FE 305 FOOD MICROBIOLOGY
Foodborne Parasites and Natural Food Toxins

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Foodborne Parasites

- Parasites are organisms that obtain the nutrients and energy they need for their life cycle from other living organisms (hosts).
- More than 300 helminth species (cestodes, nematodes and trematodes) and more than 70 protozoan species are known to threaten human health.
- Complex life cycles, many routes of transmission and long incubation periods make parasites a critical public health issue.
- Parasites are transmitted to humans in several ways;
  - food and water are the most important routes.
  - Parasitic infections result from eating the muscle or internal organs of infected animals,
  - from drinking contaminated water, and from eating vegetables and fruit irrigated or washed with such water.
  - Foods grown on soil fertilised with human or animal faeces carry a particularly high risk.

Foodborne Parasites

- Parasites occur throughout the world, but some species are restricted to particular regions.
- Some parasites use only a specific group of organisms as hosts, while others can move between many host species.
- Most parasitic infections are asymptomatic, but typical symptoms appear in some acute or chronic cases.
- A parasite well adapted to its host can live and feed in it for a long time without harming its health.
- Symptoms then appear only when the host's resistance falls.

Helminths

- Helminths are divided into three main groups:
  - Cestodes (tapeworms)
    - *Taenia* spp.
    - *Dibothriocephalus latus* (formerly *Diphyllobothrium latum*)
    - *Echinococcus* spp.
  - Nematodes (roundworms)
    - *Trichinella* spp.
    - *Ascaris* spp.
    - *Anisakis* spp.
  - Trematodes (flukes)







Cestodes (Tapeworms) - *Taenia* spp.

- *Taenia* is the most common genus of cestodes.
- These parasites have an anaerobic metabolism and obtain all their nutrients from their host.
- The larvae (cysticerci), the infective forms, occur in the intermediate host (cattle or pigs); the adult, reproducing worms live in the human intestine.
- Humans are usually infected by eating undercooked infected meat.
- Cysticerci in meat are destroyed by cooking to a core temperature of at least 60 °C or by freezing at −10 °C for at least 10 days; holding in brine for up to 3 weeks is also effective.
- Infection with the adult *Taenia* worm is called taeniasis. The two most common species are the beef and the pork tapeworm:
  - *Taenia saginata* (beef tapeworm) and
  - *Taenia solium* (pork tapeworm).

Cestodes (Tapeworms) - *Taenia* spp.

- *Taenia saginata* is common in the Middle East, Africa, Ethiopia, Thailand, India and Korea. Its larval form, *Cysticercus bovis*, is found in the active muscles of cattle (tongue, masseter, heart, diaphragm).
- When a person eats infected beef, the larva attaches to the wall of the small intestine and develops into an adult worm in about 8–10 weeks.
- The adult worm stays in the intestine: it reaches an average length of 3–5 m (up to 10 m) and can live for up to 20 years, often without symptoms. Unlike *T. solium*, *T. saginata* does not cause cysticercosis in humans.

Cestodes (Tapeworms) - *Taenia* spp.

