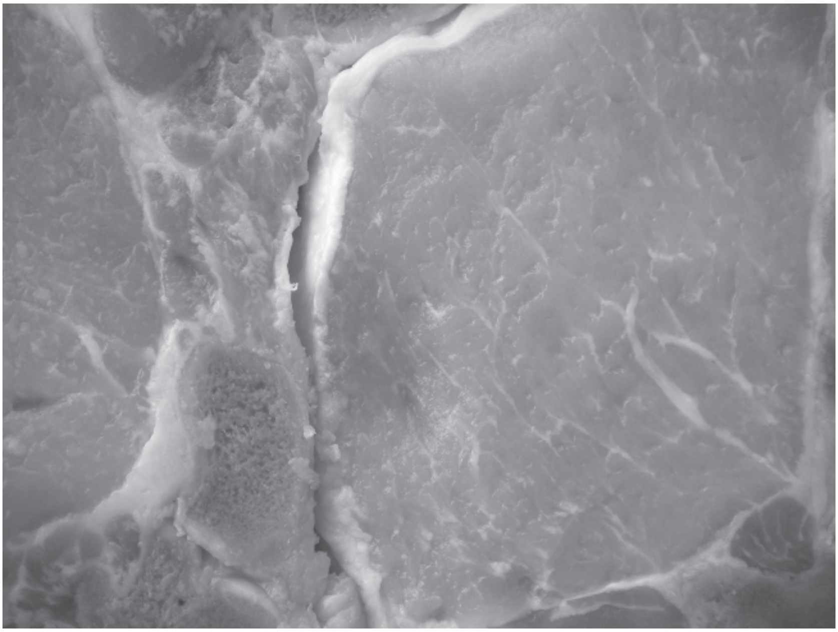
Should We Eat Meat?



Pork loin center chops. A close-up shows what most meat cuts are composed of: muscle fascicles, collagen sheaths, tendons, intra- and extramuscular fat, and bones. Photo by V. Smil.

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Meat in Nutrition

First things first: no energy conversion is more fundamental for the survival of our species than photosynthesis (primary productivity), the source – directly in raw or processed plants and indirectly in (usually cooked or processed) animal tissues – of all of our food. Eating (setting aside food smells, taste, visual appeal and all those cultural and historical connotations subsumed in the act of ingestion) can be defined in the most reductionist biophysical fashion as a process that supplies macronutrients (carbohydrates, proteins, lipids) and micronutrients (vitamins and minerals) that are required to sustain our metabolism needed for growth, maintenance and activity and hence to perpetuate life of this most advanced of all heterotrophic organisms that cannot (as all autotrophs can) synthesize their own complex nutrients from simple inorganic inputs. Foodstuffs could be then seen as nothing but more or less complex assemblages of nutrients, and meat stands out among them for many reasons.

A small definitional detour is called for first because, as is often the case when dealing with seemingly straightforward subjects, everyday usage of the word "meat" does not coincide with biophysical realities. Meat, from a *sensu stricto* structural and functional point of view, refers only to the muscular tissue of animals, and the narrowest traditional definition would limit it to skeletal muscles of wild and domesticated mammals. Horowitz (2006) documents how even during the 1950s many American housewives did not consider chicken to be a meat and how the chicken industry was encouraged to run advertising campaigns that would confer on poultry a full meat

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status. There are also some national rules that make explicit definition. According to the Food Standards Code of Australia and New Zealand, meat is "the whole or part of the carcass of any buffalo, camel, cattle, deer, goat, hare, pig, poultry, rabbit or sheep, slaughtered other than in a wild state," a definition that pointedly excludes all wild species, including kangaroos whose meat is now readily available in Australia (Williams 2007).

In contrast, a common, *sensu lato*, usage extends the noun's coverage not only to muscles of all mammals and birds (much like the understanding of our pre-industrial ancestors for whom meat was everything from squirrels to bison and from thrushes to herons) but also to muscles of amphibians and reptiles (frogs, snakes, turtles) and to all other tissues that are often integrally or proximally associated with meat, above all to embedded or surrounding fat, sometimes also to skin and to internal organs (organ meats, innards, offal – *abats* in French, *frattaglie* in Italian, *Innereien* in German), most of which are not hard-working muscles. But even this liberal definition still leaves out all seafood although few skeletal muscles are as powerful and as efficient as those propelling fast cruising bluefin tunas that can (unlike all other ectothermic fish) raise their temperature above that of the surrounding water (Block 1994).

Nor is there any clear, universal divide between "red" and "white" meat. The distinction obviously owes to the amount of myoglobin in muscles (just 0.05% in chicken, up to 2% in beef), but because all mammalian meats have higher concentrations than poultry or fish, the USDA puts all large livestock meat into the red category. In contrast, the Australian definition of red meat refers to beef, veal, lamb, mutton and goat meat, but it excludes pork as well as all game meats, including buffalo whose meat is largely indistinguishable from beef. And then there is a common culinary usage that draws the line by age: veal, lamb and piglets are white; beef, mutton and pork are red, but so are duck and goose; and (to bring yet another color into the mix) in France, all game meat is labeled *viandes noires*. But lack of strict logic is common in classifying foodstuffs: tomato is, of course, a fruit that is always classified as a vegetable, to say nothing about counting tomato paste on pizzas as a vegetable.

Meat Eating and Health: Benefits and Concerns

In this introductory chapter, I will deal first with the functional and structural properties and the basic composition of muscles and other animal tissues before I turn to specific surveys of meat as a source of energy that comes (given the virtual absence of carbohydrates in muscles) only from two macronutrients, lipids and high-quality proteins. Most societies could always secure abundant, or at least adequate, amounts of carbohydrates from plants, but lipids, and even more so high-quality proteins, were relatively scarce in all traditional agricultures, as well as in the early stages of post-1500 modernization. That is why the role of animal protein in early human growth deserves particular attention.

Eating relatively large amounts of meat must have a variety of health and longevity consequences, but, as with all long-term effects of specific components of human diet, it is not easy to tease them out in an unequivocal manner from often inadequate and sometimes questionable epidemiological evidence. There is no doubt about the benefits of high-quality protein for young children in general and for their growing brains in particular, and there is also a high degree of consensus regarding the undesirability of consuming large amounts of fatty meat (although even here there are some intriguing caveats). More recently, a consensus has been emerging about the undesirability of frequent consumption of processed meat products ranging from bacon to wieners.

In contrast, solid generalizations regarding the contribution made by low to moderate meat consumption to the prevalence of the two leading causes of death in modern societies, that is, to cardiovascular and cancer mortality, are much more elusive – and hence it is difficult to say what might be the exact role of meat consumption in extending or reducing average human life expectancy. And, finally, when looking at links between meat and health, it is unavoidable to address the concerns about diseased meat, about meat-borne pathogens whose effects can range from mild individual discomfort to viral pandemics.

These risks have always been present in terms of bacterial contamination arising during the growth, killing of animals and post-slaughter treatment of carcasses and retail cuts, and several animal diseases with potential for epizootic outbreaks have always made their episodic appearance. But there have been two new developments during the past two decades: the emergence of contagious avian viruses with a strong potential for viral pandemics, and beef infected with a variant Creutzfeld–Jacob disease (vCJD) (human form of bovine spongiform encelopathy [BSE], commonly known as mad cow disease). Individual risks of the latter infection have always been minimal, but the avian influenza is a cause for legitimate worries as its future virulent manifestation can cause large global death toll.

Meat and its nutrients

Evolution has left us with no shortage of specialized organs to admire because of their intricate structures and amazing functions: brains and eyes are commonly cited as the pinnacles of evolution, but such rankings are meaningless as in living organisms only the synergy of all organs matters, and hence skins or intestines or bones or muscles are no less important. Muscles – the prime movers of heterotrophic locomotion that make all walking, running, jumping, swimming and flying possible – look macroscopically fairly simple, but viewing their structure sequentially upward from molecular level is a different matter (Aberle et al. 2001; Lawrie and Ledward 2006; Myhrvold et al. 2011).

