Coccidia (Apicomplexa) from Heteromyid Rodents in the Southwestern United States, Baja California, and Northern Mexico with Three New Species from *Chaetodipus hispidus*

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COCCIDIA (APICOMPLEXA) FROM HETEROMYID RODENTS IN THE SOUTHWESTERN UNITED STATES, BAJA CALIFORNIA, AND NORTHERN MEXICO WITH THREE NEW SPECIES FROM CHAETODIPUS HISPIDUS

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Department of Biology, The University of New Mexico, Albuquerque, New Mexico 87131

ABSTRACT: Fecal samples from 223 heteromyid rodents of 4 genera and 13 species were collected from California, New Mexico, and Texas and from Baja California Norte and Sonora, Mexico. Of these, 84 (38%) were infected with coccidian oocysts; 72 of 84 (86%) infected animals had only 1 species of coccidian. Eleven species of coccidia were identified including 1 cyclosporan and 10 eimerians; the cyclosporan and 2 of the eimerians are described as new species. Sporulated oocysts of Cyclospora angimurinensis n. sp. were subspheroidal, 21.9 × 19.3 (19–24 × 16–22) μm, with sporocysts lemon-shaped, 11.9 × 9.5 (9–15 × 8–11) μm; it was found in 1 of 20 (4%) Chaetodipus hispidus. Sporulated oocysts of Eimeria chaetodipi n. sp. were subspheroidal, 16.7 × 14.6 (13–19.5 × 12–17) μm, with sporocysts ovoidal, 8.7 × 6.6 (7.5–10.5 × 5–7.5) μm; it was found in 3 of 20 (15%) C. hispidus. Sporulated oocysts of Eimeria hispidensis n. sp. were subspheroidal, 20.5 × 17.4 (17–23 × 14–21) μm, with sporocysts lemon-shaped, 9.3 × 7.2 (7.5–10.5 × 5–9) μm; it was found in 4 of 20 (20%) C. hispidus. Prevalence of infection included 0 of 20 Chaetodipus arenarius, 0 of 16 Chaetodipus baileyi, 25 of 46 (54%) Chaetodipus californicus, 13 of 30 (43%) Chaetodipus fallax, 7 of 20 (35%) Chaetodipus formosus, 14 of 20 (70%) C. hispidus, 4 of 25 (16%) Chaetodipus penicillatus, 5 of 7 (71%) Chaetodipus spinatus, 8 of 21 (38%) C. hispidus, 5 of 7 (71%) Chaetodipus penicillatus, 4 of 20 (20%) C. hispidus, 8 of 21 (38%) Dipodomys elator, 1 of 1 Perognathus flavescens, 5 of 11 (45%) Perognathus inornatus, and 5 of 11 (45%) Perognathus flavus.

MATERIALS AND METHODS
Mice were live-trapped and fecal samples were collected from them and stored in 2% (w/v) aqueous potassium dichromate (K₂Cr₂O₇). Methods used for storage and processing fecal samples and for concentrating, measuring, and photographing oocysts have been described in detail (Duszynski et al., 1982; Stout and Duszynski, 1983). Measurements are given in micrometers (μm) with size ranges in parentheses following the means. Oocysts were measured and photographed when they were between 83 (new species) and 3,168 (previously described species) days old.Skeletons, skins, and tissues for electrophoresis for most hosts are deposited in the Museum of Southwestern Biology (MSB), The University of New Mexico (UNM). Mice collected in Hardeman, Hood, Jack, Johnson, and Somervell counties, Texas, are deposited in the Arkansas State University Museum of Zoology (ASUMZ). Syntypes (=phototypes, see Bandoni and Duszynski, 1988) of sporulated oocysts of our 3 new species have been deposited in the U.S. National Museum Parasite Collection (USNMPC), Beltsville, Maryland.

RESULTS
All rodents, their collection localities, and the coccidians with which they were infected are presented in Table I.

Cyclospora angimurinensis n. sp. (Figs. 1–3, 12)

Description
Oocyst subspheroidal with thin wall (~1) composed of 2 layers of equal thickness; outer layer smooth; micropyle absent; oocyst residuum as 3–4 clumped globes of different sizes; 1 polar body present; sporulated oocysts (n = 52) 21.9 × 19.3 (19–24 × 16–22) with L:W ratio 1.1+ (1.1–1.3); sporocysts (n = 51) lemon-shaped, 11.9 × 9.5 (9–15 × 8–11) with L:W ratio 1.25 (1.1–1.5); Stieda body present, but sub- and parasistedia bodies are absent; sporocyst residuum of small gran-
Table I. Coccidian parasites collected from pocket mice, Chaetodipus, Perognathus, and Liomys spp., and from kangaroo rats, Dipodomys elator, collected in the southwestern United States, Baja California, and northern Mexico.

