Production of *Toxocara cati* TES-120 Recombinant Antigen and Comparison with its *T. canis* Homolog for Serodiagnosis of Toxocariasis

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Abstract. Toxocariasis is a cosmopolitan zoonotic disease caused by the infective larvae of *Toxocara canis* and *T. cati*. Diagnosis in humans is usually based on clinical symptoms and serology. Immunoglobulin G (IgG)-enzyme-linked immunosorbent assay kits using *T. canis* excretory–secretory (TES) larval antigens are commonly used for serodiagnosis. Differences in the antigens of the two *Toxocara* species may influence the diagnostic sensitivity of the test. In this study, *T. cati* recombinant TES-120 (rTES-120) was cloned, expressed, and compared with its *T. canis* homolog in an IgG4-western blot. The diagnostic sensitivity and specificity of *T. cati* rTES-120 were 70% (33/47) and 100% (39/39), respectively. *T. canis* rTES-120 showed 57.4% sensitivity and 94.4% specificity. When the results of assays using rTES-120 of both species were considered, the diagnostic sensitivity was 76%. This study shows that using antigens from both *Toxocara* species may improve the serodiagnosis of toxocariasis.

INTRODUCTION

Toxocariasis is a global zoonotic parasitic disease caused by the infective larva of *Toxocara canis* and *T. cati*. Humans are infected by accidental ingestion of soil/dirt contaminated with embryonated eggs and/or consumption of paratenic hosts harboring the larvae. The hatched larvae penetrate the human gut wall and migrate to the liver, lungs, and other organs. They cannot develop further and remain trapped in the body tissue, causing a spectrum of clinical illness.

Most cases of human toxocariasis have been attributed to *T. canis*, and there are few reports on the role of *T. cati* in causing the disease. Because cats are a very common pet and the cat population is high, humans can also be expected to be infected with *T. cati* through similar routes as *T. canis* infection. Furthermore, sandboxes and garden soil are more often polluted with *T. cati* than *T. canis* eggs, which could further the role of *T. cati* in causing toxocariasis.

Clinical manifestations of toxocariasis in humans vary according to the number of larvae and the affected organs; they include visceral larva migrans, ocular larva migrans (OLM), neurological larva migrans, and covert toxocariasis. Diagnosis of toxocariasis is often difficult, and is primarily based on clinical signs and symptoms and serodiagnosis. Imaging techniques are also helpful in some cases. The patient’s history, including asthma, travel to tropical areas, contact with domestic animals, and consumption of undercooked meat or liver should also be considered.

Serodiagnosis of toxocariasis is often performed using commercial immunoglobulin G (IgG)-ELISA kits (IBL International GMBH, Hamburg, Germany) that use *T. canis* excretory–secretory (TES) antigens of *T. canis* second-stage (L2) larvae. Production of native TES antigen is a laborious time-consuming technique and the yield is limited. Furthermore, cross-reactivity is an issue in countries with prevalent soil-transmitted helminths. Thus, the use of specific recombinant antigens with high diagnostic sensitivity and specificity is preferable.

Despite many similarities in the antigens of *T. canis* and *T. cati*, some differences in antigenic molecules are expected; thus, it is likely that some cases of *T. cati* infection may be missed by tests targeting *T. canis*, and more research on *T. cati* antigens for serodiagnosis of toxocariasis is needed. The aim of this study was to clone and express a *T. cati* recombinant antigen, *T. cati* rTES-120, and compare its seroreactivity with the *T. canis* homolog.