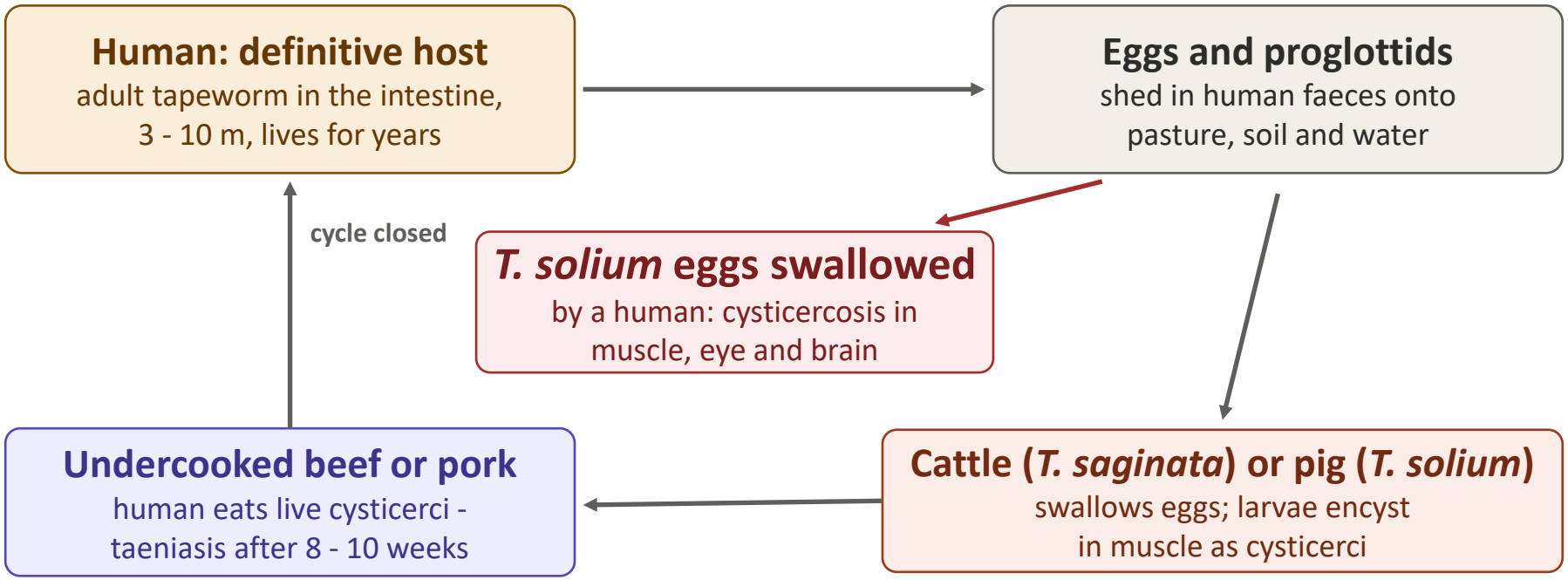
- *T. saginata* infections are mostly asymptomatic.
  - About one third of patients experience nausea or a hunger-like abdominal pain relieved by frequent eating.
  - Later, constipation, diarrhoea, weight loss and dizziness may be added to these epigastric symptoms.
  - Patients often notice the infection when motile segments (proglottids) appear in the perianal region, in the stool or on underwear.
  - Praziquantel and niclosamide are the most effective drugs for treating taeniasis.
- Careful meat inspection in slaughterhouses and the detection of infected animals are effective in controlling the parasite.
- Cattle are infected by grazing on pasture contaminated with human faeces, so sanitation breaks the cycle.

Cestodes (Tapeworms) - *Taenia* spp.

Taenia solium infections are rare in Muslim countries, where pork is seldom eaten, but common in Mexico, Central and South America, Africa, parts of South and South-East Asia and Eastern Europe.

- Pigs are the intermediate hosts and humans the definitive hosts.
- Humans can, however, also act as intermediate hosts: if they swallow *T. solium* eggs (from contaminated food or water, or by autoinfection), the larvae develop in their own tissues. This makes *T. solium* far more dangerous than *T. saginata*.
- Eating raw or undercooked pork containing the larvae (*Cysticercus cellulosae*) leads to taeniasis, with the adult worm in the intestine. Swallowing the eggs leads to cysticercosis: the larvae encyst in the muscles, eyes and brain (neurocysticercosis, a leading cause of acquired epilepsy worldwide).
- Intestinal *T. solium* infections, like those of *T. saginata*, are usually asymptomatic.
- In people with low immunity, nausea, cramps, loss of appetite, weakness and fatigue may be seen.

Life Cycle of Taenia: Taeniasis and Cysticercosis



Breaking the cycle

meat inspection at the slaughterhouse (masseter, heart, diaphragm)
cook meat to a core temperature of at least 60 °C, or freeze at −10 °C for 10 days
no human faeces on pasture: sanitation and sewage treatment
treat human carriers (praziquantel, niclosamide); hand and food hygiene against *T. solium* eggs

Dibothriocephalus latus (fish tapeworm)

- This parasite (formerly *Diphyllobothrium latum*) is common in Finland, Scandinavia, the Baltic region, Alaska, Canada, Japan and Peru, where raw or undercooked fish is widely eaten.
- Its definitive hosts are humans and fish-eating mammals. The eggs reach lakes and seas with sewage; the larvae pass through crustaceans to fish, and humans are infected by eating the fish.
- Infections are usually asymptomatic, but heavy infections cause abdominal pain, diarrhoea and, because the worm absorbs vitamin B_{12}, megaloblastic anaemia. The adult worm can reach 10 m in the human intestine.
- Infection is prevented by avoiding raw or undercooked fish. Cooking to a core temperature of at least 60 °C, or freezing at −20 °C for at least 24 hours (or −35 °C for 15 hours), kills the larvae.

