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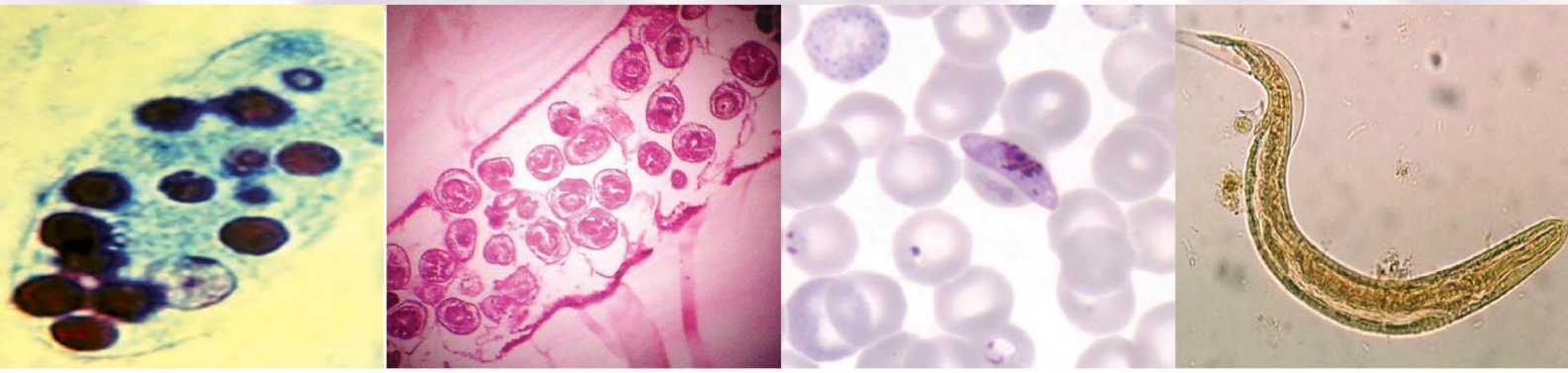
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Essentials of MEDICAL PARASITOLOGY



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Sandhya Bhat

Foreword
Lynne S Garcia

JAYPEE

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Nematodes—I (Intestinal Nematodes)

12 CHAPTER

CHAPTER OUTLINE

- Classification
- General description
- Large intestinal nematodes
  - *Trichuris trichiura*
  - *Enterobius vermicularis*
- Small intestinal nematodes
  - Hookworm
  - *Strongyloides* species
  - *Ascaris* species

Nematodes are probably the most widespread animal group occurring in the world. Many of them are non-pathogenic and exist as free living forms in fresh or marine water and soil, while few of the species can be pathogenic and exist as parasitic form in both animals and plants.

CLASSIFICATION

Systemic Classification

Systemic classification is based on Anderson et al. (1974) classification. Phylum Nematoda has two classes Adenophorea and Secernentea which are different in many ways (Tables 12.1 and 12.2).

Classification Based on Habitat

Most of the nematodes inhabit in the intestine while some (e.g. filarial worms) reside in various tissues (Table 12.3).

Table 12.1: Differences between class Adenophorea and Secernentea

Characteristics	*Class Adenophorea*	*Class Secernentea*
Sensory structure (phasmids)	Absent	Present
Esophagus	Modified with presence of: • Gland cells (stichocytes) or • Reserve organ (trophosome)	Normal appearance
Excretory organs	Without lateral canals	Lateral canals present
Caudal papillae	Absent	Present
Infective form to the definitive host	First stage larva (*Trichinella*) or embryonated eggs (*Trichuris, Capillaria*)	Third stage larva or embryonated eggs (e.g. all other nematodes)

Classification Based on They Lay Egg or Larva

Nematodes can be classified into three groups based on they lay eggs or larvae after fertilization:

1. **Oviparous:** Following fertilization, the female worms produce eggs that take some time to hatch out to form larvae in the environment
   - Most of the intestinal nematodes are oviparous except *Strongyloides*. Examples include hookworm, *Ascaris*, *Trichuris*, *Enterobius*, etc.
   - Here, the diagnosis is made by detection of eggs in feces.
2. **Viviparous:** Female worms directly give birth to larvae; there is no egg stage.
   - Most of the somatic nematodes are viviparous. Examples include filarial worm, *Trichinella* and *Dracunculus*
   - Here, the diagnosis is made by detection of larva in tissues or blood.
3. **Ovoviviparous:** Here, the female worms lay eggs containing larvae; which immediately hatch out
   - Example includes *Strongyloides* species
   - The larvae are the diagnostic form detected in stool examination.

GENERAL DESCRIPTION

Nematodes pass through six developmental stages (Fig. 12.1) adult worm, egg stage and four larval stages (L_1–L_4). Each larval stage transforms to the next by shedding of the cuticle (called as **molting**).

Adult Worm

❖ **Shape:** Nematodes are elongated, cylindrical or filariform in shape with both the ends pointed. They are unsegmented without any appendages

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Table 12.2: Systemic classification of phylum nematoda (Anderson et al. 1974)

Superfamily	*Family*	*Genus*
Class: Adenophorea		
Trichinelloidea	Trichinellidae	*Trichinella*
	Trichuridae	*Trichuris, Capillaria*
Class: Secernenatea		
Oxyuroidea	Oxyuridae	*Enterobius*
Ascaridoidea	Ascarididae	*Ascaris, Toxocara, Baylisascaris, Lagochilascaris*
	Anisakidae	*Anisakis*
Ancylostomatoidea	Ancylostomatidae	*Ancylostoma, Necator*
Rhabditoidea	Strongyloididae	*Strongyloides*
Strongyloidea	Chabertiidae	*Oesophagostomum, Ternidens*
	Syngamidae	*Mammomonogamus*
Gnathostomatoidea	Gnathostomatidae	*Gnathostoma*
Metastrongyloidea	Angiostrongylidae	*Angiostrongylus*
Trichostrongyloidea	Trichostrongylidae	*Trichostrongylus*
Filarioidea	Onchocercidae	*Wuchereria, Brugia, Loa loa, Onchocerca, Mansonella, Dirofilaria*
Dracunculoidea	Dracunculidae	*Dracunculus*
Thelazioidea	Thelaziidae	*Thelazia*
Dioctophymatoidea	Dioctophymatidae	*Dioctophyme*

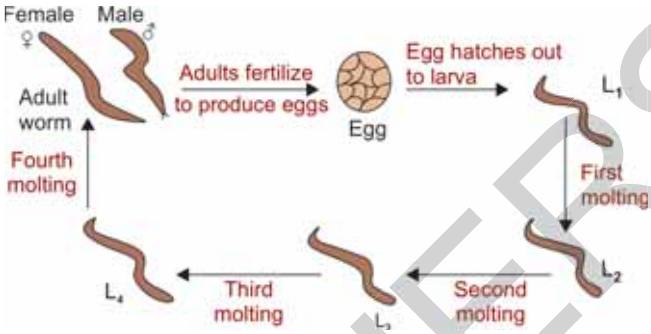


Fig. 12.1A: Developmental stages of nematodes

- **Size:** Variable, ranging from less than 5 mm (hookworm, *Trichinella* and *Strongyloides*) to as long as one meter (*Dracunculus*). Female worms are longer than male worms
- **Symmetry:** Body is bilaterally symmetrical (one plane) while head is radially symmetrical (multiple plane)
- **Body wall:** Made up of outer layer of tough acellular cuticle and inner layer of longitudinal muscle
- **Locomotion:** Nematodes move by contraction of the longitudinal muscles
- **Alimentary canal:** It is well developed and consists of mouth at the anterior end followed by a muscular and glandular esophagus, intestine and rectum that leads to subterminal anus at the posterior end. In some species (e.g. hookworm) mouth bears the teeth (cutting plate). The esophagus (or pharynx) may bear posterior bulb