MATERIALS AND METHODS

Collection of *T. cati* second-stage larvae. Adult female *T. cati* were collected from the intestines of stray cats and kittens, and the mature worms were washed with phosphate-buffered saline (PBS), pH 7.2. The uteri of gravid worms were dissected and the fertile eggs were placed in a 2.5% formalin solution. This was incubated at 28–30°C for 30 days to allow for embryonation of the larvae. Larvae were harvested and processed according to methods by Alcantara-Neves and others and Mohamad and others. In brief, the formaldehyde was removed by washing five times with sterile PBS. An equal volume of 7–14% sodium hydrochloride (Sigma-Aldrich, St. Louis, MO) was added, and the solution was placed on a shaker at room temperature for 15 minutes until the eggs lost their external layer. Since sodium hydrochloride is very toxic to the larvae, the decoated eggs were then washed 10 times with sterile PBS. Approximately 10 mL of RPMI-1640 medium (Sigma-Aldrich) containing 100 IU/mL penicillin (Sigma-Aldrich), 100 μg/mL streptomycin (Sigma-Aldrich), and 2.5 μg/mL amphotericin B (Sigma-Aldrich) was added to the eggs, followed by incubation at 37°C with continuous bubbling of a 5% CO2 gas mixture in 95% nitrogen for 1 hour. The suspension was transferred to a Baermann apparatus. The collected larvae were washed two times with cold sterile RPMI-1640 medium and transferred into a microcentrifuge tube. The number of larvae in each microcentrifuge tube was recorded. Finally, 10 times volume of an RNA stabilization reagent (RNAlater, Qiagen, Hilden, Germany) was added to the tube.

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placed at 4°C for 2 hours, and stored at –80°C. The use of the animals and the study protocol was approved by the Animal Research Ethics Committee of Shiraz University of Medical Sciences.

**Human serum samples.** A total of 86 serum samples from Iran and Malaysia were used. This comprised 47 serum samples from patients diagnosed with toxocariasis based on clinical symptoms and serology and 39 control serum samples. The latter were from 20 healthy individuals and 19 patients with other diseases, including ascariasis (N = 2), strongyloidiasis (N = 1), taeniasis (N = 2), hydatidosis (N = 4), hynemolepiasis (N = 2), fascioliasis (N = 2), leishmaniasis (N = 3), malaria (N = 2), and toxoplasmosis (N = 1). All serum samples were tested with a commercial T. canis IgG-ELISA kit to confirm that the toxocariasis serum samples were positive and the control samples were negative for the anti-Toxocara IgG antibody. The use of the aforementioned stored serum samples was approved by the human research ethics committees of the institutions involved in this study. The Research Ethics Committee at Shiraz University of Medical Sciences reviewed the proposal and approved the collection and use of the patients’ samples (ref. no, 2015-258). The Human Research Ethics Committee at Universiti Sains Malaysia permitted the use of previously banked serum samples at Institute for Research in Molecular Medicine (INFORMM) for diagnostic test sensitivity and specificity determination.

**RNA extraction.** Total RNA was extracted from T. cati larvae using an RNasy Mini kit (Qiagen, Hilden, Germany) according to the manufacturer’s protocol. Briefly, the larvae in RNA later solution were removed from the –80°C freezer and centrifuged for 10 minutes at 16,000 × g. The pellets were washed with 1 × PBS to remove any remaining RNA later solution, lysis buffer was added, and the suspension was passed 10 times through a 20-gauge (0.9 mm) needle attached to a 1 mL sterile plastic syringe to obtain a homogenous lysate. This was followed by the addition of ethanol to the lysate, and the mixture was applied to the RNeasy Mini spin column. Total RNA bound to the membrane in the column and was eluted in RNeasy-free water. The yield and purity of the total RNA were assessed using a NanoPhotometer™ (Implen GMBH, München, Germany) and stored at –80°C.