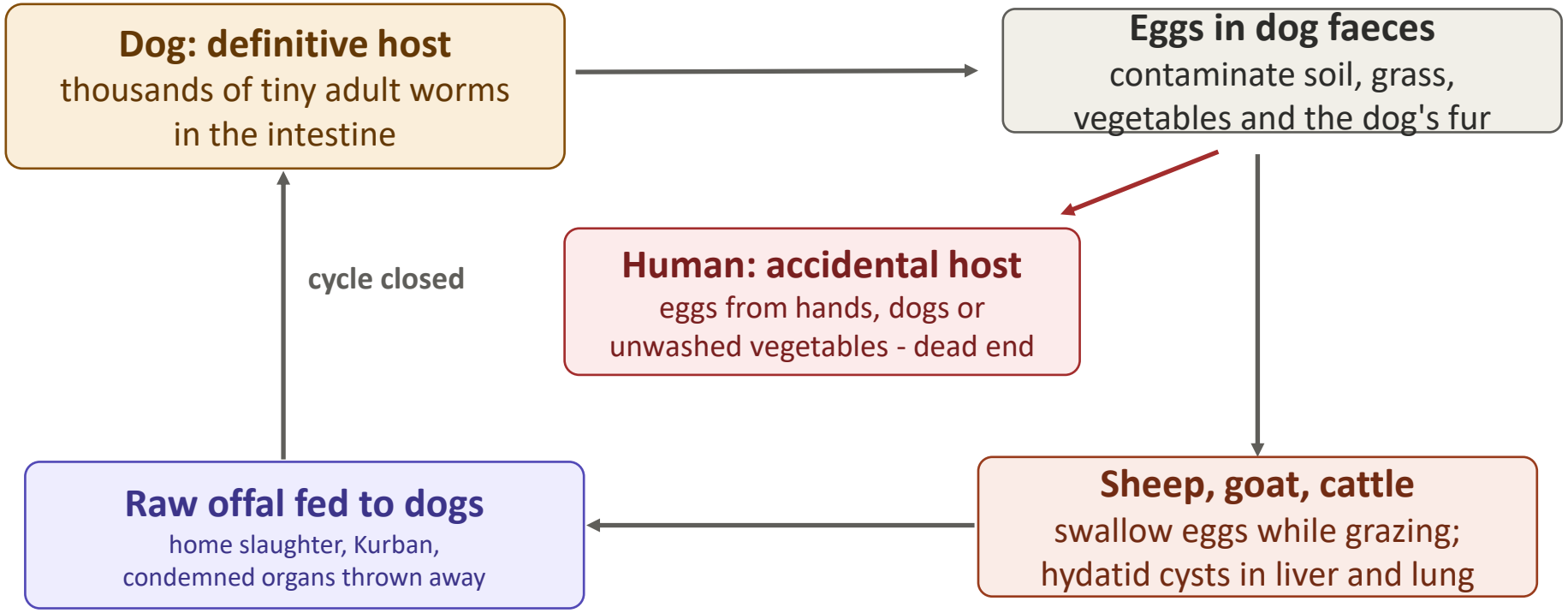
Echinococcus spp.

- This genus is endemic in Asia, the Middle East, Africa and the Mediterranean countries, including Türkiye.
- Its two most important members are:
  - *Echinococcus granulosus*, which causes cystic echinococcosis (hydatid disease), and
  - *Echinococcus multilocularis*, which causes alveolar echinococcosis.
- *E. multilocularis* is less common, but alveolar echinococcosis grows like a tumour and has a much higher fatality rate.
- The definitive hosts of both parasites are carnivores such as dogs, foxes and wolves, which harbour the adult worm.
- Sheep, goats, cattle, pigs and horses (or rodents for *E. multilocularis*) are intermediate hosts. Humans become accidental intermediate hosts by swallowing eggs with contaminated food or water or from the hands after contact with dogs.

Echinococcus granulosus

- One of the smallest tapeworms (3–6 mm), it nevertheless causes serious infections in humans. Cystic echinococcosis is one of the most important zoonoses in Türkiye.
- The adult worms live in the intestine of carnivores, and their eggs are shed in the faeces.
- In humans, the larvae hatched from swallowed eggs reach organs such as the liver, lungs, kidneys and spleen, where they form fluid-filled hydatid cysts; the disease is called hydatidosis.
- The cysts range in size from a pinhead to a goose egg or larger and grow slowly over years.
- Large cysts in the lungs or liver compress the organ; rupture can cause severe coughing, anaphylactic shock and the spread of new cysts.
- The most effective control measures are to prevent dogs from eating infected offal at slaughterhouses and on farms, and to deworm dogs regularly with praziquantel; a vaccine for sheep (EG95) is also available.
- It is also important to inform slaughterhouse workers and the public about the disease.

Echinococcus: Humans as Accidental Hosts



Breaking the cycle

never feed raw offal to dogs; destroy condemned organs at the slaughterhouse
deworm dogs regularly with praziquantel; control stray dog populations
vaccinate sheep (EG95 vaccine) where available
wash hands after contact with dogs and wash vegetables thoroughly

Nematodes (Roundworms)

- This group contains important foodborne parasites such as *Trichinella*, *Ascaris* and *Anisakis*.
- Some nematodes are transmitted by the faecal–oral route without intermediate hosts, while others, such as *Trichinella*, occur as encysted larvae in meat or fish and settle in the muscles of the people who eat them.