Table 12.3: Classification of nematodes based on habitat

Intestinal human nematodes	*Somatic human nematodes*	*Animal nematodes that rarely infect man*	
		Larva migrans	*Other animal nematodes*
Small intestine *Ascaris lumbricoides* (common roundworm) *Ancylostoma duodenale* (old world Hookworm) *Necator americanus* (American or new world Hookworm) **Large intestine** *Trichuris trichiura* (whipworm) *Enterobius vermicularis* (threadworm or pinworm)	**Filarial worm** (1) ***Lymphatics*** *Wuchereria bancrofti* *Brugia malayi* *Brugia timori* (2) ***Skin*** *Loa loa* (also eye) *Onchocerca* (also eye) *Mansonella streptocerca* *Mansonella ozzardi* (Serous cavity) (3) ***Serous cavity*** *Mansonella perstans* **Other human somatic nematodes** *Trichinella spiralis* *Dracunculus medinensis* (Guinea worm)	**Visceral larva migrans** *Toxocara* (Liver) *Angiostrongylus cantonensis* (CNS) *Angiostrongylus costaricensis* (abdomen) *Anisakis* *Gnathostoma* *Baylisascaris* **Cutaneous larva migrans** *Ancylostoma braziliensis* *Ancylostoma caninum* *Ancylostoma ceylanicum* *Gnathostoma* species *Uncinaria stenocephala* *Bunostomum* species	**Zoonotic filariasis** *Dirofilaria* **Intestine** *Capillaria philippinensis* *Trichostrongylus* species *Strongyloides fuelleborni* *Oesophagostomum* *Ternidens* species **Conjunctiva** *Thelazia* species **Liver** *Capillaria hepatica* **Kidney** *Dioctophyma* species **Respiratory tract/lungs** *Mammomonogammus* *Capillaria aerophila* *Ascaris suum*

Abbreviation: CNS, central nervous system.

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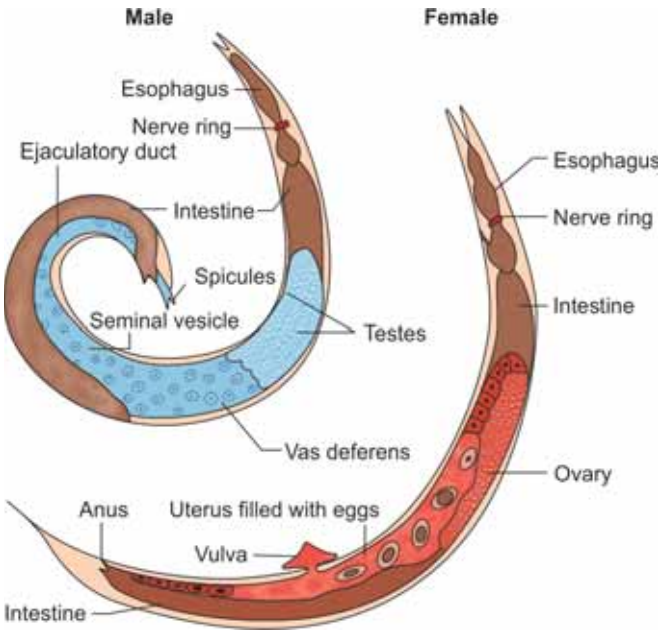


Fig. 12.1B: Adult male and female nematode (schematic diagram)

