Efficacy of Iron Oxide Nanoparticles in Diagnosis of Schistosomiasis

Ahmed Eid¹ MBCh, Khairy Abdel-Hamid² MD, Mohamed Abdel-Hafez³ MD, Anwar Hosainy² MD, Ibrahim R Aly³ MD

ABSTRACT

Background: One of the worldwide major public health problems is urinary schistosomiasis that is caused by *Schistosoma haematobium*. There are several immunodiagnostic methods used for that diagnosis of such disease, but some are more sensitive and specific than others. The tegumental Schistosoma-specific protein detection in serum samples is found out to be more valuable in diagnosis.

Aim of the Work: To evaluate the efficacy of iron oxide nanoparticle for diagnosis of human schistosomiasis infections and to compare between ELISA-based iron oxide nanoparticle and traditional sandwich ELISA.

Material and Methods: The tegumental antigen was purified from whole worms by DEAE-Sephadex G-75 ion-exchange chromatography and then was injected into rabbits to produce specific polyclonal antibodies (p Ab) which were then used as a primary capture in the indirect ELISA technique to reveal its reactivity using infected human sera. The anti- tegumental p Ab was then labeled with horse-radish peroxidase (HRP) and used as a secondary capture. Sandwich ELISA was done for serum samples of humans and hamsters infected with *S. haematobium*.

Results: The sensitivity of the traditional sandwich ELISA with anti-tegumental p Ab was 85% and it increased by using the sandwich IMB-ELISA to be 95% in serum. The specificity of sandwich ELISA was 88.2% and it increased by using the sandwich IMB-ELISA to be 92.6%.

Conclusion: The data obtained concluded that the IMB-ELISA appears to be a sufficiently sensitive and feasible assay for the detection of schistosomal antigenemia and the evaluation of its potential use in human schistosomiasis is in progress.

Keywords: *S. haematobium*; diagnosis; ELISA; Immunomagnetic bead ELISA technique; Paramagnetic nanoparticles.

INTRODUCTION

Schistosomiasis, which is also known as bilharziasis, is one of the most worldwide spread disease-causing the highest rates of morbidity and mortality after malaria. Schistosomiasis infects about 200 million people worldwide. The contamination takes place by getting in contact with fresh water contaminated with cercaria which penetrates the skin causing infection.¹ There are 3 main types of *Schistosoma* that cause human infections: *S. mansoni*, *S. haematobium*, or *S. japonicum*.² In Egypt, the urinary schistosomiasis is representing a serious health problem to deal with. Its complications add more burden on the national control programs and on the national economy.³ Due to controlling programs over the last decade, a decline in the prevalence of human schistosomiasis in Egypt has been reported, however the disease is still endemic in many foci.⁴ Schematically, there are three different known approaches for the diagnosis of parasitic infections, direct (detecting parasitic ova in stool or urine), indirect (relaying on biochemical assays) and immunological methods which are the most sensitive and specific methods in measure the

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immune response (antibodies) to certain parasitic antigens and/or detecting circulating parasitic antigens.\(^6\) Proteases and peptidases are proteolytic enzymes that operate in virtually every biological phenomenon. They function not only as individual enzymes but often in cascades or networks. They also provide essential functions in all life forms.\(^2\) Proteases operate at the host-parasite interface facilitating migration, digestion of host proteins and probably immune evasion.\(^8,9\)

This study aimed to determine the sensitivity and specificity of ELISA-based iron oxide nanoparticles, evaluate the efficacy of iron oxide nanoparticles for diagnosis of human schistosomiasis infections and to compare between ELISA-based iron oxide nanoparticle and traditional sandwich ELISA.

**MATERIAL AND METHODS**

**Animals:** New Zealand white male rabbits were purchased from Agriculture Faculty, Cairo University (Giza, Egypt), weighing approximately 1.5 Kg and 2 months old. They were examined and confirmed to be free from parasitic infections. The rabbits were housed in the animal house at Theodore Bilharz Research Institute (TBRI) (Giza, Egypt). Adult worms were recovered from the portal mesenteric vasculatures of laboratory infected hamsters by perfusion with heparinized saline as previously described by Smithers and Terry.\(^10\)

**Parasites:** Adult worms of *Schistosoma haematobium* used for the preparation of purified tegumental antigen were supplied from the Schistosome Biological Supply Program Unit at Theodore Bilharz Research Institute (SBSP, TBRI) Giza, Egypt. Adult worms were recovered from the portal mesenteric vasculatures of laboratory infected hamsters by perfusion with heparinized saline as previously described by Smithers and Terry.\(^10\)

**Study population:** A total of 128 individuals were enrolled in the present study. Thirty individuals were free from any parasitic infections served as normal control. Sixty patients infected with *S. haematobium* and 38 patients infected with other helminthic parasites (It included 10 patients infected with *H. nana*, 8 with *Fasciolagigantica*, 8 with *Ascaris lumbricoides* and 12 with *Ancylostomaduodenale*).

