

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