**Complementary DNA synthesis and polymerase chain reaction amplification.** Conventional reverse transcriptase polymerase chain reaction (RT-PCR) was performed using Easy-A one tube RT-PCR System (Agilent Technologies, Santa Clara, CA), according to the manufacturer’s instructions. The TES-120 forward and reverse primers were the same as that used previously and were designed on the basis of the coding sequence of the T. canis TES-120 gene (GenBank: U39815), namely: TES-120 F, 5’-ATGCAAGTCCCTATCCGTGATGCT-3’ and TES-120 R, 5’-ACAGGAGGCGACGTCAATGGG-3’. The RT reaction mix was prepared in a 1.5 mL tube by adding 6.2 μL of RNase-free water, 0.8 μL of 10 μM of RNase-free water, 0.1 μL of Easy-A Reverse Transcriptase, 1 μL of RT buffer, and 1 μL RT enzyme. A Master Mix was prepared by mixing 19.25 μL of RNase-free water, 2.5 μL of 10 × RT-PCR buffer, 0.5 μL of each forward and reverse primer, and 0.5 μL dNTP (40 mM) mix. Then, 0.5 μL of the RT mix, 0.25 μL of Easy-A High Fidelity PCR cloning enzyme, and 1.5 μL of RNA (20 ng) template were added to the Master Mix. PCR was performed as follows: first-strand synthesis at 45°C for 15 minutes; denaturation at 95°C for 1 minute; 40 cycles of denaturing at 95°C for 1 minute, template-primer annealing at 65°C for 1 minute, and extension at 68°C for 2 minutes; and final extension at 68°C for 10 minutes. Analysis of the PCR-amplified product was conducted using 1% (w/v) agarose gel electrophoresis run at 100 V for 1 hour. The expected band of ~528 bp was excised using a sterile cutter, and DNA from the gel band was extracted using the QiAquick gel extraction kit (Qiagen) according to the manufacturer’s instructions.

**Cloning of the T. cati TES-120 gene.** A-tailing of the purified PCR product was performed by incubating 100 ng of PCR product with 1 × polymerase buffer supplemented with 25 mM MgCl₂, 1 μL of dATP (25 μM), and 0.15 U of Taq polymerase (Thermo Scientific, Rockford, IL) at 72°C for 30 minutes. Ligation of the A-tailed product to pCR®-2.1-TOPO® TA vector (Invitrogen, Carlsbad, CA) was performed according to the manufacturer’s protocol. A volume of 1 μL of the ligated product was transformed into Escherichia coli TOP10 cells (Invitrogen) by electroporation. The cells were resuspended with 1 mL of LB broth and incubated for 1 hour at 37°C. The culture was then plated on an LB agar plate supplemented with ampicillin (100 μg/mL) and X-gal (20 mg/mL) at 37°C overnight. Plasmid preparations from overnight culture of five white colonies were sent for DNA sequencing using vector-specific (M13) and gene-specific (TES-120) primers.

**Sequence analysis.** Sequence analysis was performed using BioEdit software (version 7.2.5; Ibis Biosciences, Carlsbad, CA). All sequencing results were manually aligned to produce a consensus sequence. The consensus sequence was then compared with the reported sequence of the T. canis TES-120 gene (GenBank: U39815).

**Subcloning of the T. cati TES-120 gene into an expression vector.** Subcloning of the T. cati TES-120 gene into the pGEX-4T-1 expression vector (GE Healthcare, Little Chalfont, United Kingdom) was outsourced to Epoch Life Science Inc. (Missouri City, TX). The gene was codon optimized for expression in E. coli before it was synthesized, and then it was cloned into the expression vector. Upon receipt of the recombinant plasmid (T. cati rTES-120/pGEX-4T-1), it was transformed into E. coli BL21(DE3) (New England Biolabs Inc., Ipswich, MA).

**Expression and purification of T. cati TES-120 recombinant antigen.** A single colony of the recombinant bacteria was grown overnight in 250 mL of Terrific Broth (TB) supplemented with 100 μg/mL of ampicillin in a shaking incubator at 37°C. A volume of 50 mL of the culture was inoculated into 4 L of TB-ampicillin broth and cultured in a shaking incubator at 37°C until the optical density (OD₆₀₀) reached 0.4–0.6. Protein expression was induced by adding 1 mM isopropyl-β-D-thiogalactopyranoside (IPTG, Thermo Scientific, Waltham, MA) for 3 hours at 28°C in a shaking incubator.