***Trichinella* spp.**

- This genus occurs in almost all carnivores and omnivores. It includes *Trichinella spiralis*, *T. nativa*, *T. britovi*, *T. pseudospiralis*, *T. nelsoni*, *T. murrelli* and *T. papuae*; *T. spiralis* is the most important for humans.
- Eating raw or undercooked pork, wild boar or horse meat causes trichinellosis, one of the oldest known parasitic zoonoses.
- The whole life cycle takes place within one host. In pigs the larvae settle mainly in the diaphragm and tongue muscles and reach the skeletal muscles through the blood and lymph.

Trichinella spp.

- The course and symptoms of trichinellosis depend on the number of larvae eaten and where they settle. Symptoms usually appear 1–4 weeks after infection.
- The main symptoms are muscle pain, fever, swelling around the eyes, difficulty in chewing and swallowing, and conjunctivitis. Deaths are rare but occur in heavy infections, from myocarditis or encephalitis.
- Thorough cooking (core temperature at least 71 °C) destroys the larvae. Freezing at −15 °C for 20 days (pieces up to 15 cm thick) is effective for pork, but not for wild game, whose *T. nativa* larvae are freeze-resistant. Low-dose irradiation is also effective.
- In the EU every pig carcass from non-controlled holdings, and every wild boar and horse carcass, must be tested for *Trichinella* (Regulation (EU) 2015/1375).
- Pigs should be raised in controlled housing; rodent control, the use of safe feed and preventing illegal slaughter are the key measures on the farm.

Ascaris spp.

- The most important species, *Ascaris lumbricoides*, infects about 800 million people worldwide.
- Humans are its only natural host. Heavy infections cause malnutrition, growth retardation and intestinal obstruction in children, while most adults carry the worms without symptoms.
- Infection results from swallowing eggs with contaminated water, with vegetables and fruit irrigated or washed with such water, or with food prepared by infected people with poor hygiene.
- The swallowed eggs hatch in the intestine; the larvae migrate through the liver and lungs and return to the intestine to mature.
- Adult worms can live in the intestine for 1–2 years.
- Food handlers must observe hand hygiene, vegetables and fruit must be washed with clean water, and foods should be adequately heat-treated.

Anisakis spp.

- Human infection with this nematode of the family Anisakidae, anisakiasis, was first described in the Netherlands in the 1960s after the consumption of lightly salted herring (“herring worm disease”).
- *Anisakis simplex* is the most important species. It is common in Japan and other countries where raw, marinated or lightly smoked fish is eaten (sushi, sashimi, ceviche).
- Marine fish and squid are the vehicles of infection.
- Humans are only accidental hosts,
- and the larvae cannot complete their development in the human body; the definitive hosts are dolphins, whales and seals.
- Infected people develop acute stomach pain and vomiting when the larvae penetrate the gastric wall. *Anisakis* proteins also cause allergic reactions, even after the larvae have been killed by cooking. In the EU, fishery products to be eaten raw must be frozen at −20 °C for 24 h or −35 °C for 15 h.

Killing Parasites in Meat and Fish

Parasite	Typical food	Cooking (core)	Freezing
Taenia spp.	beef, pork	≥ 60 °C	−10 °C for 10 days
Trichinella spiralis	pork, wild boar, horse	≥ 71 °C	−15 °C for 20 days †
Toxoplasma gondii	lamb, pork, raw-meat dishes	≥ 67 °C	−12 °C for 3 days
Anisakis simplex	marine fish, squid	≥ 60 °C for 1 min	−20 °C 24 h or −35 °C 15 h
Dibothriocephalus latus	freshwater fish	≥ 60 °C	−20 °C for 24 h
Sarcocystis spp.	beef, pork	thorough cooking	effective freezing

Not reliable for killing parasites
cold smoking, light salting, marinating in lemon or vinegar, drying,
and microwave heating (uneven temperature)

† pieces up to 15 cm thick; not effective for the freeze-resistant T. nativa of wild game

Trematodes (Flukes)

- Trematodes are an important group of parasites that threaten health worldwide.
- The most common foodborne trematode is:
  - *Fasciola hepatica* (liver fluke): the first trematode whose life cycle was fully elucidated. Described as early as the 14th century, it harms human health and causes economic losses in sheep and cattle.
  - *F. hepatica* (family Fasciolidae) causes fascioliasis, a disease of the liver and bile ducts in humans.