Molecules of specialized proteins, actin and myosin, are organized in myofilaments that form sarcomeres whose contraction and relaxation generates all muscle motion. In turn, sarcomeres are grouped into myofibrils that are bundled into muscle fibers sheathed by a collagen matrix (endomysium); muscle fibers are bundled into fascicles that are contained within another collagen mesh (perimysium), and the entire muscle is covered by yet another collagen sheath (epimysium, or silverskin). The ends of these connective tissues merge into tendons that are attached to bones (but there are also some muscles that are not attached to skeleton). Tenderness of meat is determined by the size of fascicles (muscle grain) and by the strength and thickness of collagen sheaths. Coarser grain of more powerful muscles covered with stronger collagen results in less tender meat.

The division between light and dark meat reflects the muscle functions: rapidly twitching muscles, reserved for sudden, fast movements and brief exertion at maximum power, are lighter-colored, while the muscles for continuous but relatively low power exertions (breathing, standing, masticating) are composed of darker, slow-twitching fibers – they have more myoglobin, another specialized protein that moves oxygen from the blood to muscle cells. But there is no stark color difference in muscle color among those domesticated animals whose ancestors had large home territories or migrated over long distances: intermediate fibers of muscles in cattle or aquatic birds are all colored by myoglobin which accounts for 0.5% of muscle mass in cattle but for less than 0.1% in pigs.

Actin, myosin, collagen and myoglobin are all proteins (collagen is the most abundant protein in animal bodies), and hence muscles can be best thought of as intricate assemblies of wet proteins: on the average, living muscles contain about 75% water (extremes range from 65% to 80%), and their protein content is, at nearly 19%, the least variable major component; embedded lipids average about 3%, non-protein nitrogen (including nitrogen in adenosine triphosphate) is less than 2% and the small remainder are traces of carbohydrates (mainly glycogen) and inorganic matter (particularly iron and zinc). Because of their higher fat content, there is less water in animal carcasses (about 55% in beef and just over 40% in pork), but the protein content of their separable lean meat varies within a very narrow range, from 19% to 23%.

But most muscles also contain fat that is embedded in the sheathing collagen in order to supply long-acting aerobic fibers with a readily available and highly dense source of energy. This embedded fat also plays an essential role in meat's gustatory quality as it weakens collagen structures and makes meat more succulent, particularly once it degrades to gelatin during moist heat cooking once meat reaches 65°C. In contrast, no external application of fat can make a very lean meat as succulent as a more fatty cut, a reality that engendered a partial help through an ancient practice of larding lean cuts of meat. In some mammalian and avian species (particularly in such highly mobile wild animals as hares, deer or pheasants), there is only a small quantity of fat beyond the limited amount that is present in embedded stores, while in others there are substantial subcutaneous fat deposits as well as rich deposits surrounding internal organs.

Shares of separable lean and separable fat range widely among both beef and pork cuts. The extreme for beef are top round steak with almost 90% separable lean, just 8% of separable fat and about 2% of refuse when all fat is trimmed away, and short ribs with only about 40% of separable lean, 32% of separable fat and 27% of refuse (USDA 1992). Depending on taste preferences and health concerns, separable fat may be almost completely removed during butchering, preparation of retail cuts or final trimming before cooking, or it may be left in copious amounts on retail meat cuts and eaten as part of stews, roasts, barbecues or processed meats.

The heart is, of course, the only constantly working muscle in the human body, but among all other organ meats only tongue and gizzard are peculiar muscles (in the first instance, a complex network of muscles of great agility and omnidirectional mobility, in the second case an involuntary smooth muscle), while liver and sweetbreads (thymus) are enzyme-rich glands, tripe is a lining of ruminant stomach, and brain and kidneys are each *sui generis* organs. The composition of raw mammalian livers is very similar to that of skeletal muscles (about 70% moisture and 20–21% of protein), and tripe has about 19% of protein, but other innards are slightly to substantially less proteinaceous: kidneys and tongues have about 16% protein, hearts between 15% and 17%, sweetbreads 15% and brains only about 10% (and 80% moisture). Skin, contrary to common perception, has very high moisture content, and in some species (including pigs, chicken, ducks and geese), it is eaten as a part of broadly defined meat, either as crisply cooked part of meat in roasts or as a separate preparation.

Finally, all meat eaters also ingest some blood. Between 40% and 60% of all blood is lost by exsanguination and all but a small share of the rest is retained in viscera; as a result, the residual blood content amounts only to 2–9 mL/kg of muscle, and this minuscule rate does not appear to be affected by different ways of slaughter (Warriss 1984). When assuming mean blood content of 5 mL/kg, an annual consumption of 80 kg of boneless meat (recent US average) would imply annual intake of some 400 mL of residual blood. For comparison, the pastoral Maasai tribe in Kenya, who used to tap regularly the jugular veins of their cattle to drink blood or to collect it for mixing with milk, would draw at a time 4–5 L from a steer or a bull and half that volume from a cow or a heifer and consume several liters in a single month (Århem 1989). Maasai blood drinking has been in decline for decades, but in many societies blood is still consumed (albeit irregularly and in small amounts) in traditional dishes ranging from soups and stews to stir-fries and sausages. But a habit from the late 19th century is no longer with us: young Parisian women do not visit slaughterhouses to drink the blood of freshly killed animals in order to redden their cheeks (Gratzer 2005).

Although meat has been an important component of food energy supply during the long period of hominin evolution and a major contributor to energy intake in Paleolithic and Neolithic societies, its prime role was qualitative rather than quantitative: foods that are equally, or much more, energy-dense could be secured by gathering, but before animals were domesticated, and in societies that had limited access to aquatic foods, meat was the only source of the highest-quality protein. And while most wild animals have low, or even very low, deposits of fat, high energy density made animal lipids much sought-after, and only modern nutritional science discovered meat's value as an outstanding source of a key vitamin and of several essential minerals.

The physical and chemical properties of meat obviously determine its taste, ease of cooking, flexibility of preparation and hence the popularity of individual species or specific meat cuts. Nutritional composition is a different matter as the tissues and cuts that may rank low in terms of culinary preference may contain virtually identical shares of essential nutrients. Three kinds of preformed organic macromolecules present in plant and animal foodstuffs – carbohydrates, proteins and lipids – must be digested in relatively large quantities to serve as source of food energy, as well as sources of proteins and fatty acids that are indispensable for the growth and maintenance of human bodies. In modern diets, typical consumption rates of these macronutrients range from 10^1 g/day for proteins and lipids to 10^2 g/day for carbohydrates. In contrast, compounds and elements belonging to two distinct classes of micronutrients – vitamins and minerals – are ingested at low to very low rates, ranging from just a few grams per day for sodium and potassium to just a few micrograms per day for vitamin B11.

Meat contains virtually no carbohydrates, but it is an excellent source of high-quality proteins and fats. In those prehistoric societies that had no milking animals and no, or limited, access to aquatic species, meat was the only source of proteins needed for normal childhood and adolescent growth and adult body maintenance. The importance of meat in diets of hunters and gatherers encountered by the European expansion in the Americas, Africa, Asia and Australia has been abundantly described in the narratives of explorers and colonizers, and in the societies whose traditional way of life persisted into the 20th century, it was eventually studied and analyzed by modern ethnographers and anthropologists.