<table>
<thead>
<tr>
<th>Rodents</th>
<th>Locality</th>
<th>Mice infected/mice examined (%)</th>
<th>Coccidia spp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaetodipus arenarius</td>
<td>Baja California, Norte</td>
<td>0/20</td>
<td>—</td>
</tr>
<tr>
<td>Chaetodipus baileyi</td>
<td>Baja California, Norte</td>
<td>0/16</td>
<td>—</td>
</tr>
<tr>
<td>Chaetodipus californicus</td>
<td>Baja California, Norte</td>
<td>17/28 (61)</td>
<td>Eimeria albugiae, Eimeria arizonensis, Eimeria reedi, Eimeria scholtysecki, sp.*</td>
</tr>
<tr>
<td></td>
<td>Los Angeles Co., California</td>
<td>0/1</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Madera Co., California</td>
<td>1/2 (50)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Riverside Co., California</td>
<td>5/13 (38)</td>
<td>E. reedi, E. scholtysecki, sp.*</td>
</tr>
<tr>
<td></td>
<td>San Bernardino Co., California</td>
<td>1/1 (100)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>San Diego Co., California</td>
<td>1/1 (100)</td>
<td>E. reedi</td>
</tr>
<tr>
<td>Chaetodipus fallax</td>
<td>Baja California, Norte</td>
<td>13/30 (43)</td>
<td>E. reedi, sp.*</td>
</tr>
<tr>
<td>Chaetodipus formosus</td>
<td>Baja California, Norte</td>
<td>7/20 (35)</td>
<td>E. reedi</td>
</tr>
<tr>
<td>Chaetodipus hispidus</td>
<td>Hardeman Co., Texas</td>
<td>3/5 (60)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Hood Co., Texas</td>
<td>4/4 (100)</td>
<td>Eimeria chaetodipi, E. reedi</td>
</tr>
<tr>
<td></td>
<td>Jack Co., Texas</td>
<td>1/1 (100)</td>
<td>Eimeria hispidensis, E. reedi</td>
</tr>
<tr>
<td></td>
<td>Johnson Co., Texas</td>
<td>2/3 (67)</td>
<td>E. hispidensis, Eimeria langebarteli, E. reedi</td>
</tr>
<tr>
<td></td>
<td>Motley Co., Texas</td>
<td>1/2 (50)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Somervell Co., Texas</td>
<td>2/2 (100)</td>
<td>E. chaetodipi, E. hispidensis, Cyclospora angimurinensis, E. reedi</td>
</tr>
<tr>
<td></td>
<td>Wichita Co., Texas</td>
<td>1/3 (33)</td>
<td>E. reedi</td>
</tr>
<tr>
<td>Chaetodipus penicillatus</td>
<td>Baja California, Norte</td>
<td>0/11</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Sonora</td>
<td>3/13 (23)</td>
<td>Eimeria merriami, E. reedi</td>
</tr>
<tr>
<td>Chaetodipus spinatus</td>
<td>Baja California, Norte</td>
<td>5/7 (71)</td>
<td>E. reedi, sp.*</td>
</tr>
<tr>
<td>Dipodomys elator</td>
<td>Hardeman Co., Texas</td>
<td>3/10 (30)</td>
<td>E. arizonensis, Eimeria balphae</td>
</tr>
<tr>
<td></td>
<td>Wichita Co., Texas</td>
<td>2/4 (50)</td>
<td>E. arizonensis, E. balphae</td>
</tr>
<tr>
<td></td>
<td>Wilbarger Co., Texas</td>
<td>3/7 (43)</td>
<td>E. arizonensis, E. balphae</td>
</tr>
<tr>
<td>Liomys pictus</td>
<td>Sonora</td>
<td>2/3 (67)</td>
<td>Eimeria liomyys</td>
</tr>
<tr>
<td>Perognathus flavescens</td>
<td>Motley Co., Texas</td>
<td>1/1 (100) sp.*</td>
<td>E. reedi</td>
</tr>
<tr>
<td>Perognathus flavus</td>
<td>Hardeman Co., Texas</td>
<td>1/1 (100)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Hidalgo Co., New Mexico</td>
<td>0/1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Hood Co., Texas</td>
<td>1/1 (100)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Somervell Co., Texas</td>
<td>2/4 (50)</td>
<td>E. reedi</td>
</tr>
<tr>
<td></td>
<td>Wichita Co., Texas</td>
<td>0/1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Wilbarger Co., Texas</td>
<td>1/3 (33)</td>
<td>E. reedi</td>
</tr>
<tr>
<td>Perognathus inornatus</td>
<td>Madera Co., California</td>
<td>0/3</td>
<td>—</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td>84/223 (38)</td>
</tr>
<tr>
<td>4 genera</td>
<td>13 species</td>
<td>17 localities</td>
<td>11 spp.</td>
</tr>
</tbody>
</table>