**Preparation and purification of tegumental from *S. haematobium* Antigen:**

Fresh adult worms of *Schistosoma haematobium* were suspended in 10 ml of phosphate buffer saline (PBS) and dialyzed against lytic buffer [8 M Urea, 2M Thiourea, 4% 3,3, Cholamidepropyl dimethylammonium, propanesulfonate (CHAPS), 50 M Dithiothreitol (DTT), 20 M MTris and complete Mini Protease Inhibitor Cocktail Tablets (Roche)]. After dialysis, the adult worms were homogenized under continuous agitation for 2 hours at room temperature with glass homogenizer, followed by 10 repeated passages through a 30-gauge hypodermic needle. Then the homogenate was centrifuged at 20,000×g for 30 min at 25°C and the supernatant was collected and stored at −70°C.

Purification of schistosomal antigen was done by DEAE Sepharose CL-6B and the protein content was estimated by the Bio-Rad kit. Characterization of schistosomal antigen was done using Sodium dodecyl-sulfate polyacrylamide gel electrophoresis (SDS-PAGE) according to Harlow & Lane\(^11\) and Myers.\(^12\)

**Assessment of reactivity of the schistosomal antigen of *S. haematobium* by indirect ELISA:** This method was performed, with some modifications from the original method of Engvall and Perlmann.\(^13\)

**Immunization of rabbit for production of polyclonal antibodies:** Rabbit anti- serum was obtained by immunizing New Zealand white rabbit (approximately 1.5Kg weight) with 1 mg of purified schistosomal antigen that was given to the rabbit in the entire course of immunization. The rabbit received priming dose intramuscular injection (i.m) at four sites (1 mg purified schistosomal antigen mixed 1:1 incomplete Freund's adjuvant (CFA), (Sigma)). Three booster doses were given, each was 0.5 mg antigen emulsified in equal vol. of incomplete Freund's adjuvant (IFA), (Sigma). The first boosting was two wk. after the priming dose. The following boosting doses were given at weekly intervals, according to Fagbemi.\(^14\)

The rabbit was bled for collection of serum one week later after preliminary testing of titer by indirect ELIZA.

**Purification of rabbit anti-purified schistosomal antigen serum:** Rabbit IgG purification steps were based on two different methods: Ammonium sulfate precipitation method\(^15\) and caprylic acid treatment.\(^16\)

Protein content was measured after each purification step using the Bradford method.\(^17\) The efficiency of the purification steps was measured by 12% SDS-room temperature. The plates were washed 5 times with washing buffer. Hundred μl/well of substrate solution [one tablet of OPD (Sigma) dissolved in 25 ml of 0.05 M phosphate citrate buffer, pH 5 with urea hydrogen peroxidase (Sigma)] was added to each well and the plates were incubated in the dark at room temperature for 30 min. Fifty μl/well of 8 N H₂SO₄ was added to stop the enzyme-substrate reaction. The absorbance was measured at 492 nm using ELISA reader (Bio-Rad microplate reader Richmond, Ca).

Statistical analysis: Data are expressed as mean (M) ± standard deviation (SD). Statistical analysis was performed with the aid of the SPSS computer program (version windows 16.0).

**RESULTS**

**Characterization of *S. haematobium* membrane antigen by (SDS-PAGE)**

The protein fractions resulted from the preparation methods were analyzed by 12.5% SDS-PAGE under reducing condition and showed 2 major at 65 and 95 KDa and many minor bands representing *S. haematobium* membrane antigen (Fig. 1).
Assessment of reactivity and specificity of the prepared S. haematobium membrane antigen by indirect-ELISA

The antigenicity of the S. haematobium membrane antigen was tested by indirect ELISA technique. Serum samples from an infected human with S. haematobium gave a strong reaction against S. haematobium membrane antigen with mean OD reading equal to 0.929 and no cross-reactions were recorded with sera of patients infected with other parasites e.g., Fasciola, H. nana and Ascaris (Table 1).

