

Digestion, Nutrients and Metabolism — an explanatory deep-dive

Purpose. Where the previous deep-dives (0090-B2 biochemistry/medicine, 0090-B3 ecology) *argued*, this one *explains*. It describes step by step how the human body digests and uses food, what each nutrient is for, where bioavailability decides the outcome, and what happens clinically when something is missing. It closes with a short comparative-zoology appendix: why the cat *must* eat meat and the dog need not, how the ruminant turns grass into food — and what other digestive phenomena exist in the animal kingdom. This is not mere context: it sharpens the bundle's core thesis that humans are omnivores with a choice — unlike an obligate carnivore.

Part A — Human digestion, station by station

Digestion is the mechanical and chemical breakdown of food into absorbable building blocks, running like a conveyor belt along the roughly eight-to-nine-metre gastrointestinal tract.

A.1 Mouth. Digestion begins before swallowing. Teeth break food up mechanically (increasing surface area); saliva moistens and contains **α -amylase (ptyalin)**, which already splits starch into shorter chains — which is why long-chewed bread tastes sweet. Saliva also contains lysozyme (antibacterial) and traces of lipase. Human salivary amylase is genetically amplified (high AMY1 copy number) — an evolutionary hint at the central role of starch (cf. Layer 4 / Hardy hypothesis).

A.2 Oesophagus and stomach. The bolus is moved to the stomach by peristaltic waves. There, **hydrochloric acid (HCl)** creates a pH of ~ 1.5 –3: it denatures proteins (unfolds them), activates **pepsinogen to pepsin** (splits proteins into peptides) and kills most microorganisms. The parietal cells also produce **intrinsic factor** — a protein essential for the later absorption of vitamin B12 (see C.1). The stomach is primarily an acid/pre-digestion and storage organ; little absorption happens here (exceptions: alcohol, some drugs).

A.3 Small intestine — the actual absorption organ. In the duodenum three secretions meet:

- **Bile** (from the liver, stored in the gallbladder): emulsifies fats into tiny droplets (micelles) so lipases can act — like detergent making fat water-soluble.
- **Pancreatic juice:** contains **lipase** (fat), **amylase** (starch), **proteases** (trypsin, chymotrypsin: proteins $\rightarrow$ amino acids) and bicarbonate, which neutralises stomach acid.
- **Brush-border enzymes:** disaccharidases such as **lactase** (milk sugar $\rightarrow$ glucose+galactose), maltase, sucrase; peptidases.

Absorption occurs across the vast surface of the **villi and microvilli** (together $\sim 30\text{ m}^2$ — a tennis court folded into the belly). In the **jejunum**, sugars and amino acids enter the blood; in the **ileum**, bile acids are reabsorbed and — crucially — the **intrinsic-factor-B12 complex** binds to specific receptors.

A.4 Large intestine and microbiome. What remains undigested (mainly fibre) reaches the colon. Two things happen: water and electrolyte recovery (stool thickening) and **bacterial fermentation** by the microbiome ($\sim 10^{13-10^{14}}$ bacteria). It ferments fibre into **short-chain fatty acids (SCFAs: butyrate, propionate, acetate)** — butyrate is the main fuel of the colonic mucosa, anti-inflammatory and protective against colon cancer. Vitamin K2 and some B vitamins are also produced here bacterially. A low-fibre, meat-heavy diet shifts the microbiome (fewer SCFA producers, more TMA producers — cf. 0090-B2 §1.1).

Part B — Macronutrients: digestion and metabolism

B.1 Carbohydrates. Starch and sugar are broken down to **glucose**, taken into the blood and ushered into cells by insulin (energy, glycogen stores, possibly fat synthesis). The *form* is decisive: whole grains, legumes and vegetables deliver glucose slowly (low glycaemic index) plus fibre; isolated sugar and white flour deliver it as a spike. **Fibre** is indigestible carbohydrate (cellulose, β -glucan, resistant starch, pectin): not a “nutrient” in the narrow sense, but it regulates blood sugar, satiety, cholesterol (binding bile acids) and feeds the microbiome. Animal products contain *no* fibre — an often-overlooked qualitative difference.

B.2 Proteins and amino acids. Proteins are broken into amino acids and reassembled into the body’s own proteins. Nine amino acids are **essential** (must come from food): histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine. *Protein quality* measures how well a food supplies these (metrics: PDCAAS, the newer DIAAS). Animal protein is usually “complete”; individual plant proteins have limiting amino acids (grains: low lysine; legumes: low methionine) — but **combined over the day** (grain + legume) a complete profile results; soy and quinoa are complete on their own. The old “combine in every meal” rule is outdated; the body has an amino-acid pool. Clinically relevant: **leucine** triggers muscle protein synthesis (mTOR) — slightly lower from plants, compensable via quantity (cf. 0090-B2 §5.6).