Trematodes (Flukes)

- The parasite is common where water hygiene is poor. Eggs are shed in the droppings of infected sheep and cattle, develop in freshwater snails, and the larvae encyst (metacercariae) on aquatic plants.
- Fascioliasis has an acute and a chronic phase.
  - Humans are infected by eating watercress or other aquatic plants carrying metacercariae. The acute phase begins with liver pain 1–3 months later, followed by liver enlargement, fever, fatigue, urticaria, respiratory disorders, loss of appetite and weight loss.
  - The chronic (obstructive) phase may develop months or years later: the adult flukes settle in the bile ducts, causing epithelial hyperplasia, cholangitis, cholecystitis and obstruction of the bile ducts.
- Control depends on clean drinking and irrigation water and on not eating raw watercress from contaminated areas. Triclabendazole is the drug of choice; praziquantel is not effective against *Fasciola*.

Protozoa

- Protozoan parasites generally cause mild to moderate diarrhoea in humans,
- but they can be life-threatening for malnourished children, the elderly and immunocompromised people.
- Some infections are asymptomatic. Protozoa can live and multiply in several animal species, but they cannot multiply in food or in the environment.
- The most common foodborne protozoa are:

Giardia duodenalis

- A flagellated protozoan that multiplies asexually; it is also known as *G. lamblia* or *G. intestinalis*. It causes both outbreaks and sporadic cases.

Protozoa - *Giardia duodenalis*

- Giardiasis is transmitted by contaminated water and food, by the faecal–oral route and by direct person-to-person contact.
- Cysts reach vegetables and fruit from contaminated water and are also transmitted through food prepared by infected people.
- The infective dose is very low (about 10 cysts).
- Infected people suffer foul-smelling, fatty, mucous diarrhoea, malabsorption with rapid weight loss, abdominal cramps and nausea; without treatment this can last for months.
- Giardiasis is diagnosed by examining the stools of patients (microscopy, antigen tests or PCR).
- Patients shed very large numbers of cysts (up to about 10^7 per gram of stool).
- The cysts are relatively resistant to chlorine, so filtration, UV irradiation and ozonation are important in water treatment; cooking food thoroughly destroys them.

Protozoa - *Cryptosporidium* spp.

- Cryptosporidiosis has become recognised as one of the main causes of waterborne and foodborne diarrhoea.
- Water, raw vegetables, unpasteurised milk and apple juice, and contact with calves are important sources of infection.
- The two species that cause most human disease are *Cryptosporidium hominis* and *C. parvum*.
- Transmission is by the faecal–oral route.
- Food handled by infected people and contaminated water play an important role; the oocysts are very resistant to chlorine, and the 1993 Milwaukee outbreak from drinking water affected about 400 000 people.
- Flies, cockroaches and similar insects can also carry oocysts from faeces to food.
- After ingestion, the oocysts of this obligate intracellular coccidian release sporozoites in the small intestine, which invade the epithelial cells.
- The incubation period is 2–10 days (usually about 7 days).
    - Watery diarrhoea, abdominal pain, nausea, vomiting and fever are the common symptoms; in immunocompromised patients the diarrhoea can become chronic and life-threatening.
- Hygiene of food and water is essential. The oocysts are killed by heating (72 °C for 1 min), by UV irradiation and by ozonation, but not by normal chlorination.

Protozoa - *Cyclospora cayetanensis*

- *Cyclospora* is a coccidian protozoan of the family Eimeriidae.
- *Cyclospora cayetanensis* is the only species known to cause foodborne disease in humans.
- Infection is endemic in developing countries with poor water and sanitation. It is transmitted by the faecal–oral route, mainly through fresh produce (raspberries, basil, lettuce, snow peas) irrigated or sprayed with contaminated water.
- Humans are the only known host of *C. cayetanensis*.
- The oocysts are not infective when shed; they must sporulate for 1–2 weeks in the environment, so direct person-to-person transmission does not occur. After ingestion they infect the epithelium of the small intestine.
- Diagnosis is by microscopy (the oocysts autofluoresce under UV light) and increasingly by molecular methods such as PCR.
- Trimethoprim–sulfamethoxazole is the treatment of choice.

Protozoa - *Toxoplasma gondii*

- ***T. gondii*, the only species of its genus, causes one of the most common parasitic infections of humans and other warm-blooded animals; about one third of the world's population is infected.**
  - Cats are the definitive hosts: only they shed oocysts, the environmentally resistant form of the parasite.
  - Humans are infected by eating tissue cysts (bradyzoites) in raw or undercooked meat, by swallowing oocysts with contaminated food, water or soil, and transplacentally (from mother to fetus).
  - Oocysts in soil can also be carried to food and feed by flies, cockroaches, dung beetles and earthworms.
- Several factors contribute to foodborne toxoplasmosis:
  - raw or undercooked meat and meat products (for example home-made çiğ köfte prepared with raw meat), unwashed raw vegetables, meals eaten away from home, poor hygiene of kitchen tools and equipment, and poor hand hygiene.
- Infection is usually asymptomatic, but it can have devastating consequences for the fetus when a woman is infected for the first time during pregnancy, and for immunocompromised people.
- Cooking, freezing and gamma irradiation kill the tissue cysts: heating to 61 °C for at least 3.6 minutes (a core temperature of 67 °C in practice) or freezing at −12 °C for several days inactivates them. Pyrimethamine combined with sulfadiazine and folinic acid is the usual treatment; spiramycin is used in pregnancy.