The recombinant bacterial cells were harvested by centrifugation (10,000 × g, 30 minutes, 4°C) and the pellet was resuspended in 4 mL of ice-cold 1X GST Bind/Wash Buffer provided in GST Bind™ kit (Novagen, Darmstadt, Germany) per 100 mL culture. Lysozyme (Amresco, Solon, OH) at 0.5 mg/mL and a cocktail of protease inhibitors (Roche Diagnostics, Deutschland GMBH, Mannheim, Germany) at 14.8 μg/mL were added to the suspension and incubated on ice for 30 minutes. The cell lysate was sonicated (Misonix Sonicator 3000, Newtown, CT) on ice for 2 minutes. After centrifugation, the supernatant was treated with DNase1 (Amresco) at a final concentration of 0.5 mg/mL and incubated at 4°C for 30 minutes, followed by centrifugation at 10,000 × g for 30 minutes to remove the debris. The supernatant (lysate) was then clarified by filtration through a 0.45-μm filter membrane (Millipore, Billerica, MA).
Affinity purification of the recombinant protein was performed using GST.Bind Kit (Novagen). The lysate was incubated with the resin (pre-equilibrated with 5 volumes of 1 × GST Bind/Wash Buffer) at room temperature for 30 minutes with gentle shaking, and the resin mixture was transferred into a chromatography column. The column was washed with 10 volumes of 1 × GST Bind/Wash Buffer and the bound proteins were eluted with 3 volumes of 1 × GST Elution Buffer. Fractions were collected at 500 μL/tube for 10–15 fractions. The purity of the protein in each fraction was assessed by running sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Selected fractions were pooled and concentrated using a Vivaspintm column with a 30-kDa cut-off (GE Healthcare).

The gel band with the expected molecular mass was sent for analysis using MALDI-TOF-TOF™ 5800 System (AB SCIEX, Framingham, MA). It was first analyzed using Swissprot database, then re-analyzed using a small database called “InformmDB,” which contained 88 sequences of 15 recombinant proteins produced at INFORMM, keratin, E. coli histidine-rich proteins, bovine serum albumin, randomly selected proteins, T. canis TES-120, and T. cati TES-120 protein deduced in this study. The protein concentration was determined using RC DC™ Protein Assay (Bio-Rad, Hercules, CA), and the protein was stored at −80°C.

**Determination of the antigenicity of the recombinant antigen by western blotting.** The purified recombinant antigen (T. cati rTES-120) was loaded at 10 μg per well onto a 10% resolving gel, and SDS-PAGE was performed at 100 V. The gel was transferred onto a 0.45-μm nitrocellulose membrane (Bio-Rad) in alkaline transfer buffer (25 mM Tris-base, 190 mM glycine, 10% v/v methanol) using the Trans-Blot® SD system (Bio-Rad). The membrane was blocked with 1 × Detector™ Block solution (KPL, Gaithersburg, MD) for 2 hours at room temperature and was washed in Tris-buffered saline with Tween-20 (TBST, 10 mM Tris-HCl; pH 7.5, 150 mM NaCl, 0.05% Tween-20) for 5, 10, and finally for 15 minutes. The nitrocellulose membrane was then cut into strips, and each strip was incubated with serum samples at a 1:100 dilution in TBST overnight at 4°C. The strips were incubated with monoclonal anti-human IgG4-HRP (Invitrogen) at 1:1000 for 1 hour, washed again to remove the unbound secondary antibody, and developed on CL-XPosure film (Thermo Scientific) using an enhanced chemiluminescence substrate system (Thermo Scientific).

Western blot analysis was also performed with T. canis rTES-120 using the same primary and secondary antibodies. The recombinant protein was previously produced using T. canis TES-120 sequence14 in pGEX-5X-1 expression vector (GE Healthcare).

**Determination of diagnostic sensitivity and specificity.** The diagnostic sensitivity and specificity of both recombinant antigens were calculated as follows: sensitivity = [TP/(TP + FN)] × 100; specificity = [TN/(TN + FP)] × 100, whereby TP denotes true positive, FP is false positive, TN is true negative, and FN is false negative. True positives were the 47 serum samples from patients diagnosed clinically and serologically as toxocariasis, while true negatives were the 39 control serum samples from healthy patients and those with other infections.