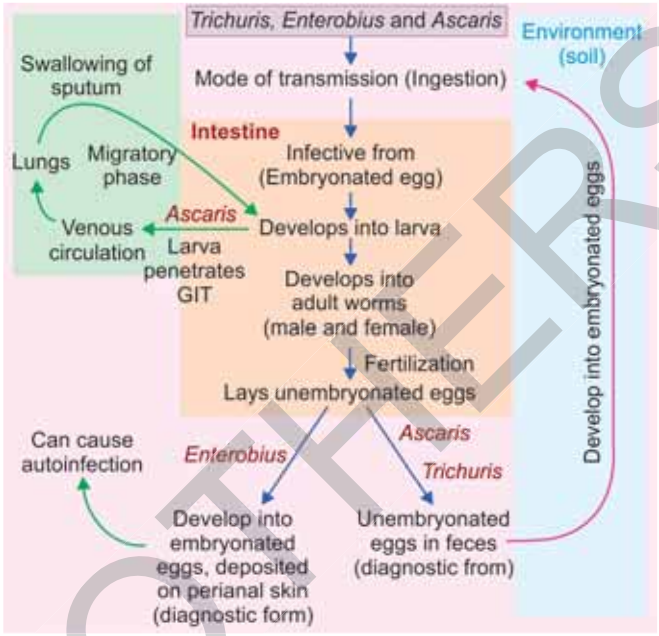


Fig. 12.2A: Life cycles of *Trichuris*, *Enterobius* and *Ascaris*

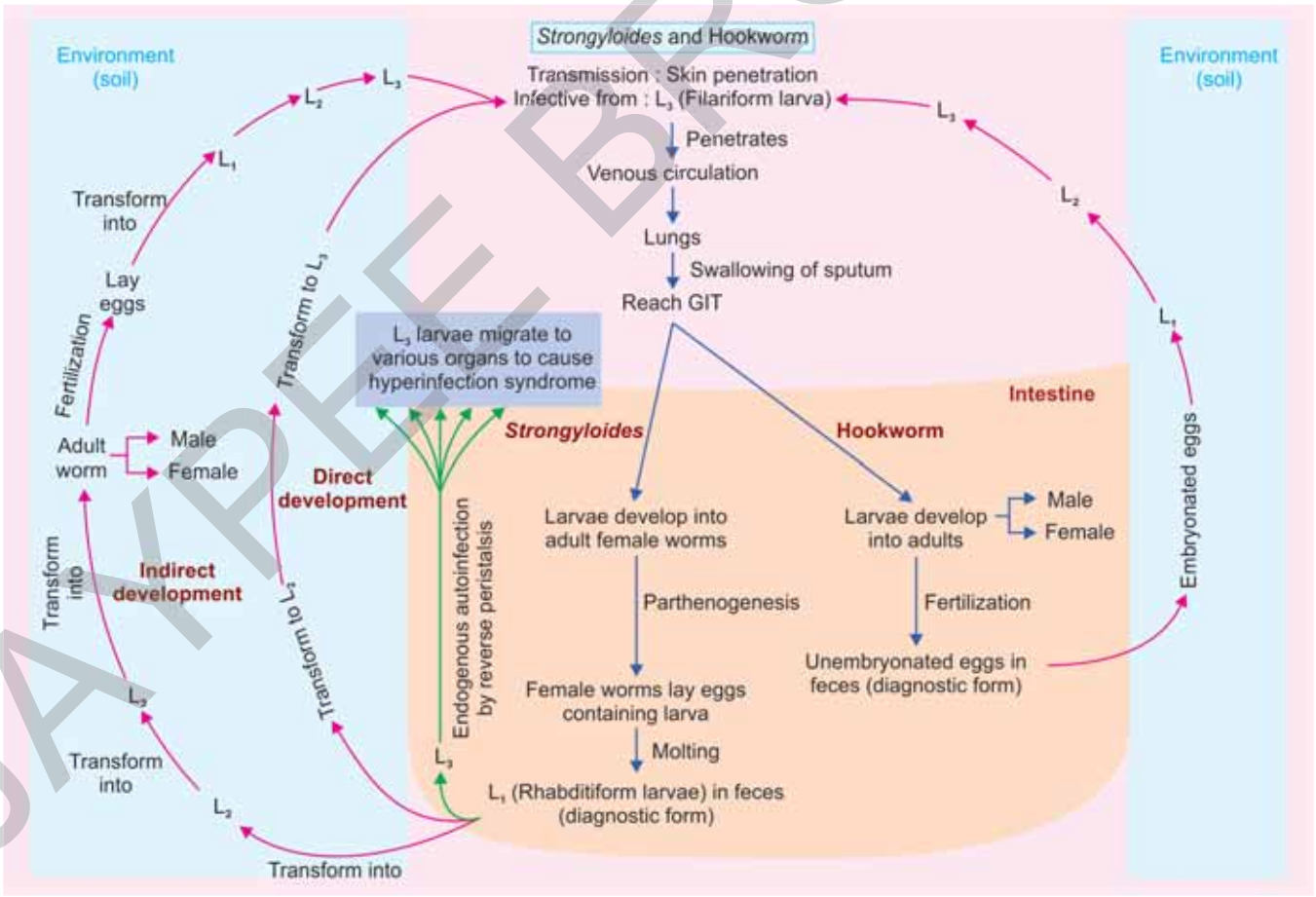


Fig. 12.2B: Life cycles of Hook worm and *Strongyloides*

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(as in *Enterobius*). The intestine or midgut is lined by a single layer of columnar cells

- **Body cavity:** They possess a body cavity or a pseudocele (space between body wall and alimentary canal) with high hydrostatic pressure which is filled with body fluid secreted by intestine and genital organs
- **Sexes:** Nematodes are diecious (bisexual), i.e. sexes are different
- **Male reproductive system:** It consists of a long convoluted tube which can be differentiated into testes, vas deferens, seminal vesicle and ejaculatory duct. Some worms also bear accessory copulatory organs like a copulatory bursa with two spicules (rod like protrusible organ present at the posterior end) and gubernaculum (an elevation of cloaca that guides the spicule during copulation). The ejaculatory duct opens subterminally at the posterior end into a common passage along with the rectum (known as cloaca) (Fig.12.2)
- **Female reproductive system:** It consists of two (common) or one convoluted tube. Each tube is differentiated into an ovary, oviduct, seminal receptacle, and uterus and then both the tubes joined to form a common vagina that opens outside through vulva (genital pore) either in the middle of the body or near the mouth (Fig. 12.2)
- **Nervous system:** It is rudimentary and consists of circular nerve ring (brain) surrounding the esophagus and six longitudinal nerve trunks (one dorsal, one ventral and four lateral). The dorsal nerve is responsible for motor control, while the lateral nerves are for sensory and the ventral one combines both the functions. Some species possess sensory structure like sensory papilla and phasmid (chemoreception organs) over the cuticle
- **Excretory system:** It is also rudimentary. Unlike cestodes, they do not have flame cells. Various ways of waste disposal are:
  - Through anus
  - Excretion of nitrogenous waste in the form of ammonia through the body wall
  - In some species, H-shaped canal along each side of body regulates nutrients and waste content
  - In few other species; An excretory gland is situated near esophagus.

Life Cycle

Nematodes complete their life cycle in one host (man) except in filarial worms (need two hosts—definitive host-man and intermediate host—mosquito) and *Dracunculus* species (need two hosts—definitive host man and intermediate host cyclops).

The life cycles of intestinal nematodes have been summarized as flowcharts in Figs 2A and 2B; the detail has been discussed under each topic subsequently in this Chapter. The pathogenesis, diagnosis and treatment are discussed in detail under individual nematodes.

LARGE INTESTINAL NEMATODES

TRICHURIS TRICHIURA

It is also called as **whipworm** as the adult worm resembles to a handle of a whip. It is one of the soil-transmitted helminth (see the highlight box at the end of this Chapter for detail).

- It was first described by Linnaeus in 1771
- About 71 species of *Trichuris* are recorded so far. However, human infection is mostly confined to *T. trichiura* and very rarely *T. suis* (pig whipworm) and *T. vulpis* (dog whipworm).

Habitat

T. trichiura resides in the large intestine of man (mainly cecum and appendix).

Epidemiology

Trichuriasis is worldwide in distribution, mainly in warm and moist climate similar to ascariasis.

- Children are commonly affected
- Global prevalence in humans is approximately 604 million.

Morphology

Similar to other nematodes, *T. trichiura* exists in three forms: adult, larvae (four stages) and egg.

Adult Worm

The adult worm is whip shaped. Anterior three-fifth is thin, hair like, coiled (like rope of a whip) and posterior two-fifth is short and thick.

- The coiled anterior part contains the esophagus and is attached to the gastrointestinal tract (GIT) mucosa whereas the posterior thick part bears the genital organs and intestine and lie free in the human intestine
- The esophagus is glandular, surrounded by a gland called as **stichosome**
- Male is whitish, 30–45 mm long and bears a coiled posterior end
- Female is longer (35–50 mm) and its posterior part is either shaped like a comma or arc (resembles a handle of a whip) (Figs 12.3 and 12.4B).

Egg

Eggs of *T. trichiura* are barrel-shaped; surrounded by a shell, bear mucus plug at both the poles.

- Elongated, measure 50–54 µm long and 22–23 µm wide
- Unembryonated when freshly passed in feces; become embryonated later in environment

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- ❖ Bile stained; yellowish-brown in color (in saline mount)
- ❖ Float in saturated salt solution.

Note: Eggs of *T. vulpis* is similar to that of *T. trichiura* but it is larger (70–80 μm × 30–42 μm) with smaller mucus plug.

Life Cycle (Fig. 12.3)

Host: Humans are the only host.
Infective form: Embryonated eggs serve as infective form.
Mode of transmission: Man (usually children) acquires infection by ingestion of contaminated food and water containing embryonated egg.

Egg-Larva-Adult Transformation

Eggs hatch out in the small intestine releasing the second stage larva, migrate to large intestine where they undergo further moltings to transform into adult worms. Adult female worms have a life span of 5–10 years.