* sp. = coccidia not identifiable because of unsporulated oocysts.

Remarks

Cyclosporans were described first from a myriapod, Glomeris sp., by Schneider (1881), but records from reptiles and mammals, especially insectivores (Pellerdy, 1974), are not uncommon. To date, there are 6 described mammalian cyclosporans, all from moles (see Duszynski and Wattam, 1988; Ford and Duszynski, 1988, 1989). The form we describe here differs from the other Cyclospora species by having an oocyst residuum and by the shape and L:W ratio of its sporozoites (1.3 vs. 1.6 or larger).

Eimeria chaetodipi n. sp.
(Figs. 4–6, 13)

Description

Oocyst subspheroidal with thin wall (<1) composed of only 1 obvious smooth layer; micropyle absent; oocyst residuum present as single small globe or absent; polar body present; sporulated oocysts (n = 43) 16.7...
× 14.6 (13–19.5 × 12–17) with L:W ratio 1.1 (1.0–1.3); sporocysts (n = 43) ovoidal, 8.7 × 6.6 (7.5–10.5 × 5–7.5) with L:W ratio 1.3 (1.1–1.6); Stieda body present; but sub- and parastieda bodies are absent; sporocyst residuum consists of a few small granules dispersed between sporozoites; sporozoites with a large, posterior refractile body.

**Taxonomic summary**

Type host: Chaetodipus hispidus hispidus (Baird, 1858), hispid pocket mouse.

Type locality: U.S.A., Texas, Hood County, 17.5 km SE Granbury off FM 2174 at Fort Spunky.

Other locality: U.S.A., Texas, Somervell County, 0.4 km NNE Nemo off County road 407.

Prevalence: Found in 3 of 20 (15%) C. h. hispidus collected from 7 counties in Texas.


Etymology: The nomen triviale is derived from the generic name of the host.

Remarks

Although sporulated oocysts of this species resemble those of *E. liomysis* in shape, the small size distinguishes them from all eimerians described previously from heteromyid rodents.

**Eimeria hispidensis n. sp.**

(Figs. 7–9, 14)

**Description**

Oocyst subspheroidal with wall ~ 1, composed of 2 layers: outer layer may be lightly sculptured, ~1/3 of total thickness; micropyle absent; oocyst residuum present as several globules of various sizes; 1 polar body present; sporulated oocysts (n = 49) 20.5 × 17.4 (17–23 × 14–21) with L:W ratio 1.2 (1.0–1.5); sporocysts (n = 49) lemon-shaped, 9.3 × 7.2 (7.5–10.5 × 5–9), with L:W ratio 1.3 (1.1–1.5); Stieda body present, but sub- and parastieda bodies are absent; sporocyst residuum of several small globules; sporozoites with a large posterior refractile body.

**Taxonomic summary**

Type host: Chaetodipus hispidus hispidus (Baird, 1858), hispid pocket mouse.

Type locality: U.S.A., Texas, Somervell County, 0.4 km NNE Nemo off county road 407.

Other localities: U.S.A., Texas, Jack County, 8.0 km SW Jacksonboro, and Johnson County, 17 km SW Cleburne off county road 1120 at George’s Creek Ranch.

Prevalence: Found in 4 of 20 (20%) C. h. hispidus collected from 7 counties in Texas.

Site of infection: Unknown, oocysts collected from feces.


Etymology: The nomen triviale is derived from the specific part of the scientific name of the host and -ensis (L., belonging to) indicating that this form comes from *C. h. hispidus*.

Remarks

Sporulated oocysts of this form are most similar to those of *E. liomysis*, but differ by having an oocyst residuum that is never found in *E. liomysis*.