B.3 Fats. Triglycerides are split by lipase into fatty acids and glycerol, absorbed in micelles, packed in the gut cells into **chylomicrons** and carried into the blood via the lymph. Fatty acids differ decisively:

- **Saturated FAs** (mainly animal, coconut): raise LDL cholesterol (causally atherogenic, cf. 0090-B2 §3).
- **Monounsaturated FAs** (olive oil, nuts, avocado): favourable/neutral.
- **Polyunsaturated FAs:** the **essential** omega-6 (linoleic acid) and omega-3 (α -linolenic acid, ALA) must be ingested. EPA and DHA are formed from ALA — but inefficiently (cf. 0090-B2 §5.3); algal DHA solves this directly.
- **Cholesterol** is not a dietary poison but a building block (cell membranes, hormones, bile acids); the body synthesises it. Dietary cholesterol affects blood LDL individually; the stronger lever is saturated fat.

Part C — Micronutrients: what for, and where bioavailability decides

C.1 Vitamin B12 (cobalamin) — the critical special case. B12 is indispensable for blood formation and nerve function (myelin sheaths). Its absorption route is complex: released from food in the stomach, bound to **intrinsic factor**, taken up receptor-mediated in the **ileum**. B12 is synthesised exclusively by **microorganisms** — plants do not reliably contain it. Animals get it via their microbiome or feed supplementation; humans via animal products *or supplement*. **Clinically:** deficiency causes megaloblastic anaemia and — more insidiously — irreversible neuropathies. Vegans must supplement; this is not a weakness of the diet but a trivial condition (cf. 0090-B2 §5.2). Many elderly and metformin/acid-blocker patients are also affected (malabsorption).

C.2 Iron — the two forms and their regulation. **Heme iron** (animal) is absorbed relatively unregulated; **non-heme iron** (plant) is subject to the body’s control via the hormone **hepcidin**: when stores are full, absorption is throttled. This is protection against iron overload — the downside of heme iron (oxidative stress, colon-cancer pathway, cf. 0090-B2 §1.4). Plant iron absorption is strongly boosted by **vitamin C** and inhibited by phytates/tannins/calcium; soaking, sprouting and fermenting break down phytates. Well-planned plant diets carry no more anaemia.

C.3 Other minerals. **Zinc** (immune system, enzymes): slightly less available from plants (phytates), covered via whole grains/legumes/nuts. **Calcium** (bone, muscle, nerve): from fortified

drinks, tofu, leafy greens, sesame — not dairy-dependent. **Iodine** (thyroid): critical for *everyone*, hence salt iodisation; seaweed a plant source but tricky to dose. **Selenium** (antioxidant, thyroid): soil-dependent, Brazil nuts very dense. **Magnesium, potassium** (abundant in plants), **sodium** (more an excess problem).

C.4 Fat-soluble vitamins. **Vitamin A:** animal as preformed retinol, plant as the provitamin **beta-carotene** (conversion individually variable) — caution: the liver accumulates retinol to toxicity (polar-bear-liver hypervitaminosis, cf. Layer 3). **Vitamin D:** sunlight-dependent, a supplement topic for *all* diets at northern latitudes (D3 from lichen is vegan). **Vitamin E** (antioxidant, plant oils/nuts). **Vitamin K1** (leafy greens, clotting) and **K2** (fermented foods + endogenous conversion, bone/vessels).

C.5 Water-soluble vitamins. B-complex (energy metabolism): mostly well covered from plants (exception B12). **Folate** (B9, cell division, pregnancy): green vegetables, legumes. **Vitamin C** (collagen, antioxidant, iron enhancer): fruit, vegetables.

C.6 “Conditionally essential” substances. **Choline** (cell membranes, acetylcholine): eggs are rich, but legumes, cruciferous vegetables and supplements cover it. **Creatine** (muscle/brain energy buffer) and **carnosine**: endogenously synthesisable, lower on a plant diet — supplementation in vegans an active, non-alarming field. **Taurine**: not essential for *humans* (self-synthesis) — but essential for the *cat* (see appendix). This difference is the key to understanding “obligate carnivore”.

Part D — Microbiome, fibre, gut health

The gut microbiome is its own metabolic organ. Fibre-rich, plant-forward food promotes SCFA producers (butyrate → mucosal health, anti-inflammation, colon-cancer protection). Meat/fat-heavy, low-fibre food promotes proteolytic and TMA-forming bacteria plus secondary bile acids (potentially pro-carcinogenic). Microbiome diversity correlates with the plant diversity of the diet. This links B.1 (fibre), A.4 (colon) and the biochemical pathways from 0090-B2.

Part E — Human medicine: deficiency syndromes and digestion-related diseases

E.1 Deficiency syndromes. B12 → megaloblastic anaemia, neuropathy, dementia-like pictures. Iron → microcytic anaemia, fatigue, performance decline. Vitamin D → rickets (child), osteomalacia (adult). Iodine → goitre, hypothyroidism, in pregnancy fetal developmental harm. Folate → neural tube defects. Vitamin A → night blindness. Vitamin C → scurvy. These syndromes are possible *regardless* of diet pattern; planning, not the label, is decisive.