Some of these studies have included revealing quantitative analyses demonstrating the importance of domesticated pigs in New Guinea (Rappaport 1968), cooperative hunting among Tanzanian Hadza (Marlowe 2010) or dependence on collected and hunted wild animals among Ache of Paraguay (Clastres 1981). As I will show in some detail in Chapter 2, meat consumption declined to low or very low levels in all densely settled traditional agricultural societies, but during those millennia of low intakes, meat never lost its status of a highly desirable food. In the Western world of the 19th and the early 20th centuries, meat was valued both as a source of protein and fat, and its rising consumption was one of the major contributors to enhanced growth, increased adult weight and improved health of rapidly urbanizing populations.

Post-WW II affluence and new nutritional and health awareness changed the perspective: with the abundance of other high-quality protein sources (seafood, eggs, dairy products), meat lost its status of indispensable supplier of protein, and fatty meat (beef in particular) lost a considerable market share to lean pork and, above all, to chicken. The composition of meat consumption has changed, but in all modern societies, be they affluent Western countries or rapid modernizers of Asia, meat remains the single largest source of high-quality protein, followed by dairy products, fish and eggs (usually, but not necessarily, in that order). Meat also supplies significant shares of essential fatty acids and important micronutrients, above all iron – a mineral whose deficiency has been common in many populations, including women in affluent countries.

Few modern scientific advances have been as consequential as the discoveries of the importance of micronutrients to human health. Deficiencies of common minerals can impede normal human growth; low intakes of vitamins compromise essential metabolic functions ranging from gastrointestinal upsets to epithelial hemorrhaging. Balanced diets supplying adequate amounts of macronutrients in foods originating from a variety of plant and animal sources do supply sufficient quantities of micronutrients, but poor eating habits mean that even in the countries suffused with food and consuming excess of carbohydrates, fats and proteins, micronutrient deficiencies are common.

Iron deficiency is one of the most widespread as well as one of the most damaging problems as it affects as many as 1.6 billion people, or more than a fifth of all humanity (deBenoist et al. 2008), and, even more tragically, in low-income countries, it impairs brain development of roughly half of all children and is associated with every fifth maternal death (Micronutrient Initiative 2009).

Meat is one of the best sources of dietary iron because it supplies this essential mineral as heme iron that is easily absorbed in the upper small intestine and that also helps to absorb non-heme iron present in plant foods, and even modest meat consumption helps to prevent iron deficiency anemia (Bender 1992). Iron content in red meat is mostly between 1 and 2 mg/100 g; it is particularly high in mutton (more than 3 mg/100 g), and it is highest in organ meats (nearly as much as 10 mg/100 g in lamb liver and kidneys). Recommended daily intakes of iron are 8–11 mg/day for children and adolescents, 8 mg/day for adult men, 18 mg/day for pre-menopause women and 27 mg/day during pregnancy (Otten et al. 2006). This means that up to 25% of daily adult male requirements can be supplied by eating a single modest serving of red meat.

Zinc is the other metal present in relatively high concentrations. The element is a part of metalloenzymes (it is actually the most common catalytic metal ion present in cell cytoplasm), and as such it plays several essential roles in the synthesis of nucleic acids, protein and insulin.

Zinc-fingers (proteins containing the element in human genome) interact with DNA and mediate gene transcription. As with other metals, zinc from plant food interacts with phytate and becomes less bioavailable than zinc present in animal foodstuffs (as a result, vegetarians should ingest about 50% more than the standard recommendation). Zinc deficiencies include retarded growth, higher rates of infection, skin lesions and impaired wound healing and are a significant factor in poor world's morbidity. Largely vegetarian diets raise the molar phytate : zinc ratios to more than 20, or even 25, well above 15 (the threshold for predicting suboptimal zinc supply) and more than double the ratios of around 10 or lower that prevail in affluent countries (International Zinc Consultative Group 2004).

That is why this study group estimated that a quarter of all people in South and Southeast Asia and in Latin America are in a zinc deficiency risk category. But nutritional surveys have shown zinc intake below recommended intakes even among children and adults in affluent countries (Samman 2007). Those recommendations are 11 mg/day for adult males and 8 mg/day for females (Otten et al. 2006), while 100 g of red meat contains 4–4.5 mg of the metal (Williams 2007). Meat is also a good source of selenium and phosphorus. And given the concerns about excessive sodium consumption, it should be noted that meat is low in sodium and richer in potassium, with the ratio of the two elements ranging from 5 : 1 to 6 : 1. Meat contains no vitamin C, very low levels of vitamins A and D and very little of thiamin, but it is rich in three vitamins of the B group, in B6, B12 (particularly in organ meats) and niacin.

B6 (a group of six pyridoxine-related compounds) is a coenzyme essential for amino acid and glycogen metabolism, and its deficiency causes seborrheic dermatitis and microcytic anemia. Its daily requirements are 1.2–1.5 mg for adults; meat contains between 0.5 and 0.8 mg/100 g, but the main dietary sources of B6 in the Western diet are fortified cereals for females (Otten et al. 2006). B12 (cobalamin) is another essential coenzyme that is stored in large amounts in the liver; on a daily basis, it is needed only in minuscule quantities (adult intakes should be just 2.4 µg/day), and its deficiency, caused by interference with its complicated process of absorption, can eventually lead to megaloblastic anemia and neuropathy (Truswell 2007). Meat contains roughly as much B12 (1–2 µg/100 g) as cheeses or eggs, but its concentrations in livers and kidneys are an order of magnitude higher.

Meat as a source of food energy

When food supply is nutritionally balanced and adequate to meet growth, maintenance and activity needs, protein is only a marginal source of energy.

In such circumstances, (i.e., for the majority of today's populations), most of the needed food energy is always derived from carbohydrates and fats, and only a small, and globally fairly uniform, portion comes from proteins: among major economies, that share ranges only narrowly between 10% for India and 13% for France. In contrast, the other two shares range much more widely, between just 45% (France, Spain) and more than 75% (some sub-Saharan countries) for carbohydrates and between 10% (Ethiopia) and just over 40% (France) for fats.

As an energy source, protein has gross energy density about 35% higher than that of carbohydrates (23 kJ/g compared to 17.3 kJ/g), and those rates are less than half the value for energy-dense lipids (39 kJ/g). Actually metabolizable energy of carbohydrates is only marginally lower (16.7 kJ/g), but the adjustment for metabolizable energy – generally known as Atwater factor correcting for losses during digestion, absorption and urinary excretion (Atwater and Woods 1896) – is relatively higher for lipids (down to 37.3 kJ/g) and it is highest for proteins (down to 16.7 kJ/g). Only when the supply of carbohydrates and fats becomes inadequate, a rising share of food energy is drawn from protein metabolism, a condition known as protein-energy malnutrition that is still fairly common in many low-income countries. Global data about the extent of undernutrition and malnutrition are derived from statistical probability assessments, and hence no accurate figures are available, but the best published estimates put the extent of undernutrition at about 925 million people, or about 13% of the global population in 2010 (FAO 2010a).

Lean meat is much less energy-dense than the most common staple plant foodstuffs, cereals and leguminous grains, with energy densities mostly between 14 and 15 kJ/g of dry weight, and its closest plant counterpart in terms of energy content are sweet potatoes with 4.6–4.8 kJ/g. And while wild animals are generally leaner than their domesticated progeny, lean meat of all species has very similar energy density. Both lean beef and lean pork contain about 4.8 kJ/g, while venison and chicken meat average about 4.4 kJ/g compared to more than 5 kJ/g for more fatty cuts of red meats or for such large wild herbivores with substantial subcutaneous fat deposits as eland or moose (Eaton 1992). And while camel humps are significant fat depots, camel meat is also lean, with no inter- or intramuscular fat (Hertrampf 2004).