**Other eimerians**

*Eimeria albigua Levine, Ivens, and Kruidenier, 1957:* Sporulated oocysts that were structurally identical to those of *E. albigua* were found in 1 Chaetodipus californicus collected at Valle de la Trinidad, Baja California Norte, Mexico (MSB #47481). This host was 1 of 28 *C. californicus* collected from several locations in Mexico; 17 of these mice were infected with various eimerians (Table I). This coccidian species was first described from *Neotoma albigua*, the white-throated woodrat (Muridae, see Anderson and Jones, 1984), from Arizona (Levine et al., 1957). This is the first report of *E. albigua* in another genus.

*Eimeria arizonensis Levine, Ivens, and Kruidenier, 1957:* Sporulated oocysts that we could not distinguish from published descriptions of *E. arizonensis* were seen in 3 *Dipodomys elator* from 3 counties in Texas and in 1 *C. californicus* from Baja California Norte (Table I). This coccidian species was first described from *Peromyscus truei* in Arizona and later described from *Peromyscus leucopus* and *Peromyscus maniculatus* in Illinois (Levine and Ivens, 1960), *P. maniculatus* in British Columbia (Levine and Ivens, 1963), and in *Peromyscus eremicus*, *P. maniculatus*, and *P. truei* in New Mexico (Reduker et al., 1987). This is the first time that oocysts resembling those of *E. arizonensis* have been found outside members of the Muridae.

*Eimeria balphae Ernst, Chobotar, and Anderson, 1967:* This species was first described from a single *Dipodomys ordii* in Utah (Ernst, Chobotar, and Anderson, 1967) and it also has been reported from 15 of 137 (11%) *D. ordii* from Texas (Short et al., 1980). This is the first report of *E. balphae* in *D. elator*, in which we found 8 of 21 (38%) examined to be infected (Table I).

*Eimeria langabarteli Ivens, Kruidenier, and Levine, 1959:* This species, first described from *Peromyscus boylii* from Chihuahua, Mexico (Ivens et al., 1959), was later found in *P. leucopus tornillo* and in *P. truei* from New Mexico and California (Reduker et al., 1985). The sporulated oocysts we saw in 1 of 2 *C. h. hispidus* from Texas were indistinguishable from those in the above descriptions. This is the first time this coccidian species has been found in a member outside the Muridae.

*Eimeria liomysis Levine, Ivens, and Kruidenier, 1958:* This species was originally described from *Dipodomys merriami* from Sinaloa, Mexico, and from *Liomys irroratus* in Jalisco, Mexico (Ivens et al., 1959), but we include one here (Fig. 10).
FIGURES 1–11. Photomicrographs of sporulated oocysts of coccidia collected from the feces of heteromyid rodents in the southwestern U.S. ×1,900. 1–3. Cyclospora angimurinensis n. sp. from Chaetodipus hispidus
riami from Baja California Norte (Stout and Duszynski, 1983). This is the first time it has been reported from Chaetodipus, in which we found it in 1 of 25 (4%) Chaetodipus penicillatus from Mexico and the U.S.A.

Eimeria reedi Ernst, Oaks, and Sampson, 1970: The original description of E. reedi is from Chaetodipus formosus (=Perognathus formosus) from California (Ernst et al., 1970). We found it in 22 of 46 (48%) C. californicus from Mexico and California, 12 of 30 (40%) Chaetodipus fallax from Mexico, 7 of 20 (35%) C. formosus from Mexico, 5 of 20 (25%) C. hispidus from Texas, 4 of 25 (16%) C. penicillatus from Mexico and California, 3 of 7 (43%) Chaetodipus spinatus from Mexico, and 5 of 11 (45%) Perognathus flavus merriami from New Mexico and Texas (Table I). Photomicrographs of sporulated oocysts of this species have not been published previously, but we include one here (Fig. 11).

Eimeria scholtysecki Ernst, Frydendall, and Hammond, 1967: This species was originally described from D. ordii in Utah (Ernst, Frydendall, and Hammond, 1967). It has been reported also from Dipodomys agilis and Dipodomys gravipes from Baja California Norte and from Dipodomys spectabilis in New Mexico (Stout and Duszynski, 1983). We found it in the feces of 3 of 46 (6.5%) C. californicus from California and Mexico (Table I). This is the first record in members outside the genus Dipodomys.