E.2 Digestion-related pathologies. **Lactose intolerance:** the physiological normal state of most of humanity (lactase activity falls after weaning; lactase persistence ~35%, cf. Layer 6) — not a disease but the biological default. **Celiac disease:** autoimmune reaction to gluten. **Irritable bowel (IBS), diverticulosis** (associated with fibre deficiency), **inflammatory bowel disease.** **Colorectal cancer:** co-influenced via heme/NOC (red/processed meat, IARC Group 1/2A, cf. 0090-B2 §2) and fibre deficiency. **Gout:** purine metabolism (uric acid) — relevant with high meat/offal intake.

E.3 Metabolic endpoints (cross-reference): atherosclerosis (LDL, causal), type-2 diabetes (heme iron, adiposity mediation), several cancers (IGF-1/mTOR, Neu5Gc) — fully in 0090-B2.

Part F (closing chapter) — Comparative digestion in the animal kingdom

A small but illuminating topic: how do *other* animals digest — and what does that say about humans? Digestive anatomy reveals the evolutionary food niche. This is exactly where it is decided whether an animal *needs* meat or merely *can* eat it.

F.1 The obligate cat. The domestic cat is an **obligate carnivore**: it *must* eat animal products because its metabolism cannot make several substances itself. It needs dietary **taurine** (or it develops heart-muscle failure and blindness/retinal degeneration), **preformed vitamin A** (cannot convert beta-carotene to retinol), **arachidonic acid** (cannot synthesise it) and has an obligate need for **arginine**. Its gut is short, its amylase activity low — it is built for a meat-rich, low-carbohydrate diet. A vegan cat without precise supplementation will fall ill. **This is the real meaning of “it needs meat” — and it applies to the cat, not to humans.**

F.2 The flexible dog. The dog descends from the wolf but became a **facultative omnivore** during domestication. Axelsson et al. 2013 (*Nature* 495:360–364, doi:10.1038/nature11837) showed: in the wolf-to-dog transition, three consecutive steps of the starch-digestion pathway were genetically strengthened — including an about **fivefold increase in AMY2B copy number** (pancreatic amylase). Dogs digest starch markedly better than wolves; this parallels the human AMY1 expansion (Layer 4) and is a fine example of diet-driven evolution. The dog *can* live mixed — the cat cannot.

F.3 The human in between. This is exactly the point for the whole work: humans are anatomically and genetically **omnivores with a plant bias** (long gut, AMY1 expansion, self-synthesis of taurine/vitamin A, B12 the only obligate animal/supplement exception). Humans are *not* obligate carnivores like the cat. From this follows not “meat is forbidden” but: humans have — unlike the cat — the biological *freedom of choice* on which the bundle’s ethical and ecological argument can rest in the first place.

F.4 The ruminants — turning grass into food. Cattle, sheep, goat, deer have a **four-part stomach: rumen, reticulum, omasum and abomasum**. Trillions of microorganisms in the rumen ferment **cellulose** (indigestible to mammals themselves) into short-chain fatty acids — the ruminant’s energy source. The animals regurgitate the digesta and chew it again (“**chewing the cud**”, rumination). By-products: **methane** (formed by archaea, climate-relevant, cf. 0090-B3 §1.4) and **microbial protein**, which the animal digests later. The rumen microbes also synthesise **B12** (if cobalt is in the feed) — which is why ruminant meat is B12-rich. Ecological punchline: ruminants can use marginal grassland (subsistence caveat) but are land-inefficient as a mass model.

F.5 Hindgut fermenters. Horse, donkey, rabbit, elephant ferment plant fibre not in a forestomach but in the **caecum/colon**. This is less efficient than the rumen (the microbes sit *behind* the main absorption site) but allows continuous intake of large amounts — the horse eats almost without pause.

F.6 Caecotrophy — faeces as a second meal. Rabbits and many rodents produce two kinds of faeces: hard pellets and soft, nutrient-rich **caecotrophs**, which they eat again directly. This recovers B vitamins and microbial protein formed in the hindgut that would otherwise be lost — an elegant trick to offset the “wrong order” of hindgut fermentation. Related phenomenon: **coprophagy** in various species.

F.7 Non-ruminant foregut fermenters. Kangaroos, hippos and **leaf-eating monkeys (Colobinae)** also have fermentation chambers before the true stomach but do not chew the cud. The giant panda is a curious special case: it has the **digestive tract of a carnivore** (short, simple stomach) yet feeds almost entirely on bamboo — and must therefore eat enormous amounts because it breaks down cellulose poorly. Evolution is no perfect engineer.

F.8 Birds. Birds have no teeth; they use a **crop** (storage/softening) and a muscular **gizzard**, often with swallowed grit (gastroliths), for mechanical grinding. Seed-eaters, nectar-feeders (hum-

mingbird), raptors — each niche has its digestive solution.

F.9 What this teaches us. The range — from the obligately carnivorous cat through the flexible dog and the fibre-fermenting ruminant to the faeces-recycling rabbit — shows: “what an animal should eat” follows from its digestive physiology, not from ideology. For humans the physiological answer is: omnivore with a plant bias and genuine freedom of choice. It is precisely this freedom that is the biological precondition for the question “*should* humans eat industrial animal products?” to be meaningfully asked at all — it does not arise for the cat.

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