Lean meat is much more energy-dense than common leafy vegetables (cabbage and spinach at about 1 kJ/g) but comparable to sweet potatoes (4.7 kJ/g), and it is much less dense than all oil seeds, be they those with exceptionally high protein content (soybeans at 16.8 kJ/g) or oil content (sunflower seeds at more than 23 kJ/g). Another way to do this comparison (assuming, simplistically, that only energy matters) is by listing approximate mass of foods needed to satisfy daily food requirements of an active adult (12.5 MJ/day): it would be about 10 kg of leaves, more than 3 kg of fruits, 3 kg of tubers or white fish, about 2.5 kg of lean meat but less than 700 g of fatty pork.

Preferences have shifted: for most people, the gustatory appeal of meat, and in traditional societies (where fatty cuts were almost always seen as highly desirable) also the largest share of food energy, was associated with fat. Large domesticated mammals have three kinds of fat: substantial subcutaneous reserves serving as energy stores, deposits surrounding and cushioning such vital organs as heart and kidneys, and, as already explained, relatively small deposits of intramuscular fat. The first two categories of fat can be easily separated from skin, meat and bones and processed to yield edible products (particularly pig's back and belly fat turned into bacon or rendered into lard), added to such meat products as sausages or used as industrial ingredients (beef tallow).

Pork fat has less than 8% of moisture and a few percent of protein and energy density of about 34 kJ/g, while beef fat is even purer and has less water and less protein and energy density of nearly 36 kJ/g. Nearly 30% of beef carcass and almost 50% of pork carcass is fat, while separable lean beef averages less than 2% of fat, and lean pork, at just over 1%, is similar to venison; only lean veal and chicken have less than 1% of meat fat. Besides obviously raising a meat's energy density, the presence of fat affects flavor and juiciness of meat and helps to create satiety, a feeling that prolongs the intervals between meals and leads to a common preference for such foods (Rogers and Blundell 1990). But, contrary to a common perception, the presence of fat is not the primary determinant of tenderness (the size of muscle fibers is).

Trend toward leaner cuts, driven above all by health concerns, has been unmistakable in all affluent societies, and meat producers have responded in three principal ways: by selective breeding and adjusted feeding practices producing leaner carcasses, by meat classification and marketing that favor leaner cuts, and by improved butchery techniques. As a result, the share of separable fat in retail meats has been declining, and Williams (2007) reported that for Australia's almost exclusively grass-fed animals, all trimmed beef cuts now have less than 5% of total fat, trimmed lamb cuts average less than 10% of fat and the only meat with more than 10% fat is regular mince. Effects of trimming and cooking on the fat content of actually eaten meat can be profound: for example, Gerber et al. (2009) found that cooking beef, veal and pork reduced the absolute fat content by 18–44%, and trimming of edible fat cut away an additional 24–60%.

But some societies and some consumers still prefer those beef cuts with high, even very high, proportion of intramuscular fat. In Japan, a country of restrained meat consumption, by far the most expensive domestically produced meat is beef that comes from the crosses of traditional black-coated, small-stature breeds of *wagyū* (Japanese cattle used for centuries as draft animals) and European animals. Kōbe beef from Hyōgo prefecture is produced by feeding penned heifers for up to three years, regularly massaging them and giving them beer to drink during the summer, and it is so highly marbled that it contains 20–25% of fat compared to 6–8% for the USDA prime beef.

The most expensive cuts look more white than red and are sold for more than $500/kg. And the even more expensive Matsuzaka beef (from Mie prefecture) has an extremely high fat/meat ratio; the animals are also fed beer in summer but are also massaged with *shōchū* (Japanese liquor). But true *wagyū* beef remains a niche market category, and in affluent countries, the common perception of animal fats has undergone a negative transformation during the past two generations: fatty meat used to be seen as desirable, deliciously filling, too often beyond the means of low-income households. Processed meat products – from French *patês* to numerous varieties of Italian *salami* – are held by many in high culinary esteem and contain a very high proportion of fat, often in excess of 40%.

Dietary recommendations by FAO/WHO experts set the acceptable range of total fat intake at 20–35% of all food energy, with minima at 15% in order to ensure not only adequate total energy intake but also the supply of essential fatty acids and bioavailability of fat-soluble vitamins A, D, E and K (FAO 2010b). Dietary guidelines for Americans recommend keeping the total fat intake between 20% and 35% of food energy while maximizing the share of polyunsaturated and monounsaturated fatty acids and consuming less than 10% of daily energy in the form of saturated fats (USDA 2010a). Recent shares of fats in average food energy supply of affluent nations have ranged from 25% to 27% in Japan (the lowest share among all affluent countries and the same as in China) to as much as 41% in France and 38% in the US (FAO 2012). Oils (corn, soybean, rapeseed, olive, etc.) are the largest source of plant fats; in Western countries, a large share of lipids came from dairy products, and the recent contribution of meat fats was less than 10% in the West (about 9% in France, 7% in the US).

Biochemically, there are three kinds of meat fats, triglycerides (3 moles of fatty acids joined to glycerol), phospholipids and cholesterol, an essential dietary ingredient involved in hormonal function and indispensable for cell wall integrity. Fatty acids are conventionally grouped into saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) categories, but this broad chemical classification ignores the distinct biochemical properties of individual acids. Modern dietary research has convincingly established that it is desirable to limit the intake of SFA and replace it by MUFA (in practice, this means by consuming more oleic or erucic acid, that is, olive and rapeseed oil) and PUFA (present in fish). Dietary recommendations for adults are to limit SFA to 10% of all energy intakes while consuming at least 6% and up to 11% of all energy as PUFA, especially as n-6 PUFA and n-3 PUFA (FAO 2010b).

A common misconception has been to see meat as a dangerously high source of SFA, while their amount, even in red meat, is actually lower, per edible portion, than the combined quantities of MUFA and PUFA. According to the USDA standard reference data base, the share of SFA is 45% in beef tenderloin, 44% in top round steak, 38% in composite retail cuts of trimmed pork, 35% in skinless chicken breast and 32% in skinless chicken thigh (USDA 2011). For comparison, SFA make up 30% in albacore tuna, 22% in salmon and 14% in olive oil. Given the variety of cuts, animal breeds and feeding regimens, it is hardly surprising that fatty acid analyses done in Brazil or Australia are not identical with USDA's averages. For example, Williams (2007) found that SFA share in Australia's beef was 41%, while the results obtained by de Almeida et al. (2006) for Brazilian beef emphasize the often large difference among specific cuts, with bottom round steak having 45% SFA and top round steak 52% SFA, but the bottom round containing three times as much SFA in absolute terms.

Comparisons of the just-cited US shares with Australian and Brazilian values for grass-fed animals do not indicate that grazing lowers SFA content. Just the opposite was found by Rule et al. (2002) who examined fatty acids in free-ranging and feedlot-fed bison and beef, but they also found that the grass-fed animals have higher shares of PUFA. Similarly, Leheska et al. (2008), who analyzed US ground beef and strip steaks by using samples from 15 grazing operations in 13 states and comparing them with feedlot beef, found that grass-fed ground beef had significantly more SFA (55% compared to 47%) and significantly less of more healthy MUFA (42% compared to 50%) than did the feedlot beef. For strip steaks, the difference was smaller (52% SFA for grass-fed and 48% SFA for feedlot beef), while the concentrations of PUFA did not differ between the two kinds of meat. In contrast, several studies found that increased grass intake led to decrease of SFA concentrations (French et al. 2000). Ruminant meats (and dairy products) also contain conjugated linoleic acid, a naturally occurring *trans* fat shown by *in vitro* and experimental animal studies to have potential health benefits due to its cancer-inhibiting effect at several sites, above all in the mammary gland (Bhattacharya et al. 2006).