Adults Laying Unembryonated Egg

Within 2–3 months (prepatent period), the female worms following fertilization start laying unembryonated eggs. Each female worm can lay 14,000–20,000 eggs per day for 1–3 years.

Embryonation

The unembryonated eggs passed in the feces are not infective. It takes about 10–14 days to become embryonated (it undergoes two molts to produce second stage larva within the egg shell). Embryonation occurs at 25°C in warm and moist condition. Such embryonated eggs are infective to man.

Pathogenicity and Clinical Feature

Incubation period varies from 70 to 90 days. Most infected individuals are asymptomatic, with or without having eosinophilia.

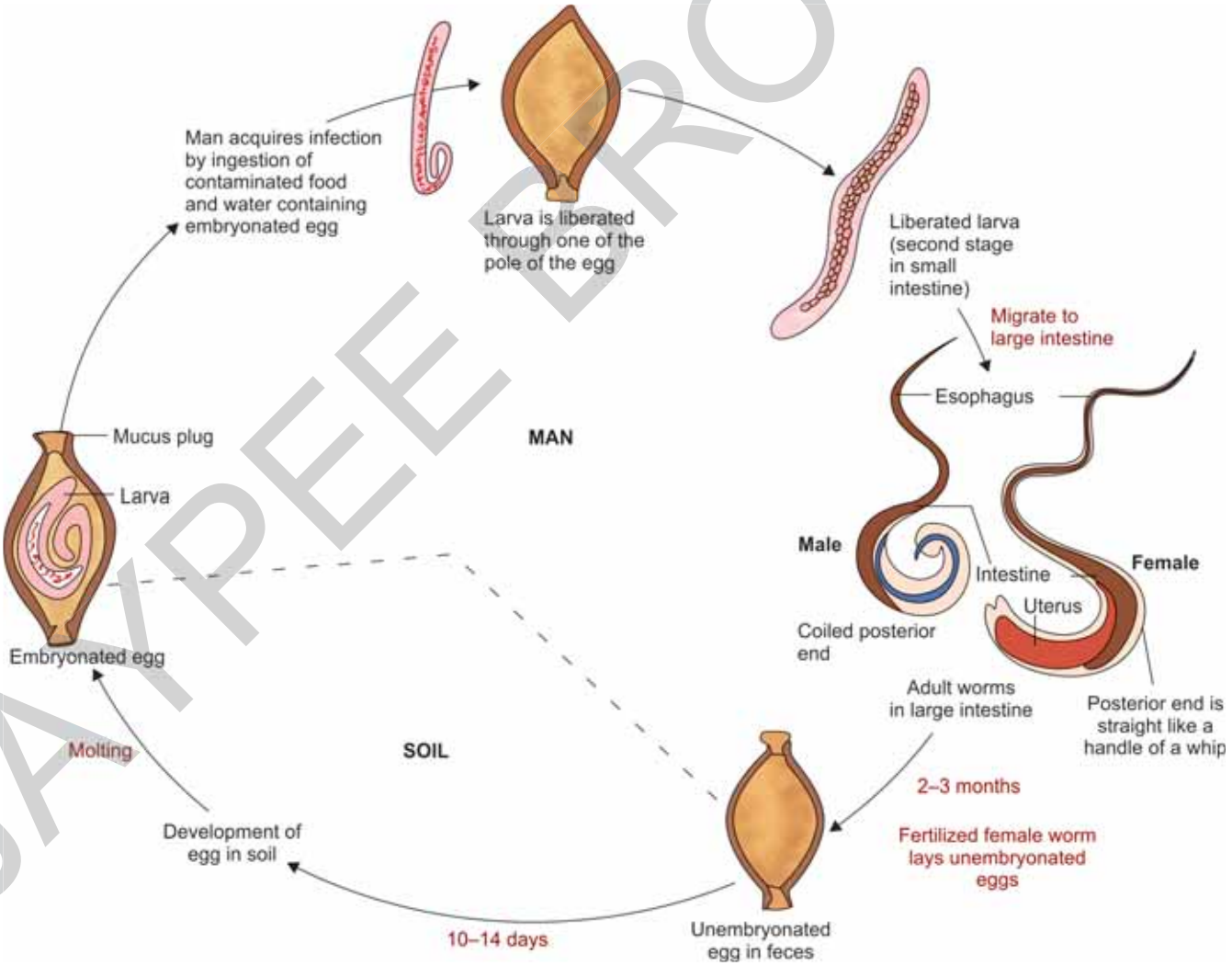


Fig. 12.3: Life cycle of *Trichuris trichiura*

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In people with heavy infections: Adult female worm gets buried in the large intestinal mucosa that leads to:

- ❖ Mechanical distortion: Leading to inflamed, edematous, and friable mucosa
- ❖ Allergic response by the host: Large number of macrophages infiltrate in the lamina propria that produce tumor necrosis factor-α (TNF-α).

Common manifestations include:

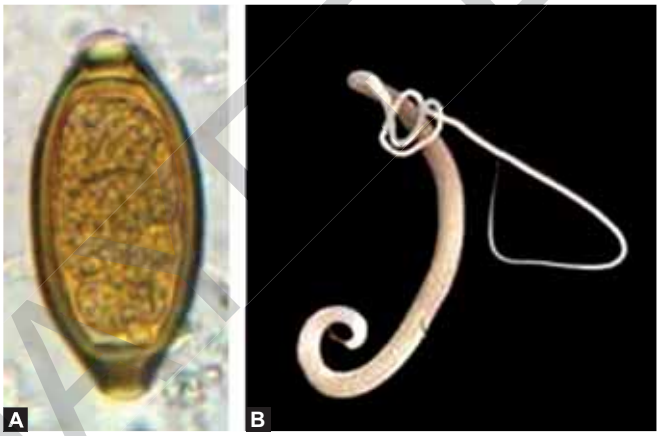
- ❖ Abdominal pain, anorexia, etc.
- ❖ *Trichuris dysentery syndrome*—bloody or mucoid diarrhea resembling inflammatory bowel disease
- ❖ Iron deficiency anemia occurs as a result of blood loss; not due to blood ingestion as seen in hookworm
- ❖ Recurrent rectal prolapse (due to heavy worm load in the rectum and malnutrition)
- ❖ Growth retardation and impaired cognitive function (due to the release of anti-inflammatory cytokines induced by the secretory molecules of *Trichuris* species).

Laboratoy Diagnosis

Stool Examination

Because the level of egg output is high (approximately 200 eggs/g of feces per worm pair), microscopic examination of a single fecal smear is sufficient for diagnosis of symptomatic cases (Figs 12.4A and B).

- ❖ The characteristic 50 × 22 μm barrel-shaped, bile-stained *Trichuris* eggs (with mucus plugs at the ends) are readily detected on stool examination either by direct wet mount or following concentration of the stool (Fig. 12.4A)
- ❖ Preservative: Formalin is preferred to preserve the stool samples



Figs 12.4A and B: *Trichuris trichiura* (A) Egg in saline mount; (B) Adult female

Source: A—Dr Anand Janagond, Associate Professor of Microbiology, S. Nijalingappa Medical college, Bagalkot, Karnataka (*with permission*); B—DPDx Image Library, Centers for Disease Control and Prevention (CDC), Atlanta (*with permission*).