Protozoa Against Water Treatment

	Chlorination	Filtration (≤ 1 µm)	UV irradiation	Boiling
Bacteria e.g. *E. coli*	effective	partial	effective	effective
Viruses e.g. norovirus	effective	not effective	partial	effective
***Giardia* cysts** 8 - 12 µm	partial	effective	effective	effective
***Cryptosporidium* oocysts** 4 - 6 µm	not effective	effective	effective	effective
***Cyclospora* oocysts** 8 - 10 µm	not effective	effective	limited data	effective

Why it matters

The 1993 Milwaukee outbreak: *Cryptosporidium* passed a treatment plant that met the chlorine standards and made about 400 000 people ill. Washing berries or herbs in chlorinated water does not remove *Cyclospora* - prevention must happen at the farm.

Protozoa - *Sarcocystis* spp.

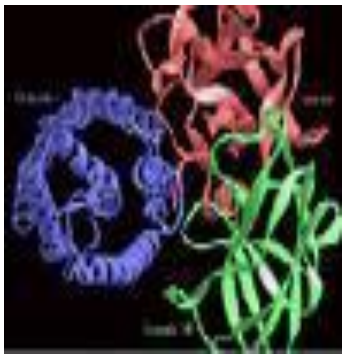
- *Sarcocystis* species are coccidian protozoa that need two different hosts to complete their life cycle.
- Sexual reproduction takes place in the intestine of the definitive hosts (humans, cats, dogs), and asexual cysts (sarcocysts) form in the muscles of the intermediate hosts (cattle, sheep, pigs).
- Of the more than 200 known species, two use humans as definitive hosts and cause intestinal sarcocystosis: *Sarcocystis hominis* (from beef) and *S. suihominis* (from pork).
- After raw meat containing sarcocysts is eaten, the released organisms penetrate the lamina propria of the small intestine, where sexual reproduction takes place.
- With *S. hominis* the incubation period is 3–6 hours and the symptoms (nausea, diarrhoea) are mild; *S. suihominis* causes more severe symptoms.
- Sarcocysts are detected in the striated muscle of carcasses by microscopic examination; serological (ELISA) and DNA-based molecular methods are also used.
- Meat must be cooked thoroughly or frozen effectively to inactivate the parasite,
- and raw beef and pork should not be eaten.

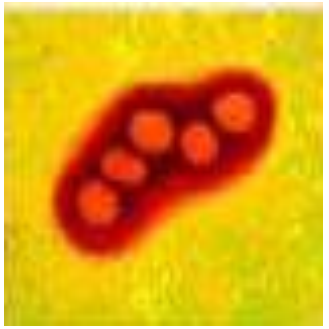
Food Toxins

- Foods can encounter factors that impair their safety at every stage of the chain, from farm to fork.

- What is a toxin?
- A toxin is a substance that damages biological systems at a certain dose and/or over a certain period when it is taken in by mouth, by inhalation or through the skin.







Foodborne toxins

Toxins	Sources
Fungal Toxins	
Aflatoxins	peanuts, grains
Ochratoxins	grains
Ergotamines	grains, grass seeds
Zearlenones	grains
Plant Toxins	
Pyrrolizidine alkaloids	herbal teas
Solanine	tomato family
Gossypol	cottonseed oil
Oxalates	spinach, beets, poke
Ricin	castor oil
Cyclopeptides	mushrooms
Hydrazines	mushrooms
Cyanotoxins	stone fruits
L-concavalin	alfalfa
Seafood Toxins	
Ciguatoxins	seafood
Tetrodotoxin	seafood
Scombrotoxin	seafood

Food Toxins

- Natural food toxins are chemical compounds that occur naturally in foods. They are:
  - plant toxins,
  - mushroom toxins,
  - toxins of animal origin.

Plant toxins

Plant toxins include:

- cyanogenic glycosides (bitter almonds, apricot kernels, cassava),
- phytohaemagglutinins or lectins (raw kidney beans),
- protease inhibitors,
- lathyrogens,
- favism-inducing compounds (vicine and convicine in broad beans),
- goitrogens,
- glycyrrhizin (liquorice),
- saponins,
- solanine (green potatoes),
- gossypol (cottonseed),
- myristicin (nutmeg),
- biogenic amines,
- caffeine and theophylline,
- erucic acid,
- nitrate,
- safrole and its derivatives,
- carotatoxin,
- pyrrolizidine alkaloids,
- metal-binding compounds (oxalate, phytate),
- antivitamin factors.