While many fatty acids are easily substituted by other structurally similar compounds, there are two essential fatty acids that must be present in all healthy diets: linoleic acid (a primary ω-6 PUFA) and α-linolenic acid (an ω-3 PUFA) must be digested completely preformed in order to become precursors of prostaglandins (that act as regulators of gastric function, smooth-muscle activity and hormonal release) and parts of cell membranes. Inadequate supply of these acids is manifested in scaly rash, dermatitis, neural abnormalities and reduced growth. US guidelines for linoleic acid recommend average per capita intakes of 17 g/day for adult men and 12 g/day for adult women, while the rates for α-linolenic acid are set at, respectively, 1.6 and 1.1 g/day. Red meat, with between 0.3 (beef) and 0.4 g (mutton) of ω-6 fatty acids per 100 g of edible portion, is as good or a better source of these nutrients as oily fish, but ω-3 acids are far more abundant in oily fish (more than 2 g/100 g compared to just 0.1–0.2 g/100 g).

Cholesterol is a part of cell membranes, and hence its content in the muscles of all mammals is fairly similar: contrary to common perception, beef or pork are not exceptionally high in cholesterol. The actual averages are mostly between 50 and 75 mg/100 g for well-trimmed beef and pork and 60–80 mg for chicken (de Almeida et al. 2006; Williams 2007). Cholesterol concentrations in red meat are higher than for some wild buffaloes and pheasants (both less than 50 mg) but lower than many published values for antelopes, deer and caribou that range, depending on the species, between 80 and 110 mg (Medeiros et al. 2001; USDA 2011). According to the US dietary guidelines, daily cholesterol intake should be less than 300 mg/capita (USDA 2010a). If meat were the only source of dietary cholesterol, this would translate to a maximum of 400 g of beef a day.

Meat's share of overall food energy supply was inevitably low in early hominins devoid of suitable hunting and butchering tools. It reached its evolutionary peak in Pleistocene hunting societies skilled at killing many species of (now mostly extinct) megafauna, was much lower in early sedentary societies combining foraging and cultivation of crops, and reached its lowest levels in all traditional agricultural societies practicing intensive cropping (and virtually absent in some of them). In Western societies, it began to rise with the 19th-century urbanization and industrialization, and in most of them it rose to averages unprecedented in history (albeit still lower than prehistoric means).

All of these supply and consumption shifts will receive detailed quantitative coverage (based on the best available evidence) in Chapters 2 and 3, while in this section I will briefly survey energy densities of all common species and many favorite cuts of meat. Here, I will just note the recent shares of meat in the total retail-level supply of food energy in the world's largest economies: for affluent nations, they range, much like the shares for protein, only narrowly from 11% as the EU mean to 12% in the US and 14% in Spain; remarkably, China's meat share in food energy supply is now as high as in Spain, but the share remains low in Japan (a bit over 6% because of the country's traditional preference for seafood), and it is minuscule (about 0.6%) in India.

High-quality protein and human growth

Meat's importance in human diets is primarily due to the supply of high-quality protein, secondarily to the provision of essential fatty acids and micronutrients and finally as a source of food energy. Dietary proteins are indispensable for all heterotrophic growth, including the maintenance and replacement of tissues. Nine amino acids are not synthesized by humans and must be ingested fully preformed: these essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) contain on the average about 16% of nitrogen and are irreplaceable precursors of all structural and functional proteins that form skeletal and other muscles, internal organs and bones as well as all complex, metabolically active compounds (enzymes, hormones, neurotransmitters and antibodies).

Dietary proteins are also needed in order to make up for small but constant nitrogen losses due to the shedding of skin particles, cutting of hair and nails, and excretions in urine (Pellett 1990). Obligatory nitrogen excretions dominate with between roughly 40 and 70 mg/kg in adulthood (mean of just over 50 mg/kg); other losses amount to less than 10 mg/kg. Recommended daily intakes are quantified in terms of reference (or ideal) protein that combines the presence of adequate amounts of all essential amino acids with easy digestibility. Chicken egg or cow milk protein have been the two most common whole food choices, but any animal protein has the same high ranking, and so any meat or any fish could be used as a source of ideal protein as well.

Obviously, inferior proteins that contain suboptimal amounts of one or more essential amino acids as well as those that are difficult to digest cannot support the same rate of growth. In vegetarian diets, protein quality is usually most affected by lysine deficiency (this essential amino acid is present in relatively low amounts in all cereal grains) or by shortages of sulfur-containing methionine and cystine (whose levels are relatively low in all leguminous grains). In everyday diets, complete (ideal) proteins (with more than adequate shares of all essential amino acids) are available only in foods of animal origin (meats, fish, eggs, dairy products) as well as in mushrooms, but all plant foods have incomplete proteins (with one or more amino acids relatively deficient).

This means that the scores for protein quality of common vegetarian diets based on grain or tuber staples will be only around 70 and even as low as 60 compared to 100 for a reference protein, and that in order to receive adequate intake of all essential amino acids, infants will have to consume 40–70% more of protein in their meatless diets than they would have to eat in a mixed diet containing some dairy products, meat or fish. The second key variable is actual digestibility of proteins. The ratio for egg and dairy protein is, respectively, 97% and 95%, and at 94% the rates for meat and fish are nearly as high (FAO/WHO 1993). In comparison, digestibility for whole wheat, corn and oatmeal are 85–86% and for beans less than 80%, and the rates for legume-rich mixed diets are as low as 77–78% in India and Brazil.

Since the early 1990s, the preferred method for evaluating the protein quality of foods has been to use protein digestibility-corrected amino acid scores (PDCAAS). These scores take into account age-related scoring patterns of amino acid requirements (different for children and adults) and adjust them for digestibility (FAO/WHO 1993). Reference PDCAAS for casein and egg white is 1.00, beef scores 0.92, chickpeas around 0.7 but lentils, as well as whole wheat, only 0.52 (Sarwar et al. 1989). Mixed diets including animal foods, where all amino acids are always present in more than adequate amounts, will get fairly high scores; for example, combining whole-wheat products and beef raises PDCAAS to 0.85, and for a typical Western diet based on refined wheat flour, the ratio will be above 0.9.

After decades of studies, we have a fairly good understanding of protein and amino requirements in human nutrition. The FAO and WHO specify the "safe level of intake" (i.e., the minimum needed to maintain protein balance) at 0.83 g/kg/day for adults of both sexes (FAO/WHO 2007). A woman weighing 50 kg will thus need 42 g of protein a day, and a 75-kg man will require 62 g/day. For infants, these recommendations fall from 1.31 g/kg/day at six months of age (or about 10 g/day) to 1.14 g at one year and to 0.9 g/kg/day at the age of ten years, translating to an average daily intake of about 25 g/capita. Additional protein is needed during pregnancy and lactation. For comparison, the US dietary reference guidelines estimate the average daily protein requirement at 0.66 g/kg for adults and set the recommended daily allowance at 0.80 g/kg/day for both sexes (FNB 2005), while the reference values for Australia and New Zealand are 0.84 g/kg for adult men and 0.75 g/kg for adult women (NHMRC 2006).

All of these values refer to ingestion of proteins with a digestibility-corrected amino acid score value of 1.0, which means that appropriately higher amounts will be needed with diets whose proteins have inferior PDCAAS. These conservatively specific requirements are well below the values of the amount of protein that is actually available in average per capita food supply not only of all affluent countries but also many populous modernizing nations. During the first decade of the 21st century, average daily protein supply was in excess of 100 g/capita both in the US and France; it was around 90 g/capita in Japan as well as in China with Brazil not far behind (FAO 2012). Meat supplied roughly a third of all protein (and more than half of all high-quality protein from animal foodstuffs) in the US as well as in Brazil, more than a quarter in France and a fifth in China.