**RESULTS**

The total amount of T. cati RNA isolated was 0.7 μg, with a purity (OD260/OD280 ratio) of 2.02 by NanoPhotometer™ (Implen GMBH). Gel electrophoresis analysis of the amplified RT-PCR product showed a single band between 500 and 600 bp (Figure 1). Using the sequence data of the five recombinant plasmids, a T. cati rTES-120 consensus sequence of 528 bp was obtained, and this sequence has been deposited into Genbank (accession number: KP717078).

Figure 1. Amplified reverse transcriptase polymerase chain reaction (RT-PCR) product of T. cati recombinant TES-120 (rTES-120), electrophoresed on a 1% agarose gel. Lane 1: 100 bp DNA Ladder H3 RTU (GeneDireX, Taiwan ROC); Lane 2: negative control; Lane 3: amplified product of T. cati rTES-120 gene coding sequence (531 bp).
sensitivity and specificity of *T. cati* rTES-120, and Table 2 shows results for *T. canis* rTES-120. The diagnostic sensitivity of *T. cati* was 70.2% (33/47) and of *T. canis* was 57.4% (27/47). If a serum was considered positive if it reacted with either the *T. cati* or *T. canis* antigen, the assay diagnostic sensitivity was 76.6% (36/47). The diagnostic specificity of both antigens was high, but *T. cati* rTES-120 showed a higher specificity.

**DISCUSSION**

Toxocariasis is caused by infection with *T. canis* or *T. cati*, but the importance of the latter as an etiologic agent of the disease has been underestimated.\(^2\,^15\) It is generally accepted that toxocariasis is mainly caused by *T. canis*, but the contribution of *T. cati* in causing toxocariasis may be substantial in some populations.\(^2\,^14\) For example, in countries with predominant Muslim populations where cats are more favored than dogs as household pets, more cases of toxocariasis may originate from infected cats.\(^4\) Human infections by *T. cati* have been identified in several studies. One report, by Petithory and others,\(^16\) used a mini-Ouchterlony test to show that three of 10 OLM patients showed a greater reaction to *T. cati* antigen than *T. canis* antigen. Other studies have also
reported OLM patients who strongly reacted to T. cati antigen and weakly to T. canis antigen in ELISAs. In another report, the liver biopsy of a patient with visceral larva migrans showed the presence of larvae, and the Ouchterlony test was strongly positive for T. cati.

Native TES is widely used for diagnosis and seroepidemiological studies. It is obtained from in vitro larval culture and contains a mixture of highly immunogenic glycoproteins. Meanwhile, T. cati TES is rarely used for Toxocara serodiagnosis. This may be because of the greater difficulty in its production, and because the T. canis TES is generally thought to be able to detect infections by both species. Kennedy and others compared the excretory–secretory antigens of T. cati and T. canis, and reported considerable similarities between their secreted antigens. However, one of eight monoclonal antibodies produced (Teb2) was found to be species specific for a carbohydrate determinant, and this determinant is widespread on T. canis glycoproteins. This implies that serology using T. canis antigens may not detect some T. cati infections. In a recently published paper, T. canis and T. cati excretory–secretory antigens were analyzed using a panel of sera from pigs experimentally mono-infected with the two species. The results showed a heterogenic protein pattern between individual hosts, in particular with T. cati-infected pigs, and that there was no protein candidate of potential diagnostic value to discriminate between infections with the two species, thus it supported the view that existing serological methods are unable to distinguish between T. canis and T. cati infections.

Commercial diagnostic kits are known to have issues with specificity when used in countries endemic with soil-transmitted helminthiasis, which is because of the non-specific nature of components of native TES antigens that cross-react with other helminth antigens. Serological diagnostic tests based on standardized recombinant antigens will enable higher diagnostic specificity to be achieved. Recombinant antigens that have been used for toxocariasis detection have included rTES-120, rTES32, rTES30, and rTES26. Previous studies showed good diagnostic potential of T. canis rTES-120. Thus, in this study, we produced rTES-120 from T. cati and compared its diagnostic value with the T. canis homolog.