- ❖ Whip shaped adult worms of 3–5 cm long, are occasionally seen on proctoscopy (Fig. 12.4B).

Other Findings

- ❖ Peripheral blood eosinophilia (<15%)
- ❖ Increased serum IgE level.

Treatment	*Trichuris trichiura*
❑ Mebendazole (500 mg once) or albendazole (400 mg daily for three doses) is safe and moderately effective for treatment, with cure rates of 70–90% ❑ Ivermectin (200 mg/kg daily for three doses) is also safe but is less effective.	

Trichuris suis Therapy

Eggs of *Trichuris suis* are used for treatment of active ulcerative colitis. They induce a shift from T_H1 to T_H2 immune response counteracting the T_H1-mediated pathogenesis of active ulcerative colitis.

Prevention

Trichuriasis can be prevented by improved personal hygiene, proper disposal of feces and improved nutrition with dietary iron.

ENTEROBIUS VERMICULARIS

Enterobius vermicularis is also called as **pinworm** or **threadworm.**

- ❖ It is described first by Leuckart, in 1865
- ❖ *E. vermicularis* is the only species. The second species *E. gregorii* is identical to *E. vermicularis* (except the basal portion of spicule) and now it is considered as the younger stage of *E. vermicularis.*

Habitat

The adult worm remains attached to the large intestine (cecum, appendix and adjacent portion of colon) by their mouth end.

Epidemiology

Global prevalence in humans: Globally, around 209 million people are infected by pinworms:

- ❖ The prevalence is maximum in school children between the age of 5 and 14 years
- ❖ People carry the infection for years together due to auto infective cycles
- ❖ **It has been said that:** "*You had the infection as a child, you have it now and you will again get it when you have children*"
- ❖ **Factors promoting infection:** Overcrowding and impaired hygiene, poor personal care (nail biting or inadequate hand washing).

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Morphology

The life cycle of *Enterobius* passes through three forms: adult, larvae (four stages) and egg; similar to other nematodes.

Adult Worm

Adult worm of *Enterobius* is small, white and thread-like (hence named as threadworm).

- **Cervical alae:** The adult worm bears a wing-like expansion of the cuticle near the anterior end
- **Double bulb esophagus:** The posterior end of the esophagus is dilated to form globular bulb
- Male worm is smaller (2–5 mm long × 0.1–0.2 mm wide) and the posterior one-third is tightly curved and bears a copulatory bursa with spicules at the posterior end. Males die soon after fertilization
- Female worm is longer (8–13 mm long × 0.3–0.5 mm wide), and the posterior one-third is tapering, straight, thin and pointed (looks like a pin, hence called as pinworm).

Eggs

- **Shape:** Oval or planoconvex (one side is convex and the other side is flat because it is compressed laterally)
- **Size:** 50–60 µm long × 20–30 µm wide (Fig. 12.5)
- **Surrounded by:** Double layered egg shell
- Non bile-stained, colorless in saline mount
- Embryonated egg when freshly passed contains a tadpole shaped larva inside
- Floats in saturated salt solution.

Life Cycle (Fig. 12.6)

Host: Humans are the only host.
Infective form: Embryonated eggs are infective to man.
Mode of transmission: Man (usually children) acquires infection by:

- Ingestion of eggs contaminated with fingers due to inadequate hand washing or nail biting habit
- **Autoinfection:** Autoinfection is of two types:
  1. Endogenous autoinfection—it occurs by retrograde migration of the larva hatched from the eggs in the perianal skin.
  2. Exogenous autoinfection—through contaminated finger.
- Infection can rarely occur through inhalation of the air-borne eggs.

Development in Man

Eggs usually contain the fully developed larvae. Larvae hatch out from eggs in the cecum and then develop into adult worms.



Fig. 12.5: Egg of *Enterobius vermicularis* (saline mount)
Source: DPDx Image Library, Centers for Disease Control and Prevention (CDC), Atlanta (*with permission*).

- Adult worms undergo maturation within 1 month. After fertilization with female worms, the male worms usually die. Gravid female worms fully filled with eggs migrate to large intestine (rectum, colon) and start laying eggs on the perianal skin. Adult female worms usually lay 10,000 eggs/day (Figs 12.7C and D)
- The eggs are embryonated and are the infective stage to man. The prepatent period is about 3–4 weeks
- Female worm lives for about 2 months but because of the autoinfection the cycle continues.

Pathogenicity and Clinical Features

- **Asymptomatic:** Most of the infections are asymptomatic
- **Symptomatic patients:**
  - **Age and sex:** Females, children and young adults are often symptomatic than males and older people
  - **Cardinal symptoms:** Perianal pruritus often worse at night as a result of the nocturnal migration of the female worm
    - The worms may be found in undergarments and can also be found lying in the buttock area of infected children
    - Repeated scratching is the main reason of contaminated finger; which causes auto-infection.
  - Excoriation of the perianal skin and bacterial super-infection may occur (due to continuous scratching of the skin)
  - Abdominal pain and weight loss (may be seen in heavy infections).
- **Migration of the worm:** Rarely, pinworms invade the female genital tract, causing vulvovaginitis and pelvic