Europe is the only continent where average per capita consumption of meat protein has become saturated at about 25 g of protein a day by the end of the 20th century; all other continents have seen steady increases to maxima of nearly 40 g/day in Australia and 30 g/day in the Americas, rates that are an order of magnitude higher than in the world's least developed countries (FAO 2012). Among the world's most populous nations, only the overwhelmingly vegetarian India and Bangladesh stand out with less than 60 g/day of total protein supply, with meat contributing just 2% in India and less than 3% in Bangladesh. Given the combination of inevitable nutrient losses along the food chain, of low amino acid scoring, of poor digestibility of the subcontinent's legume-dominated plant proteins and of unequal access to food, it is obvious that a daily protein supply of less than 60 g/day is, at best (among better-off social strata and in some regions), barely adequate, while hundreds of millions of people remain undernourished: not surprisingly, in absolute terms India has the largest number of malnourished people (FAO 2010a).

One of the more intriguing recent studies has been an investigation of meat eating and cognition in China's Guangzhou province (Heys et al. 2010). When compared to no meat consumption in childhood or to eating meat just once a year, daily meat eating was positively associated with both immediate and delayed recall score in a study of more than 20,000 Chinese men and women aged 50 years and over. Studies in Nepal and Kenya demonstrated a similarly beneficial effect on motor milestone acquisition and on growth and cognitive function among children (Neumann et al. 2003; Siegel et al. 2005). If further confirmed, these findings would be of great importance, given that some 60% of the world's people with dementia now live in modernizing countries where meat intakes are often very low.

On the other end of the global nutritional spectrum are societies with a surfeit of food and high incidence of obesity: there, too, adequate protein intakes can be beneficial. Because dietary protein is more satiating than carbohydrate or fat, diets with more protein are more likely to reduce food intake and result in greater weight loss than high-carbohydrate diets; eating lean meat can thus help to reduce the rates of obesity and type 2 diabetes (Noakes et al. 2007).

Carnivory and civilizational diseases

The pattern of morbidity and mortality had changed during the latter part of the 20th century, as inoculation reduced and eventually eliminated the incidence of once common infectious diseases, as antibiotics became widely available to treat life-threatening bacterial infections, and as better sanitation and stricter preventive legislation cut the risk of food poisoning and dangerous exposure to environmental pollutants. As a result, the Western world and, with only a slight delay, the urbanized areas of lower-income countries have experienced the rising frequency of so-called civilizational diseases, illnesses whose genesis is associated with lifestyle – including diet, stress and lack of physical activity – and whose incidence increases with greater longevity.

The list of these diseases ranges from asthma to osteoporosis, but the two largest categories (and also the two leading causes of death in modern societies) are cardiovascular diseases (CVD, including cardiac and vascular mortality, or its major subcategory, coronary heart disease, CHD) and cancers. Diet, in general, and meat consumption, in particular, have been singled out as major contributors to the genesis of CVD (among recent studies, see Williamson et al. 2005; Kontogianni et al. 2008). But critical reviews of these statistical associations do not reveal any convincing causation at low to moderate levels of meat consumption, and the overall statistical association weakens considerably once the fat is separated from meat (Li et al. 2005; Givens 2010; McAfee et al. 2010).

The now classic link between the consumption of meat (fatty meat to be precise) and higher incidence of CVD mortality was established by the Seven Countries Study that focused on the links between CHD and lifestyle factors, particularly dietary fat intake (Keys 1980; Alonso et al. 2009). The study, whose baseline surveys were conducted between 1958 and 1964, included 16 cohorts of men between 40 and 59 years of age in seven countries, and its most widely reported outcome was a strong positive correlation between the average intake of saturated fats (coming from meat as well as from separated animal fats and eggs and from hydrogenated plant oils) and CHD mortality.

The difference between low- and high-fat diets was particularly well demonstrated by contrasting American and northern European cohorts with two Japanese cohorts, the first one from a farming village of Tanushimaru, the second one from a predominantly fishing village of Ushibuka. Men in the Japanese villages had age-standardized 25-year CHD mortality between just 30 and 36/1,000 compared to rates in excess of 100/1,000 for their US and northern European counterparts. Only a cohort from Crete had a lower mortality rate at 25/1,000, while the mean for Mediterranean diets was 40–90/1,000 (Menotti et al. 1999). The most significant predictors of high CHD mortality were the average intakes of butter, lard, margarine and meat, while higher consumption of legumes, oils and alcohol had the strongest negative correlations. And the continuing contrast between the Japanese and Western diet appears to confirm the fat–disease link, as average intake of fats is more than a quarter of all food energy in Japan compared to a third or more of the total in the West, and the Japanese CVD mortality is significantly lower.

But what was once a widely accepted epidemiological dogma is now anything but that. The obvious qualification that should have always been made was that the link was between fats and CVD, not between lean meat and CVD, and that the intakes of solid saturated fats (butter, lard, margarine) had the highest correlations with disease frequency. But more important facts for deconstructing even that simple fat–CVD link became soon available. Curiously, the Seven Countries Study did not include any men from France, and hence its result had entirely missed what came to be known as the French paradox, namely, the coexistence of low CHD mortality with high intakes of saturated fat and dietary cholesterol (Renaud and de Lorgeril 1992).

The prevalence of this paradox was soon found in other parts of Mediterranean Europe (Masia et al. 1999), and its initial explanation attributed the effect primarily to frequent drinking of red wine. The latest explanations also take into account composition of the entire diet with high fruit and vegetable intakes and regular physical activity (Ferrières 2004). And Spain's rapid dietary transition after the collapse of Franco's regime and accession to the EU provided strong support for the Spanish paradox: even as the country's per capita meat consumption rose to be the highest in the EU (accompanied by increasing dairy intakes), its CVD mortality decreased after 1976 (Serramajem et al. 1995).

Finally, another study documented what might be labeled the Japanese paradox: average per capita intakes of fats, meat and dairy products were increasing during the 1960s, 1970s and 1980s and led to higher mean blood cholesterol levels, higher average body mass, higher mean blood pressure and higher incidence of overweight – but the CHD mortality remained the same (Toshima et al. 1994). The validity of this paradox has been extended to the 1990s by showing that despite similar cholesterol levels and similar blood pressures among Japanese and American men, the Americans had CVD mortality about twice as high as the Japanese (Sekikawa et al. 2003).

By now, we have sufficient evidence to make several important conclusions about the links between meat and CVD. Modern lean red meat trimmed of visible fat has low content of saturated intramuscular fat – even beef muscle has less than 5% fat, and marbling fat concentrations as low as 20–50 g/kg are possible (Scollan 2003) – and low cholesterol content, and its low to moderate consumption does not raise total blood cholesterol and LDL cholesterol levels (Li et al. 2005; McAfee et al. 2010). People eating lean beef, pork and chicken in addition to typical Western diet will get much more fat (total and saturated) from fast and snack foods, oils, spreads and baked goods. Moderation makes a critical difference even when assessing the link between all red meat (lean, fatty and processed) and CVD.

Many studies that looked at red and processed meat consumption and CHD have been poorly designed, and this limits their confident interpretation. While most of them controlled for the main confounding variables (age, body mass index, alcohol, smoking, physical activity, etc.), they do not give absolute figures for the amounts of meat associated with higher CVD risks and use instead inconsistent "servings" or "portions" whose size is particularly difficult to standardize when the studies rely on dietary recall; another questionable approach is to calculate the degree of risk by contrasting the lowest and the highest quintiles of meat intake, a choice that excludes most of the people who consume moderate amounts.

The most comprehensive meta-analysis of these studies, based on 20 publications whose adequate design qualified for inclusion, found that red meat intake was not associated with CHD (relative risk of incident CHD when eating 100 g/day of red meat was 1.0), that processed meat intake had a strong correlation (relative risk of 1.42 when eating 50 g/day) and that total meat intake had an intermediate association, with relative risk of 1.27 when consuming 100 g/day of all meats (Micha et al. 2010). But as Bryan (2011) pointed out, such risk quantifications leave us confused: if a 42% higher relative risk that might arise from eating processed meat should lead to reduced meat consumption, what is then the lesson of the European EPIC-Oxford study that found vegetarians having increased colon cancer incidence (relative risk 1.39) when compared with meat eaters (Key et al. 2009)? That we should eat fewer vegetables?