The T. cati rTES-120 sequence was elucidated by performing RT-PCR on T. cati RNA using primers based on the T. canis sequence. The length of the T. cati TES-120 sequence was 528 bp, that of T. canis TES-120 was 531 bp, and there was 84% similarity between the two. The T. cati TES-120 sequence was codon optimized to E. coli-preferred codons, custom cloned into the pGEX-4T-1 expression vector, and transformed into E. coli BL21(DE3). The molecular mass of the expressed GST-fused protein was approximately 44 kDa and its seroreactivity with a panel of serum samples from toxocariasis patients and controls was determined. As a comparison, previously produced T. canis rTES-120 was also tested with the serum samples. Detection of the specific IgG4 antibody was used in this study because it has been shown to display high diagnostic specificity for serodiagnosis of toxocariasis.

We found that T. cati rTES-120 showed good diagnostic value, because its diagnostic sensitivity (70%) was higher than T. canis rTES-120 (57%). A total of 24 of 47 (51%) Toxocara serum samples were reactive with both recombinant antigens, nine samples were reactive only with T. cati rTES-120, and three serum samples were reactive only with T. canis rTES-120. If a positive sample by either T. canis or T. cati rTES-120 was taken to be a positive result, the assay diagnostic sensitivity was 76%. These results emphasize the importance of using recombinant antigens of both species to achieve improved diagnostic sensitivity. Another notable point is that 11 (23%) serum samples were not reactive with either recombinant antigen. Thus, this shows that more than one type of recombinant antigens were probably needed to achieve even higher diagnostic sensitivity. This supported the findings of our previous report that showed the combination

### Table 1

<table>
<thead>
<tr>
<th>Type of serum sample</th>
<th>Number of samples</th>
<th>Number of positive results</th>
<th>Percentage of positive results</th>
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<tr>
<td>Toxocariasis</td>
<td>47</td>
<td>33</td>
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<tr>
<td>Healthy people</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other diseases*</td>
<td>19</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

rTES-120 = recombinant TES-120. Diagnostic sensitivity: 70.2% (33/47). Diagnostic specificity: 100% (39/39).

* Comprised the following diseases: ascariasis (N = 2), strongyloidiasis (N = 1), hydatidosis (N = 4), microcytic anemia (N = 3), tachyzoites (N = 2), fascioliasis (N = 2), leishmaniasis (N = 3), malaria (N = 2), and toxoplasmosis (N = 1).
of *T. canis* rTES30 and rTES-120 was required to achieve 100% diagnostic sensitivity.14

The diagnostic specificity of both recombinant antigens was high, but that of *T. cati* rTES-120 (100%) was slightly higher than *T. canis* rTES-120 (94%). The reduced specificity of the latter was due to false-positive reactions of three of 12 serum samples from leishmaniasis cases. Because a minority (25%) of the serum samples of the leishmaniasis patients were cross-reactive, this may be attributed to other non-specific factors, and increasing the purity of the *T. canis* rTES-120 may eliminate the cross-reactivity.

In a previous study from Malaysia, two *T. canis* rTES-120 antigens were produced in bacterial and yeast host cells and evaluated in IgG-ELISAs.24,25 The results showed that all *Toxocara* patients serum samples (N = 22) reacted with both recombinant antigens. In our previous study, *T. canis* rTES-120 was tested with an IgG4-ELISA and showed a high sensitivity of 93%.14 In this study, almost 40% of the toxocariasis samples were from Iran, and the rest from Malaysia (which were different from the serum samples used in our earlier study). Thus, the lower diagnostic sensitivity of *T. canis* rTES-120 in this study may be attributed to the use of a different set of serum samples.

In conclusion, we have produced *T. cati* rTES-120 that showed potential diagnostic value and had higher diagnostic sensitivity than *T. canis* rTES-120. When combined with its *T. canis* recombinant homolog, the sensitivity for toxocariasis serodiagnosis was enhanced. Thus, the results of this study add to the growing body of evidence that reliance on antigens from one *Toxocara* species may not be adequate for the serodiagnosis of toxocariasis.

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