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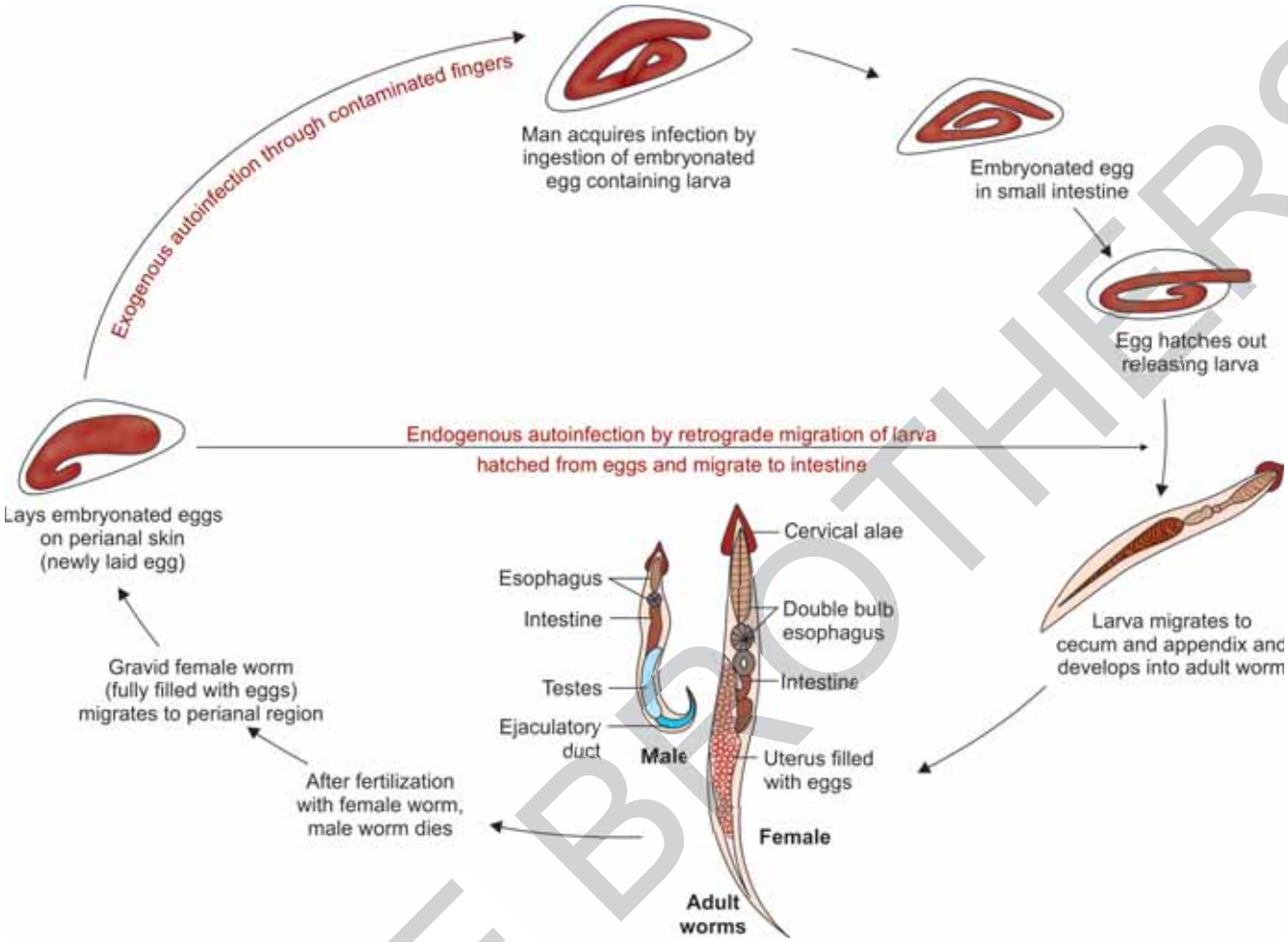


Fig. 12.6 Life cycle of *Enterobius vermicularis*

or peritoneal granulomas. Other sites involved are urinary tract, peritoneal cavity, lungs and liver

- Eosinophilia is inconsistent.

Laboratory Diagnosis

The female worms lay eggs in the perianal area; not in the rectum. Hence, eggs are rarely detected by stool examination; around 5% of cases.

- The eggs deposited in the perianal skin are collected by applying cellophane tape or its modification called, NIH swab. Eggs are non bile-stained, plancoconvex in shape, containing a larva inside (Fig. 12.5)
- The adult female worms may occasionally be found in the feces or crawling to the perianal skin (Fig. 12.7B)
- **Number of specimens:** A series of 4–6 consecutive tapes may be necessary as the female worms migrate intermittently
- **Timing:** Samples should be collected when the chance of egg deposition is more such as late in the evening, when the patient has been sleeping for several hours, or first thing in the morning.

Cellophane Tape Method

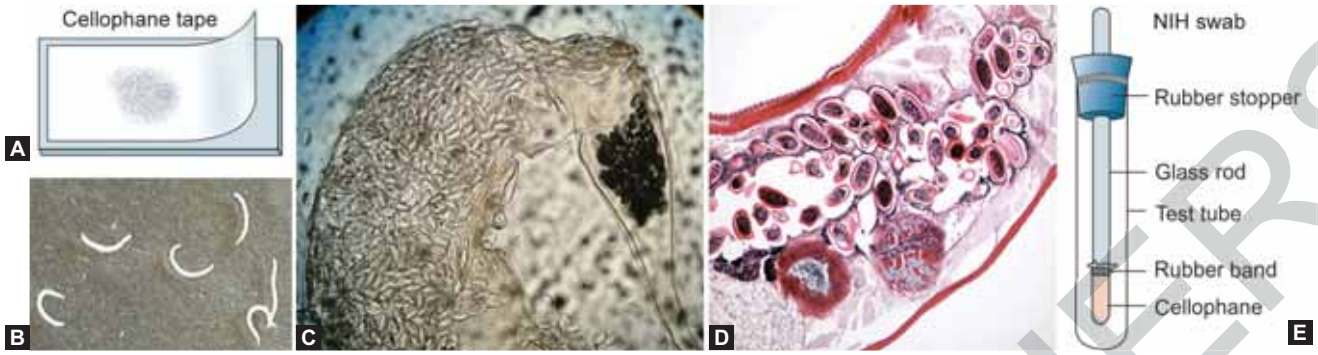
Eggs are detected by the application of clear cellulose acetate tape to the perianal region in the morning before the child goes for bath. The tape is then applied on the clear glass slide. The slide is observed under microscope for the detection of pinworm eggs (Fig. 12.7A).

NIH Swab Method

It is devised in National Institute of Health, USA (Fig. 12.7E).

- It consists of a glass rod attached to a cellophane tape by a rubber band
- The other end of the glass rod is fixed by a rubber stopper and kept in a test tube
- The cellophane part of the glass rod is rolled over the perineal and perianal skin area to collect the sample

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Figs 12.7A to D: *Enterobius vermicularis* (A) Cellophane tape; (B) Adult worms (actual size); (C) Adult female worm containing numerous eggs; (D) Longitudinal section of an adult female worm shows many planoconvex eggs; (E) NIH swab method (schematic)

Source: B and C—Head of Department, Microbiology, Meenakshi Medical College, Chennai; D—DPDx Image Library, Centers for Disease Control and Prevention (CDC), Atlanta (*with permission*).

❖ After the tape is transferred to a slide, microscopic examination will detect *Enterobius* eggs, which are planoconvex, flattened along one side, measure 50–60 µm × 20–30 µm, containing a larva inside.

Treatment	*Enterobius vermicularis*
❑ One of the following drugs can be given: ➢ Mebendazole (100 mg once) ➢ Albendazole (400 mg once) or ➢ Pyrantel pamoate (11 mg/kg once; maximum, 1 g) ❑ The same treatment should be repeated after 2 weeks ❑ Treatment of household members is advocated to eliminate asymptomatic reservoirs of potential reinfection.	

Prevention

Total prevention is neither realistic nor possible as the transmission is so common; aided by autoinfection. Improving personal hygiene such as proper washing of bed clothes, keeping nail short and clean, frequent hand washing are the key measures to contain the transmission.

SMALL INTESTINAL NEMATODES

HOOKWORM

Hookworm is one of the important causes of iron deficiency anemia in both tropics and temperate countries. It is so named because the anterior end of adult worm is bent. It is one of the soil-transmitted helminth (see the highlight box at the end of this Chapter for detail).

Classification

Hookworm belongs to the family Ancylostomatidae which consists of two species infecting humans. *Ancylostoma duodenale* and *Necator americanus.* The word *Ancylostoma* is derived from hooked mouth (*Ancylos*—hooked, *stoma*—mouth). Hookworm comprises of several species, which infect humans and animals.