The largest study included in the just-cited meta-analysis followed more than half a million Americans (aged 50–71 years at baseline) for 10 years, and it found that the risk of CVD was modestly elevated for both men and women only in the highest quintile of red and processed meat consumption in which the average intakes for men were, respectively, more than three times and nearly three times than in the second quintile (Sinha et al. 2009). Men in the highest quintile ate 68.1 g/1,000 kcal, that is – assuming about 2,300 kcal/day – about 55 kg of red meat a year compared to only about 8 kg/year in the lowest and 18 kg/year in the second lowest quintile. Links to stroke also remain uncertain: three studies found no association, while a Swedish study of women found that total red and processed meat consumption carried a significantly increased risk of cerebral infarction but not of total stroke or cerebral hemorrhage (Larsson et al. 2011), while for men there was no association with the fresh red meat and a positive link between processed meat consumption and stroke (Larsson et al. 2011a).

Most epidemiological studies of links between meat consumption and cancer – possible biochemical explanations of such causation are reviewed in Ferguson (2010) – have focused at red and processed meat and colon cancer: links with gastric cancer, a disease rare in rich countries, is not convincing, and those with breast and prostate cancers did not show up in large epidemiological studies (Corpet 2011). But a meta-analysis of ten studies concerning the association between breast cancer and red meat consumption in premenopausal women suggested the summary relative risk at 1.24, with 1.57 for case-control studies and 1.11 for cohort studies (Taylor et al. 2009). A number of suggested pathways that link red meat consumption and breast cancer involve hormonal action, and this would indicate a possible role of meat eating in the increasing incidence of hormone receptor-positive breast cancers documented in the US population since the early 1990s.

But a link between red meat intake and the colorectal cancer is seen as much more convincing, and a recent summary of this evidence led the World Cancer Research Fund (WCRF) to recommend limited consumption of red meat and avoidance of processed meat (WCRF and AICR 2009). Corpet's (2011) experimental studies with rats concluded that this is due to a true causative association and not due to confounding factors. But, as with the CVD link, two meta-analyses of more than 40 studies present more qualified conclusions (Norat et al. 2002; Larsson and Wolk 2006). Most notably, total meat consumption (red, white, processed) is not linked to colorectal cancer risk. When compared with consumers in the lowest quintile, the relative risk is significantly higher for people consuming the largest quantity of red meat, and similar level of risk (about

1.3) applies to eating processed meat. Again, the quantities make all the difference: WCRF and the American Institute for Cancer Research (2009) recommend the limit of 500 g/week of fresh red meat, or an average annual per capita consumption of up to about 25 kg.

And the latest prospective evaluation – using the Health Professionals Follow-up Study for men (1986–2008) and Nurses' Health Study for women (1980–2008) – looked at red meat consumption and mortality due to both CVD and cancer, and it has only confirmed the conclusions reached since 1990 (Pan et al. 2012). After correcting for major lifestyle and dietary risk factors, it found, once again, a linear dose response with the risk ratio of total mortality averaging 1.13 for one serving a day increase for fresh meat (standard serving size being 85 g, or a cumulative intake of 31 kg/year) and 1.2 for processed red meat, with specific risk ratios at 1.18–1.24 for CVD and 1.10–1.16 for cancer mortality. The author also estimated that substituting one serving of meat per day by other foods would lower mortality risk by 7–19%, and that the overall mortality could be reduced by about 9% for men and almost 8% for women if everybody consumed no more than half a serving of meat a day.

Despite many specific uncertainties, the cumulative epidemiological evidence is thus fairly conclusive, both in cases of CVD and cancer links to meat consumption: moderate meat intakes are the optimal choice to counsel, particularly when considering the benefits of ingesting complete proteins and easily absorbable micronutrients. Given a diverse diet, moderate food energy intake may be a much more important determinant of health and longevity than a particular dietary composition; this benefit is due to a positive effect of caloric (or dietary) restriction, a matter to which I will return in Chapter 5.

Diseased meat

Concerns about the safety of meat for human consumption have always included the risk of contamination due to improper slaughtering, storage or processing procedures and the presence of natural pathogens. Despite the advances in public hygiene and stricter rules for production and food treatment, the risk from natural pathogens remains common in the 21st century (Sofos 2008). Trichinellosis is the most recurrent problem among pigs and foot-and-mouth disease among cattle as well as pigs (Pozio 2007). Human trichinellosis is acquired by eating raw or inadequately cooked pork that harbors larvae of *Trichinella spiralis*, a small tissue-dwelling nematode that lives in domestic and wild animals in all inhabited continents and whose adult worms colonize human duodenum and jejunum. Worldwide incidence of human trichinellosis is underreported, but annually there are at least 10,000 cases with low (about 0.2%) rate of mortality.

Not surprisingly, trichinellosis has been relatively frequent in the world's largest pork-eating nation, with the outbreaks during 2000–2003 reaching nearly 1,000 cases and causing 11 deaths (Cui et al. 2011), while in the US less than 50 cases have been reported recently per year. Brucellosis, caused by different species of fever-inducing genus *Brucella*, has been similarly rare. These bacteria can infect all domestic animals but are not usually found in meat, and their transmission to humans has been greatly reduced with pasteurization of milk (Franco et al. 2007). The annual incidence in the US has been recently less than 100 cases.

Foot-and-mouth disease (also known as hoof-and-mouth disease) is due to a highly contagious virus of the Picornaviridae family (*Aphtae epizooticae*). Infected animals have high fever, foamy salivation and blistered feet. Fortunately, human infections are very rare, but the economic impact of regional or national epizootics is considerable. By far the most extensive recent foot-and-mouth disease epizootic began in England in February 2001, and the eventual infection of more than 2,000 animals led to mass slaughter of about seven million sheep and cattle and huge pyre burning of their carcasses, with estimated losses of about $16 billion (Ferguson et al. 2001). More recent, and less severe, outbreaks took place in parts of China in 2005, yet again in the UK in 2007 (confined to a small area in Surrey), but another nationwide infestation, that began in November 2010 in South Korea, led to a slaughter of some three million pigs and more than 100,000 cattle.

Infestations of meat by commonly occurring bacteria pose the most frequent risk and create the highest public health concern. By far the most common pathogenic bacteria ingested with meat belong to a ubiquitous species *Escherichia coli*, whose hundreds of strains reside without any ill effects in human and animal intestines. For example, among nearly 12,000 meat samples collected from four US states between 2002 and 2008, more than 80% of chicken and turkeys, nearly 70% of beef and more than 40% of pork were contaminated (Zhao et al. 2012). An overwhelming majority of these bacteria cause no problems and perish during cooking, but in 1982 a virulent strain O157:H7 of Shiga-toxin producing *Escherichia coli* (STEC) was first identified in contaminated and undercooked hamburger meat in the US.

Its ingestion may cause only a temporary discomfort in healthy adults, but it can result in severe illness (often marked by bloody diarrhea) among healthy people and a rapid death in children due to hemolytic uremic syndrome that leads to acute kidney failure. The Centers for Disease Control and Prevention estimates that in the US there are annually more than 73,000 STEC infections resulting in more than 2,000 hospitalizations and 60 deaths, and Frenzen et al. (2005) put the annual cost of STEC at nearly half a billion dollars.

But the foodborne bacterial pathogen that causes most illness, hospitalizations and deaths is caused by nontyphoidal *Salmonella*: in 2011, there were more than one million cases of illness, nearly 20,000 hospitalizations and close to 400 deaths (CDCP 2012). *Salmonella enterocolitis* infects the lining of the small intestine, and it is the most common cause of food poisoning in affluent countries. Abdominal and muscle pain, chills, fever, diarrhea and vomiting usually go away after two to five days, but dehydration is a dangerous risk in small children and infants (Pegues and Miller 2009). Improper handling and storage of poultry and eating of undercooked chicken and turkey are the most common sources of bacteria. Species of *Campylobacter* are responsible for more than 800,000 illnesses and some 70 deaths every year.