### Table 1: Reactivity of S. haematobium membrane antigen by indirect ELISA

<table>
<thead>
<tr>
<th>Serum Samples</th>
<th>OD readings at 492 nm (M ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. haematobium</td>
<td>0.929 ± 0.042</td>
</tr>
<tr>
<td>Fasciola gigantica</td>
<td>0.291 ± 0.071</td>
</tr>
<tr>
<td>H. nana</td>
<td>0.18 ± 0.011</td>
</tr>
<tr>
<td>Ascaris lumbricoides</td>
<td>0.24 ± 0.056</td>
</tr>
</tbody>
</table>

OD= optical density, SD= standard deviation

### Protein content determination of the purified anti-S. haematobium IgG-pAb

The total protein content of the rabbit’s crude serum-containing anti-S. haematobium pAb was 7.2 mg/ml. Using the 50% ammonium sulfate precipitation method, the protein content was 5.1 mg/ml, while following a 7% caprylic acid precipitation method, the content dropped to 3.5 mg/ml. Finally, the protein content of the highly purified anti-S. haematobium IgG-pAb subjected to ion-exchange chromatography method (DEAE Sephadex A-50 ion exchange column chromatography) was 2.1 mg/ml. Figure (3) shows the OD_{492} profile of the IgG fractions obtained following purification by DEAE Sephadex A-50 ion-exchange column chromatography. The eluted IgG is represented by a single peak with a maximum OD value 0.48 at fraction number 17.

### Characterization of anti-S. haematobium IgG-pAb by SDS-PAGE

The purity of IgG-pAb after each step of purification was assayed by 12% SDS-PAGE under reducing conditions. Analysis of 50% ammonium sulfate-precipitated proteins by 12% SDS-PAGE under reducing conditions showed that precipitated proteins appeared as several bands. The purified IgG-pAb after ion exchange chromatography was represented by only 2 bands, Land H-chain bands at 31 and 53 kDa, respectively. The pAb appears free from other proteins (Fig. 4).
ELISA
The produced anti- *S. haematobium* membrane antigen IgG-pAb diluted 1/250 in PBS/T buffer gave strong reactivity to *S. haematobium* membrane antigen. The OD means reading at 492 nm for *S. haematobium* membrane antigen was 2.84 compared to 0.24, 0.19, 0.31 and 0.41 for Fasciola, *H. nana*, *Ancylostoma* and *Ascaris* infected sera, respectively (Table 2).

<table>
<thead>
<tr>
<th>Parasitic antigen</th>
<th>OD readings at 492 nm (m ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. haematobium</em></td>
<td>2.84 ± 0.21</td>
</tr>
<tr>
<td><em>F. gigantica</em></td>
<td>0.24 ± 0.13</td>
</tr>
<tr>
<td><em>H. nana</em></td>
<td>0.19 ± 0.11</td>
</tr>
<tr>
<td><em>A. duodenale</em></td>
<td>0.31 ± 0.14</td>
</tr>
<tr>
<td><em>A. lumbricoides</em></td>
<td>0.41 ± 0.10</td>
</tr>
<tr>
<td><em>E. vermicularis</em></td>
<td>0.18 ± 0.13</td>
</tr>
</tbody>
</table>

Table 2: Specificity of rabbit anti- *S. haematobium* membrane antigen IgG-pAb against different parasitic antigens by indirect ELISA

Detection of *S. haematobium* membrane antigen in serum samples by sandwich ELISA
The cut off value was 0.342. When detecting *S. haematobium* membrane antigen in serum, the results were positive in 3 cases (82%) of group A, while 4 cases were negative (28%). In group B (patients with other parasitic infections) 3 cases were detected as positive (2 with *Fasciola*, 1 with *Ancylostoma* infection) and 7 cases with *H. nana* infection, while the other 3 cases were negative. All healthy control patients were negative. The sensitivity of *S. haematobium* membrane antigen detection in serum was found to be 8%. However, the specificity was found to be 100% in the healthy control group and in the patients with other parasitic infections. There is a highly statistically significant difference between the positivity in *S. haematobium* infected group and the other two tested groups (P < 0.001) (Table 3).

Table 3: Results of *S. haematobium* membrane antigen detection in serum samples by sandwich ELISA

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Positive cases</th>
<th>Negative cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O.D (X ± SD)</td>
<td>O.D (X ± SD)</td>
</tr>
<tr>
<td>Healthy control (n=30)</td>
<td>-</td>
<td>0.321±0.02</td>
</tr>
<tr>
<td><em>Ancylostoma</em> (n=60)</td>
<td>3 (1.15±0.12)</td>
<td>9 (0.303±0.05)</td>
</tr>
<tr>
<td><em>Fasciola</em> (n=8)</td>
<td>3 (0.424±0.03)</td>
<td>5 (0.228±0.06)</td>
</tr>
<tr>
<td><em>H. nana</em> (n=8)</td>
<td>3 (0.543±0.06)</td>
<td>5 (0.228±0.04)</td>
</tr>
<tr>
<td><em>Ascaris</em> (n=10)</td>
<td>0 (-)</td>
<td>10 (0.274±0.08)</td>
</tr>
<tr>
<td><em>Ancylostoma</em> (n=12)</td>
<td>2 (0.761±0.05)</td>
<td>10 (0.262±0.04)</td>
</tr>
</tbody>
</table>