❖ Human parasite:
- *A. duodenale* or old world hookworm
- *N. americanus* or new world hookworm or American hookworm.

❖ Animal parasites that rarely infect man, causing cutaneous larva migrans
- *Ancylostoma braziliensis*
- *Ancylostoma caninum* (more common than other animal species)
- *Ancylostoma ceylanicum*
- *Uncinaria stenocephala.*

History

❖ *A. duodenale* was first detected by an Italian physician Dubini in 1843 and life cycle and pathogenesis was described by Arthur Loss in 1898

❖ *N. americanus* was first described by Stiles in 1902 in Texas, USA, hence called as **American hookworm or the American murderer.**

Epidemiology

World

Hookworm infection is widespread. Globally, nearly 900 million people are infected. *N. americanus* infection (835 million) is more common than *A. duodenale* (135 million).

❖ *A. duodenale* is prevalent in southern Europe, North Africa, and northern Asia

❖ *N. americanus* is the predominant species in the Western world, found throughout Central and South Africa, Central and South America

❖ In Southeast Asia including India, both the species coexist

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- Hookworm infection is almost eradicated from Europe and USA
- Males and young adults (15–25 years) are commonly affected; but the anemia due to iron loss is more severe in children and pregnant women.

India

Hookworm infection is widely prevalent in India. More than 200 million people are estimated to be infected in India.

- *N. americanus* is predominant in South India and *A. duodenale* in North India
- *Necator* is seen in all the states except in Punjab and Uttar Pradesh
- Recently, another species, *A. ceylanicum* has been reported from a village near Kolkata
- Heavily infected areas are: Assam (tea gardens), West Bengal, Bihar, Odisha, Andhra Pradesh, Tamil Nadu, Kerala and Maharashtra.

Endemic Index

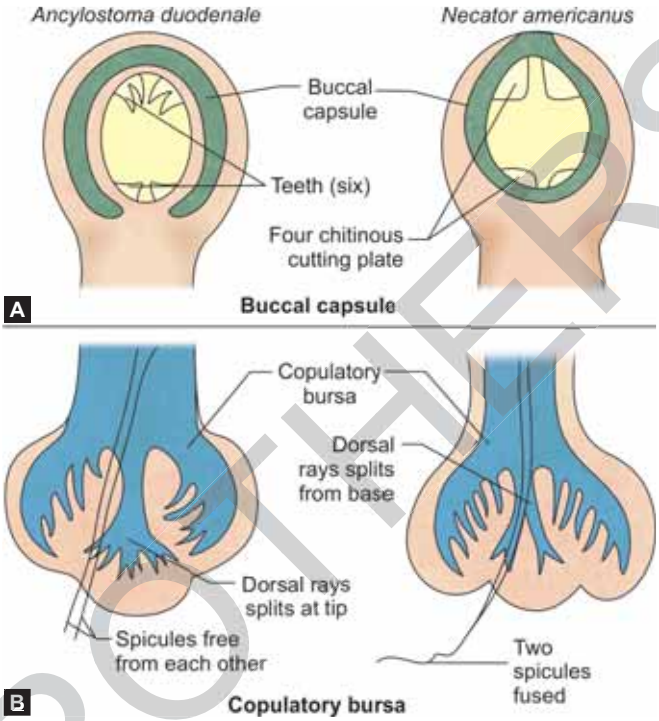
Chandler's index is used in the epidemiological studies of hookworm disease to estimate the morbidity and mortality in the community due to hookworm infection (which depends much upon the worm load).

Morphology

Hookworm has three morphological forms: adult, larvae (four stages) and egg; similar to other nematodes.

Adult Worm (*A. duodenale*)

- **Size:** Male worm is smaller (7–11 mm) than the female (9–13 mm)
- **Shape:** Straight except the anterior end which is bent dorsally (in the same direction of body curvature), hence called as **hookworm**
- **Color:** Adult worm is pink or grayish-white but may look reddish due to ingested blood
- **Mouth:** It is present at the anterior end, directed dorsally. It contains the buccal capsule which is lined by a hard substance bearing six teeth (four hook-like teeth on ventral surface and two knob like teeth dorsally) (Fig. 12.8A)
- **Glands:** The digestive system is attached with five glands, one of them is the esophageal gland secreting a substance that prevents clotting
- **Copulatory bursa:** Presence of copulatory bursa in the caudal end of males differentiates it from the female worms of *A. duodenale* (Table 12.4) (Fig. 12.8B)
  - It is the umbrella like expansion of the posterior end of male worm bearing two spicules, consists of three lobes (one-dorsal and two-lateral)



Figs 12.8A and B: (A) Buccal capsule and (B) Copulatory bursa of *Ancylostoma duodenale* and *Necator americanus* (schematic)

Table 12.4: Differences between male and female worms of *Ancylostoma duodenale*

Features	*Male worm*	*Female worm*
Size	Smaller (5–11 mm)	Longer (9–13 mm)
Copulatory bursa	Present posteriorly	Absent
Posterior end	Expanded due to copulatory bursa	Tapering and straight pointed tail
Genital opening	Opens in cloaca along with anus	Opens separately in the middle

  - All the three lobes again split in a tripartite fashion. Dorsal lobe contains three dorsal rays; each lateral lobe contains five rays (two-ventral and three lateral rays). So total numbers of rays are 13 (Fig. 12.8B).
- Other features are similar to any nematode described at the beginning of the chapter
- Adult worm of *N. americanus* is different from *A. duodenale* (Table 12.5).

Egg

Hookworm eggs are:

- Oval-shaped, measures 60 × 40 μm
- Not bile stained, appear colorless in saline mount
- Surrounded by thin, hyaline, translucent egg shell
- Ovum (embryo) is segmented; comprises of 4 to 32 blastomeres (Figs 12.9A and B)

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Figs 12.9A to C: Hookworm (A) Egg with four blastomeres; (B) Egg with many blastomeres; (C) Rhabditiform larva

Source: A to C—DPDx Image Library, Centers for Disease Control and Prevention (CDC), Atlanta (*with permission*).