Mushroom toxins

1. Protoplasmic poisons
2. Neurotoxins
3. Gastrointestinal irritants
4. Disulfiram-like toxins
5. Mixed poisonings

Toxins of Animal Origin

- Saxitoxin (paralytic shellfish poisoning)
- Tetrodotoxin (pufferfish)
- Scombrotoxin (histamine fish poisoning)
- Grayanotoxins in toxic honey (“mad honey”)
- Avidin (raw egg white)
- Biogenic amines

Mad Honey from the Black Sea Region

Rhododendron
R. ponticum and *R. luteum* in the Black Sea mountains

→

Nectar with grayanotoxins
collected by bees in spring

→

"Deli bal"
bitter, sold as a folk remedy or aphrodisiac

→

30 min - 3 h later
dizziness, sweating, nausea, slow pulse, low blood pressure

How the toxin acts
grayanotoxins keep sodium channels open in nerve and heart cells - strong vagal stimulation, bradycardia, AV block, fainting

Outcome
treated with atropine and fluids;
most patients recover within 24 h;
deaths are rare

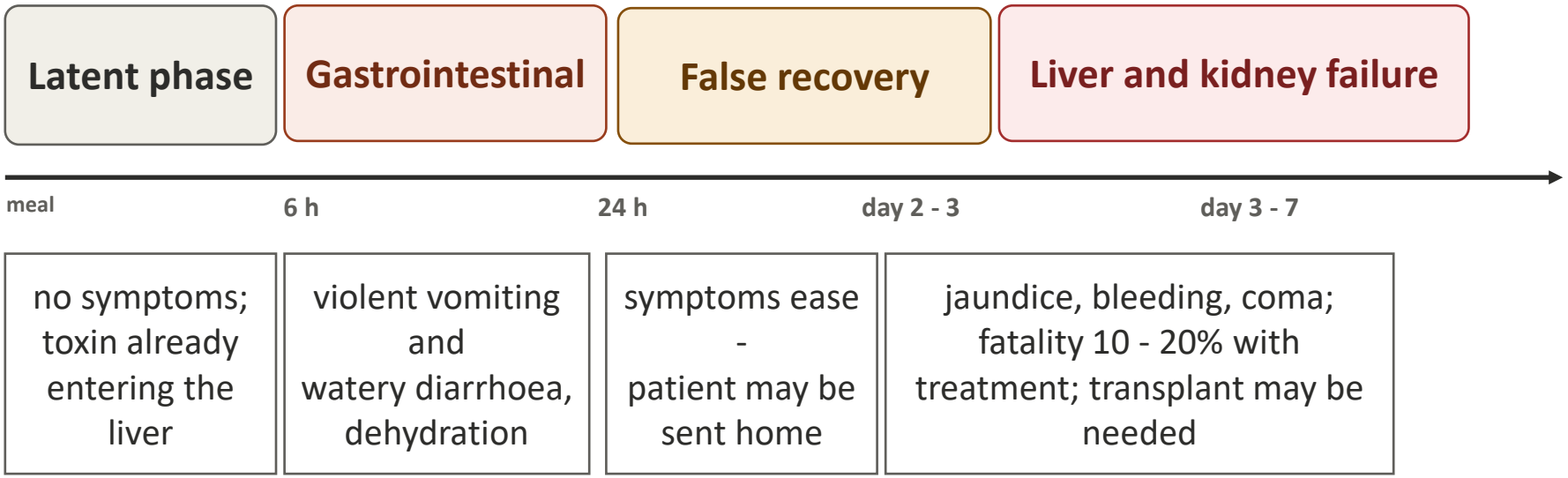
Food safety lessons
the dose matters: poisoning usually follows eating more than a spoonful
toxin content varies with region, season and harvest - no safe amount can be promised
the toxin is not destroyed by heating or storage
cases are reported in Türkiye every year and in travellers who bring the honey home

Mushroom Poisoning

a) Amatoxins and phallotoxins

- are responsible for most deaths from mushroom poisoning;
- they are produced by *Amanita phalloides* (death cap), *A. virosa*, *A. verna* and *A. bisporigera*.
- *A. phalloides* alone causes about 90–95% of fatal mushroom poisonings worldwide.
- The lethal dose of amatoxins is about 0.1 mg per kg body weight - a single mushroom cap can kill an adult. Amatoxins are not destroyed by cooking or drying.
- The poisoning is characterised by:
  - a long symptom-free period (6–24 hours, usually 8–12 hours);
  - then abdominal pain, vomiting, profuse watery diarrhoea, thirst and reduced urine output;
  - weakness, prostration and pain; an apparent improvement on day 2–3 is followed by
  - acute liver and kidney failure after 3–7 days; with modern treatment the fatality rate is about 10–20%, higher without treatment;
  - survivors may have irreversible liver and kidney damage and may need a liver transplant.