**DISCUSSION**

Members of the family Heteromyidae (kangaroo rats, pocket mice, and their allies) constitute a morphologically and ecologically diverse collection of rodents that possesses adaptations that allow inhabitation of arid and semiarid regions of the southwestern United States and Mexico. These rodents nest in underground burrows that range from simple tunnels made by juveniles to intricate systems composed of 2 or more entrances constructed by adults (Blair, 1937). Often, no more than 1 individual inhabits a burrow system, and its feces are usually deposited in blind side tunnels. These 2 factors may limit exposure of certain taxa of heteromyid rodents to coccidian oocysts. However, the overall prevalence of infection (84/223, 38%) is moderate, and other factors (behavior, genetic, phys-
logic) may account for Chaetodipus arenarius, Chaetodipus baileyi, Perognathus inornatus, and certain cohorts of Chaetodipus penicillatus to be negative for coccidia.

A higher prevalence of infection appears to be related to those taxa that avoid desert extremes by ranging farther into the plains and prairie regions of the midwestern United States where climatological conditions account for more humidity and precipitation. For example, when the rodents we examined are placed into 2 geographic groups, a western group of 9 species in 3 genera (C. arenarius, C. baileyi, C. californicus, C. fallax, C. formosus, C. penicillatus, C. spinatus, P. inornatus, L. pictus) and a midwestern group of 4 species in 3 genera (C. hispidus, D. elator, Perognathus flavescens, P. flavus), a significant difference in prevalence is evident (56/170 [33%] vs. 28/53 [53%), \( \chi^2 = 7.3, P < 0.007 \).

Although some of the coccidians reported from heteromyid rodents may be host specific (e.g., the new species from C. hispidus), there is at least circumstantial evidence of less host specificity among others. For example, where P. flavus and C. hispidus coexist in Somervell County, Texas, they were not found to share the 3 new species described from the latter host. The reasons for such apparent host specificity in these coccidians of C. hispidus are obscure but may be related to the fact that this rodent is unique morphologically (Hafner and Hafner, 1983) and biochemically divergent (Patton et al., 1981) from all other congeners and from Perognathus spp. At the other extreme, some heteromyid eimerians seem to have a more cosmopolitan host range when we used the only measure available to us, namely, sporulated oocysts. For example, the combination of size, shape, and internal structures described by Ernst et al. (1970) make sporulated oocysts of Eimeria reedi a unique entity, and we found such oocysts in the fecal material of 7 species of Chaetodipus and Perognathus from California, New Mexico, Texas, and Mexico. In addition, the sporulated oocysts of several other species of coccidia originally reported from murid rodents by us and by others were seen to cross familial boundaries to heteromyid hosts, using the same criteria as above. Given that some internal structures, such as residua, may change in size and shape over time in stored, sporulated oocysts, we recognize that careful cross-transmission and life cycle studies are needed to examine this whole problem in much more detail.

Stout and Duszynski (1983) provided a summary of coccidia from kangaroo rats (Dipodomys spp.) in the western United States, Baja California, and northern Mexico. They reported that of 1,590 specimens representing 11 species of Dipodomys from various regions of North America and Mexico, only 13.4% were positive for coccidia and that prevalence of infection for any host ranged from 0 to 45%, rarely exceeding 25%. In the present study, 8 of 21 (38%) D. elator from northern Texas harbored coccidia.

Finally, we have provided a description of a new species of Cyclospora from a host outside the mammalian order known to be infected commonly with members of this genus, namely, insectivores. Although a suitable host, the eastern mole (Scalopus aquaticus), is distributed throughout much of central and eastern Texas, including counties sampled by us, these moles are scarce or absent in stony and gravelly soils. The study site in Somervell County from which the type host of C. angimurinensis was collected does not support soil types inhabited by S. aquaticus (i.e., moist, sandy loam) and, most importantly, moles have not been trapped there, and we have never observed surface burrows there. Thus, we believe that C. angimurinensis does not represent a population of oocysts from a mole just passing through the intestinal tract of C. hispidus.

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We thank Dr. Steve J. Upton for technical assistance. C.T.M. thanks G. Roberts for allowing access to his properties and the Texas Parks and Wildlife Department for Scientific Collecting Permit SPO44-1. We are also indebted to Drs. J. H. Bandoli, T. L. Best, S. B. George, D. J. Hafner, L. L. Janacek, K. E. Peterson, D. W. Reduker, R. M. Sullivan, and T. L. Yates and to A. S. Christmas, J. A. Cook, D. A. Goebel, J. Haydock, and J. Planz for collecting many of the heteromyid rodents in our samples, to Mr. Todd Hill, Albuquerque TVI, for screening many of the samples and for his help in identifying some of the coccidians seen, and to Lynn A. Hertel for the line drawings.

LITERATURE CITED