Table 4: Results of *S. haematobium* membrane antigen detection in serum samples conjugated with IO by sandwich IMB-ELISA

Table (4) shows the incidence of positivity for antigen detection in human sera by the two diagnostic techniques used in the study. The two techniques illustrated a high percentage of positivity reaching 100% in serum of the high infection subgroup. In the moderate infection subgroup, the incidence of positivity for antigen in serum was 80%, 92%, 84% and 96% by sandwich ELISA, sandwich IMB-ELISA, respectively. Whereas, in the light infection subgroup, the incidence of positivity for antigen in serum was 80%, 92%, 84% and 96% by sandwich ELISA, sandwich IMB-ELISA, respectively.

The other parasites-infected groups mainly with *Fasciola gigantica* showed some degree of cross-reactivity with antigens in human sera.

**DISCUSSION**

Schistosomiasis is one of the main occupational diseases, acquired by man through activities associated with freshwaters such as farming, washing, bathing, and recreation. It has been recognized as a disease of significant socio-economic and public health importance second to malaria. Urinary schistosomiasis remains a major health burden in endemic areas of Africa and the Middle East,
affecting more than 110 million people in rural, agricultural and peri-urban areas. Estimates show that at least 220.8 million people required preventive treatment in 2017, out of which more than 102.3 million people were reported to have been treated. Preventive treatment, which should be repeated over a number of years, will reduce and prevent morbidity. Schistosomiasis transmission has been reported from 78 countries. However, preventive chemotherapy for schistosomiasis, where people and communities are targeted for large-scale treatment, is only required in 52 endemic countries with moderate-to-high transmission.

In Egypt, schistosomiasis is still representing a serious health problem to deal with. Its complications add more burden to the national control programs and on the national economy. Due to control programs over the last decade, a decline in the prevalence of human schistosomiasis in Egypt has been reported; however, the disease is still endemic in many foci. The Schistosomiasis haematobium infected 60% of the population in the Northern and Eastern parts of the Nile Delta and only 6% in the Southern part.

The present work aimed to evaluate the efficacy of iron oxide nanoparticles for diagnosis of human Schistosomiasis infections, determine the sensitivity and specificity of ELISA-based iron oxide nanoparticles and compare between ELISA-based iron oxide nanoparticles and traditional sandwich ELISA.

The two Schistosomiasis antigens were used in the production of anti-Schistosomiasis IgG antibodies. Their antigenicity was tested indirect ELISA technique and purified Schistosomiasis antigens gave positive reaction against Schistosomiasis infected sera and no cross-reactions against other parasites sera. The stronger reactivity was in favor of purified antigen.

The recorded sensitivity of sandwich ELISA using anti-circulating microsomal antigen (whole antigen coated on microbead) was 85% and 95%, respectively, and their specificities were 88.3% and 93.3%, respectively. As noted, higher diagnostic indices (sensitivity and specificity) were recorded in IO conjugated IgGs than traditional IgGs ELISA models. In this study, the use of IO conjugated with IgG led to increasing the number of their binding sites and adsorptive capacity. This was attributed to their small size. Many authors used novel nano-diagnostic assays in the diagnosis of many parasitic infections, e.g., Schistosoma japonicum, Schistosoma haematobium. Lei et al. developed ELISA assay using IgYpAb-coated with a magnetic bead as a capture Ab and IgMm Ab as antigen-detection Ab against S. haematobium. The recorded sensitivity was 100% and 91.5% (in acute and chronic infection, respectively) and specificity 96.7%-100% with clonorchiasis and paragonimiasis positive cases. Ibrahim et al. also developed a novel IMB-ELISA based IgG for the detection of excretory/secretory antigens in rabbit sera infected with S. haematobium. The reported sensitivity and specificity of the assay were 95% and 93.7%.

The recorded sensitivity of ELISA using anti-S. haematobium circulating microsomal fraction antigen. The reported sensitivity and specificity of the assay were 96.5% and 96.3% compared to 88.2% and 87.3% by traditional sandwich ELISA.

It was noted that the application of the nanomagnetic beads significantly increased the sensitivity, specificity, and incidence of positivity of the technique towards higher detection of the antigen in moderate and light infected patients. The sensitivity of the traditional sandwich ELISA was 85% in serum and it increased by using the sandwich IMB-ELISA to be 95% in serum. The specificity of sandwich ELISA was 88.3% in serum and it increased by using the sandwich IMB-ELISA to be 93.3% in serum.

**CONCLUSION**

The data obtained concluded that the IMB-ELISA appears to be a sufficiently sensitive and feasible assay for the detection of schistosomal antigenemia and the evaluation of its potential use in human schistosomiasis needs more research.

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