Death Cap Poisoning: The Deceptive Delay



Warning signs

symptoms that begin more than 6 hours after a meal of wild mushrooms suggest amatoxin poisoning; cooking, drying and freezing do not destroy amatoxins

What saves lives

early hospital admission, activated charcoal, fluids, silibinin to block uptake by the liver, liver transplantation if needed; never eat wild mushrooms unless expertly identified

Mushroom Poisoning

b) Ibotenic acid and muscimol poisoning

- Fly agaric (*Amanita muscaria*) and panther cap (*A. pantherina*) contain ibotenic acid and muscimol.
- They grow under pine and birch trees.
- A few grams of mushroom cause symptoms within 0.5–2 hours.
- Symptoms: dizziness, confusion, visual distortions, hallucinations, hyperactivity, excitability and delirium, sometimes with sweating, salivation and vomiting.
- The symptoms usually subside within about 10–24 hours.
- Deaths are rare in adults,
    - but children who eat large amounts may develop convulsions, coma and, rarely, die.

Microbial Toxins

- **Mycotoxins**
  - aflatoxins,
  - ochratoxins,
  - patulin,
  - trichothecenes,
  - fumonisins.

Mycotoxins

- Mycotoxins, produced by some moulds during their metabolism, are the most harmful natural food toxins.
- Moulds grow on crops in the field and during storage. Some, but not all, produce toxic substances that cause disease when eaten by humans or animals; these are called mycotoxins.
- Mould growth in foods is difficult to prevent entirely, but it can be reduced by good agricultural practice, rapid drying and hygienic processing and storage.
- Toxigenic moulds are a particular problem in developing countries without controlled storage, and in warm, humid tropical regions.
- Mycotoxins differ widely in their toxicity and in their effects on human health.
- The effect depends on the type and amount of toxin consumed. Most mycotoxins are produced by *Aspergillus*, *Penicillium* and *Fusarium* species. Not every strain of these moulds produces toxin, and one mould may produce several toxins, which makes generalisations difficult.

Aflatoxins

- Aflatoxins are produced mainly by *Aspergillus flavus* and *A. parasiticus*.
- They are difuranocoumarin derivatives. About 20 related compounds are known; the most important are B_1, B_2, G_1, G_2, M_1 and M_2, of which B_1 is the most toxic. They are sensitive to light.
  - They are formed mainly when food and feed are stored at unsuitable moisture and temperature. They are not destroyed at cooking temperatures and decompose only at about 240–300 °C.
- In 1960 the death of 100 000 turkeys in England ("Turkey X disease") was traced to a toxic substance produced by *A. flavus* in peanut meal; it was named aflatoxin.
- The main target organ is the liver. Aflatoxins cause acute liver damage (aflatoxicosis) and are also carcinogenic: aflatoxin B_1 is classified by IARC in Group 1 (carcinogenic to humans).
- Aflatoxins are found in mouldy plant foods (nuts, maize, dried figs, spices) and, as aflatoxin M_1, in the milk of animals given mouldy feed; residues can also occur in liver, kidney and eggs.

Ochratoxins

- Ochratoxins are mycotoxins found in mouldy cereals such as barley, wheat and maize.
- Mouldy barley fed to pigs has caused significant animal losses (porcine nephropathy) in Denmark and elsewhere. The toxin is produced by *Aspergillus ochraceus*, *A. carbonarius* (in grapes) and *Penicillium verrucosum* (in cereals in cool climates); three forms, A, B and C, are known.
- Ochratoxin A (OTA) is the most toxic.
- OTA forms when these moulds grow on cereals, coffee beans, cocoa beans, dried vine fruit, wine, spices and pulses. It damages the kidney, and it has been linked to kidney disease in humans (Balkan endemic nephropathy).
- The most effective ways to prevent mycotoxins in cereals are:
  - harvesting the grain when fully ripe, and
  - drying it rapidly to below about 14% moisture. When the humidity of the store rises, moulds multiply and produce mycotoxins.
  - Like peanuts, cereals must be stored dry and protected from mould.

Patulin

- Patulin is a mycotoxin produced by some *Penicillium*, *Aspergillus* and *Byssochlamys* species.
- It occurs mainly in apple juice made from mouldy apples (*Penicillium expansum*), and also in other fruit juices and mouldy bread.
- Patulin was first studied as an antibiotic. It is toxic to the gastrointestinal tract (oedema, haemorrhage, nausea, vomiting) and genotoxic in animal studies, but IARC does not classify it as carcinogenic to humans (Group 3).
- SO_2 and ascorbic acid break patulin down, and alcoholic fermentation destroys it. It is stable in acidic conditions (up to pH 6) and survives pasteurisation, so removing rotten fruit before pressing is the key control. The EU limit for fruit juices is 50 µg/kg.