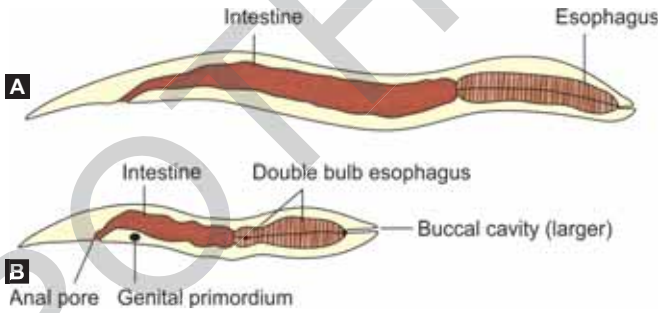
Table 12.5: Differences between adult worm of *Ancylostoma duodenale* and *Necator americanus*

Adult worm	*Ancylostoma duodenale*	*Necator americanus*
Size	Large and thick	Smaller and more slender
Bending of anterior end	Bends in the same direction of body curvature	Bends in the opposite direction of body curvature
Buccal capsule	Bears six teeth • Four hook-like ventral teeth • Two knob-like dorsal teeth	• Four chitinous cutting plates present • Two ventral and two dorsal • Dorsomedian teeth are present
Copulatory bursa	• Bifurcation is tripartite • Total number of rays 13 • Dorsal ray splits at the tip • Two spicules are present freely	• Bifurcation is bipartite • Total number of rays 14 • Dorsal ray splits from the base • Both spicules are fused at the tip
Posterior end of female worm	Bears a spine	No spine present in females
Vulva opens at	Behind the middle of the body	In front of middle of the body
Pathogenicity	More pathogenic because of: • Larger size, armed with teeth and more migratory • Blood loss 0.15–0.26 mL/worm/day	Less pathogenic • **Except:** Ground itch and dermatitis (more severe) • Blood loss 0.03 mL / worm/day

- ❖ There is a clear space between the egg shell and the embryo
- ❖ Floats on saturated salt solution
- ❖ Eggs of both *A. duodenale* and *N. americanus* are morphologically indistinguishable.

Larva

There are four stages of hookworm larva (L_1 to L_4)



Figs 12.10A and B: Hookworm (*Acylostoma duodenale)* (A) Filariform larva; (B) Rhabditiform larva

- ❖ First stage larva is called as rhabditiform larva (Figs 12.9C and 12.10B)
- ❖ L_3 stage larva is called as filariform larva and is the infective form to man
- ❖ Filariform larva is longer (660–720 μm) than the rhabditiform larva (100–150 μm), the esophageal bulb extends to about one-third of the body length and the posterior end is more acutely tapered (Fig. 12.10A)
- ❖ The rhabditiform larva of *A. duodenale* and *N. americanus* is morphologically similar but they differ in the morphology of their filariform larva (Table 12.6).

Life Cycle (Fig. 12.11)

Host: Hookworm involves only one host (man).
Infective stage: Third stage filariform (L_3) larva acts as the infective form.
Mode of transmission: Through penetration of skin by the third stage larva (by walking bare foot in dampen soil). Though rare, but other routes of transmission of the larva has been reported through oral, in utero and transmammary routes.

Migratory Phase

Following penetration, the L_3 larvae enter into the small subcutaneous venules and through venous circulation, reach to the right side of heart and finally to the lungs.

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Table 12.6: Differences between filariform (L3) larva of *Ancylostoma duodenale* and *Necator americanus*

Filariform (L_3) larva	*Ancylostoma duodenale*	*Necator americanus*
Size	720 µm	660 µm
Shape	Head end is blunt and tail is pointed	Same as *Ancylostoma*
Cuticle	Bears faint transverse striations	Bears prominent transverse striations
Buccal capsule	Shorter (10 µm), lumen larger and bound by two thin chitinous wall	Larger (15 µm), lumen short and bound by two thick chitinous wall
Esophagus-intestinal junction	No gap between esophagus and intestine	Gap between esophagus and intestine due to prominent anterior dilatation of intestinal lumen
Intestine	Posterior end of intestine has a refractile body	Refractile body absent

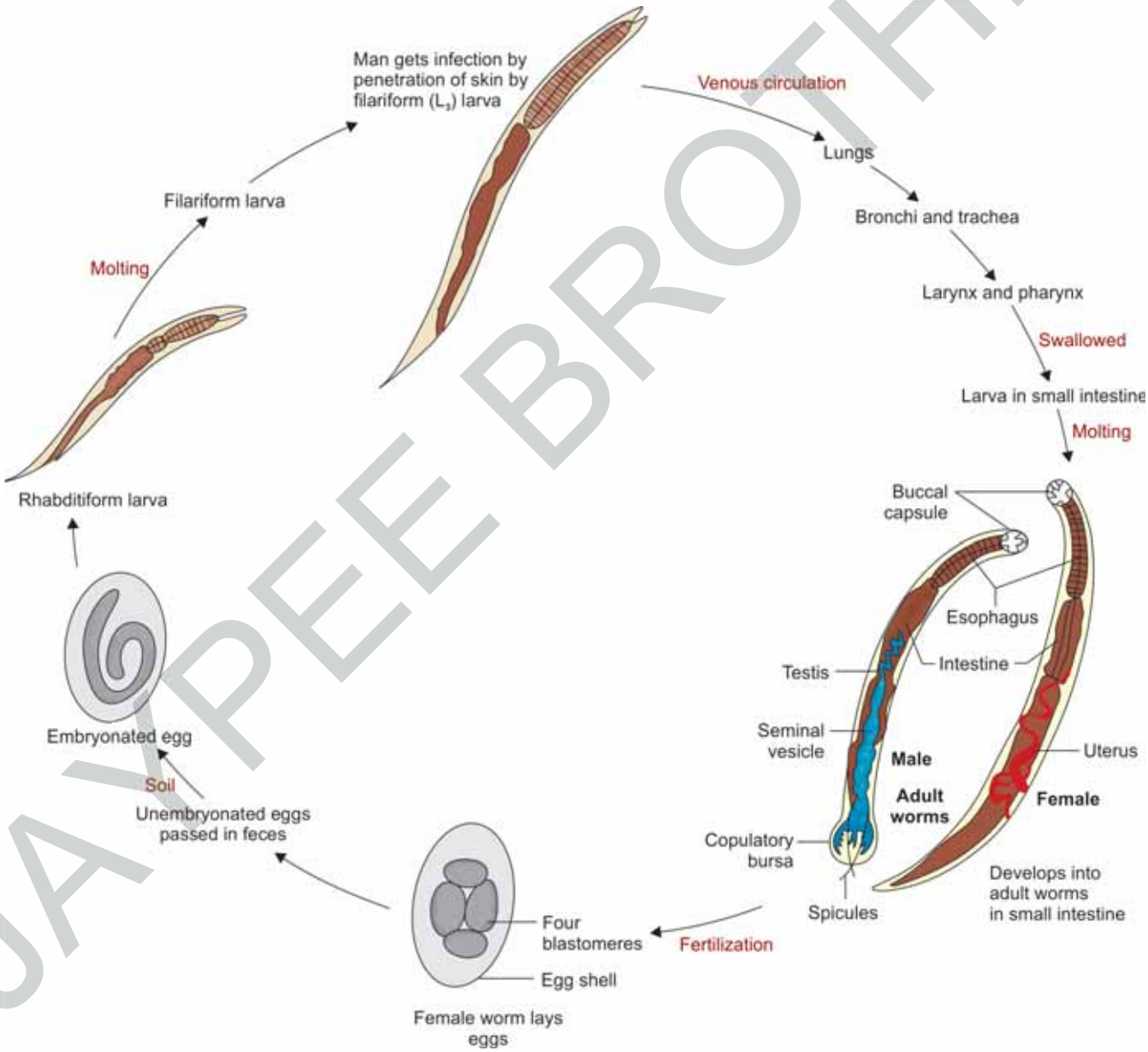


Fig. 12.11: Life cycle of hookworm

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