Salmonella occurrence is common not only on raw chicken in low-income countries but also in Europe and North America, with recent studies finding the prevalence of 68% in Addis Ababa, 66% in Bangkok, 60% in Oporto (Portugal), 36% in Belgium and Spain, and within a range of 39–65% in six of China's provinces and in Beijing and Shanghai (Yang et al. 2011) – while the old US standard tolerated *Salmonella* presence in up to 23.5% of samples of carcass rinses. In 2010, the USDA issued a new performance standard that limits *Salmonella* contamination of raw chickens to 7.5% of samples tested, and it also set up, for the first time, standards for *Campylobacter* genus; the two measures were expected to prevent nearly 40,000 of *Campylobacter* infection and 26,000 cases of salmonellosis (USDA 2010b).

These statistics must be seen in a realistic risk perspective. More than 300 million Americans eat meat, and hence four meals a day (breakfast, lunch, dinner, snack) would imply 1.2 billion meals that could contain some meat. Even when assuming that all *Escherichia*, *Salmonella* and *Campylobacter* infections come from meat – a great exaggeration as *Escherichia* is often ingested in water, juices, vegetables, fruits and milk, and *Salmonella* poisoning often comes from milk, eggs and vegetables – the annual total of roughly 1.9 million cases would mean that the risk of getting ill would be when eating roughly one out every thousand meals.

One out of every 40,000 meals would be followed by hospitalization, and one out of 2.2 million meals would carry a risk of foodborne death – and those roughly 500 deaths should be compared with about 20,000 deaths caused in the US by the annual influenza and with nearly 100,000 deaths due to hospital-acquired bacterial infections (Peleg and Hooper 2010). Moreover, proper meat handling in kitchen and cooking to recommended temperature reduce these risks to negligible rates. That is why an entirely different disease-related risk is much more worrisome: antibiotic-resistant bacteria in meat have potentially life-threatening and economically costly consequences.

Experiments dating to the late 1940s discovered that antibiotics digested with feed boosted weight gain of broilers by at least 10%, and already in 1951 the US Food and Drug Administration (FDA) approved the use of two common compounds (penicillin and chlortetracycline) as commercial feed additives, with oxytetracycline following in 1953, and these compounds have been used as inexpensive growth enhancers by the entire livestock industry. By the end of the 20th century, US poultry producers were using more antibiotics than either pig or cattle growers, but the total use of antibiotics in American livestock has remained contested for decades. In 2001, the Union of Concerned Scientists claimed that the past published totals of use were drastic (almost 50%) underestimates and put the annual US consumption at 11,150 t (UCS 2001). The best available recent summation by the FDA (2010) is about 13,000 t in 2009, or about 80% of the country's total use of these compounds.

Overuse of antibiotics increases the risks of widespread occurrence of antibiotic-resistant bacteria, particularly of the ubiquitous *Escherichia* and *Salmonella*. Zhao et al. (2012) found that in nearly 12,000 meat samples collected between 2002 and 2008, half of *E. coli* bacteria were resistant to tetracycline, more than a third to streptomycin and nearly a quartet to ampicillin, all commonly used to treat people. These decades-old concerns are being addressed by more restrictive rules. In early 2012, the FDA announced its prohibition of any prophylactic use of cephalosporins (antibiotics commonly used to treat human infections, including a still common pneumonia) in livestock and limited the use in farm animals to only two cephalosporin compounds (Gilbert 2012). Perhaps the most worrisome is the recent finding that nearly half of all meat sold in US supermarkets is contaminated with *Staphylococcus aureus*, whose specific genotypes in different meats point to its origin in the animals rather than in the human handlers (Waters et al. 2011).

This species is now infamous for its high degree of antibiotic resistance (96% of samples in studied meats were resistant, more than half of them to at least three different drugs), and its methicillin-resistant strains (MRSA) pose a greater danger to hospitalized patients than their illnesses or operations because that drug has been, in many cases, the last effective treatment. Until recently, MRSA findings in animals were limited to dairy cattle with mastitis, but since 2005 a bacterial clone (CC398, whose origin remains unknown) has been colonizing pigs, calves, dairy cows and broilers (Vanderhaeghen et al. 2010). Obviously, a possibility of this clone, and other virulent microbes, spreading to humans is a major concern. Animal-to-human spread of antibiotic resistance can take place by direct contact with animals as well as through the food chain, and Marshall and Levy (2011) summarize well-documented cases of such transmissions. Modeling suggests that the appearance of antibiotic-resistant commensal bacteria in humans has the greatest impact in the earliest stage of emerging resistance (Smith et al. 2002).

As if these risks were not enough, our dubious commercial choices have created an entirely new disease risk by converting cattle, that paragon of slowly chewing herbivores, into cannibalistic carnivores eating the rendered bodies of their deceased conspecifics. This unnecessary but common practice has been responsible for the genesis of BSE, commonly known as mad cow disease. The origins of the disease remain conjectural, but feeding young calves with meat-and-bone meals rendered from sheep may be a most likely explanation (Smith and Bradley 2003). Its first incidence was noted in the UK in 1986, and it was eventually found in more than 30 countries (mostly in Europe, also in Canada, the US and Japan) and led to prolonged disruptions of international beef trade. Fortunately, the initial fears about the extent of transmission to humans in the form of vCJD proved exaggerated, and the British statistics show 122 confirmed and another 54 probable vCJD deaths between 1990 and the end of 2011, with the peak of 28 cases in the year 2000 followed by a rapid decline to 5 deaths by 2005 (NCJDRSU 2012).

And the concerns about BSE overlapped with worries about a widespread diffusion of poultry-borne influenza. A new influenza subtype H5N1, capable of killing nearly all affected chicken within a few days, was first detected in Hong Kong's poultry markets in April 1997, and the very next year this highly pathogenic form caused the first human death, infecting a three-year-old boy directly without passing through an intermediate host (Sims et al. 2003). By the time that episode ended, 18 people died and 1.6 million birds were slaughtered (Snacken et al. 1999). By 2003, a highly pathogenic subtype H5N1 reappeared, and within three years it spread to both domestic and wild birds throughout East and Southeast Asia, and from there it spread westward all the way to several European countries. Fortunately, the strain was not easily transmissible to humans, and by 2005 there were fewer than 100 deaths in Vietnam, Thailand and Indonesia, but the outbreak forced mass slaughter of infected poultry: 40 million chicken were killed in Thailand in 2004 (Chotpitayasunondh et al. 2004).

This virus will always be with us, spreading from its natural reservoirs in South China's duck flocks (Chen et al. 2004) – and it will also retain its pandemic potential (Li et al. 2004). As a result, we cannot exclude the possibility that a future pandemic influenza (whose timing cannot be predicted but whose return is inevitable) will emanate from domesticated poultry. Between 2003 and 2011, avian influenza killed 343 of the 582 infected people, a very high mortality rate of 59% – and a clear cause for concern should the virus become easily transmissible between humans. In the early months of 2012, the virus again killed a small number of people in China and Southeast Asia. Although it is highly unlikely that high (59%) mortality rate based on the known cases of Asian deaths would not be the norm should H5N1 cause a true pandemic, even mortalities on the order of 1–2% would be enough to cause global death rate higher than in 1918 flu pandemic (Butler 2012). And there are always new concerns: in 2011, a new virus (named Schmallenberg after the German town where it was first found) causing fetal malformations and stillbirths began to spread among ruminant animals in Germany, the Netherlands and Belgium; fortunately, its spread to humans appears unlikely (SMC 2012).