CHAPTER 15

Comparative and Evolutionary Perspectives on Human Brain Growth

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15.1 INTRODUCTION

The evolution of large human brain size has had important implications for many aspects of human biology, including our species' distinctive patterns of growth and development. What is extraordinary about these large brains is their high metabolic costs. As shown in Table 15.1, brain tissue has a very high energy demand per unit weight, roughly 16 times that of muscle tissue.[1,2] On average, adult humans spend some 400 kcal/day on brain metabolism.[1] Yet, despite the fact that humans have much larger brains per body weight than other primates or mammals, the resting energy demands for the human body are no more than for any other mammal of equivalent size.[3] Consequently, humans expend a much larger share of their resting metabolic rate (RMR) to "feed their brains" than other primates or mammals.[4]

To support the high metabolic demands of their large brains, humans have diets of much higher quality — more dense in calories and nutrients — than other primates.[3] On average, humans consume higher levels of dietary fat than other primates[5] and much higher levels of key fatty acids that are critical to brain development.[6,7] Moreover, humans are distinctive in their developmental changes in body composition, having

Table 15.1 Weight, metabolic rate, total energy costs and energy costs as percentage of resting metabolic rate (RMR) for selected organs in the human body

Organ	Weight (kg)	Metabolic rate (kcal/kg/hour)	Total energy costs (kcal/day)	Proportion of RMR (%)
Brain	1.40	12.17	409	23
Liver	1.60	11.88	456	25
Kidney	0.30	15.94	115	6
Skeletal muscle	28.30	0.75	509	28

Source: Data from Holliday,[1] based on a 70 kg adult male.

higher levels of body fatness than other primate species, and these differences are particularly evident early in life.

Humans achieve their large brain sizes through a pattern of brain growth that is also distinctive from other primates. In all primate species (including humans), the brain grows most rapidly before birth. Yet, while brain growth in other primates slows dramatically after birth, in humans, that rapid rate of prenatal brain growth continues for about the first year after birth.[8,9] Consequently, compared to other primates, humans are born relatively "underdeveloped", with brain sizes that are a much smaller proportion of their final adult brain size.[8,10] In addition, the very high energy demands of continued rapid rates of "fetal-like" brain growth during the first year after birth place unique metabolic and nutritional constraints on human infants.

This chapter draws on comparative information from human and primate biology to explore the influence of brain size and metabolism on human growth and development. It begins by examining how variation in brain size influences metabolic demands and dietary/nutritional patterns among modern primates. Next, it briefly considers the ecological and nutritional factors that have promoted the evolution of human brain size. The chapter then examines patterns of early life brain growth in humans and how they differ from those of other primates. Finally, it explores how the high energy demands of brain growth in early childhood shape nutritional needs, patterns of growth and development, and body size and composition.

15.2 COMPARATIVE PERSPECTIVES ON BRAIN SIZE AND METABOLISM

The high energy costs of large human brains are evident in Figure 15.1, which shows the *allometric* (scaling) relationship between brain weight (g) and RMR (kcal/day) for humans, 36 other primate species and 22 non-primate mammalian species. The solid line is the best-fit regression for non-human primate species, and the dashed line denotes the best-fit regression for the non-primate mammals. The data point for humans is shown with a star.

The differences in the regressions imply that for a given metabolic rate, primates have systematically larger brains than other mammals. Humans, in turn, are outliers on the
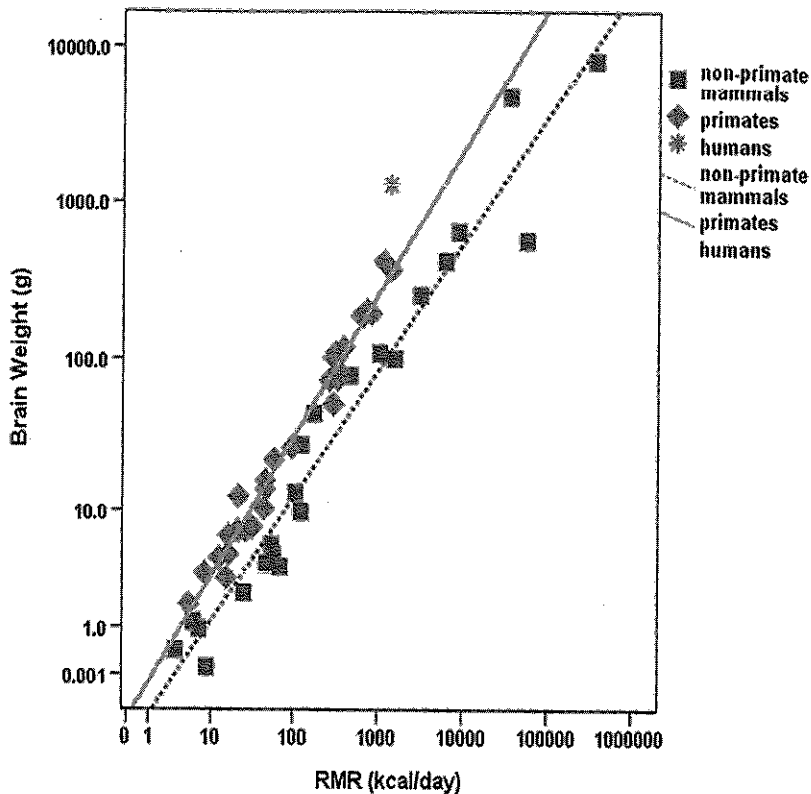
Figure 15.1 Log–log plot of brain weight (BW; g) versus resting metabolic rate (RMR; kcal/day) for humans, 36 other primate species and 22 non-primate mammalian species. The primate regression line is systematically and significantly elevated above the non-primate mammal regression. For a given RMR, primates have brain sizes that are three times those of other mammals, and humans have brains that are three times those of other primates. This figure is reproduced in the color plate section.

primate regression, having much larger brains than expected for their RMR. In caloric terms, this means that brain metabolism accounts for around 20–25% of RMR in adult humans, compared to about 8–10% in other primate species, and roughly 3–5% for non-primate mammals.

To accommodate the metabolic demands of their large brains, humans consume diets that are more dense in energy and nutrients than other primates of similar size.

Figure 15.2 shows the association between dietary quality and body weight in living primates, including modern human foragers. The diet quality (DQ) measure shown here was developed by Sailer et al.,[11] and reflects the relative proportions (by volume) of different types of food source, ranging from low-quality, energy-poor items like leaves, bark and stems, to foods that are higher in quality such as ripe fruit and animal material.
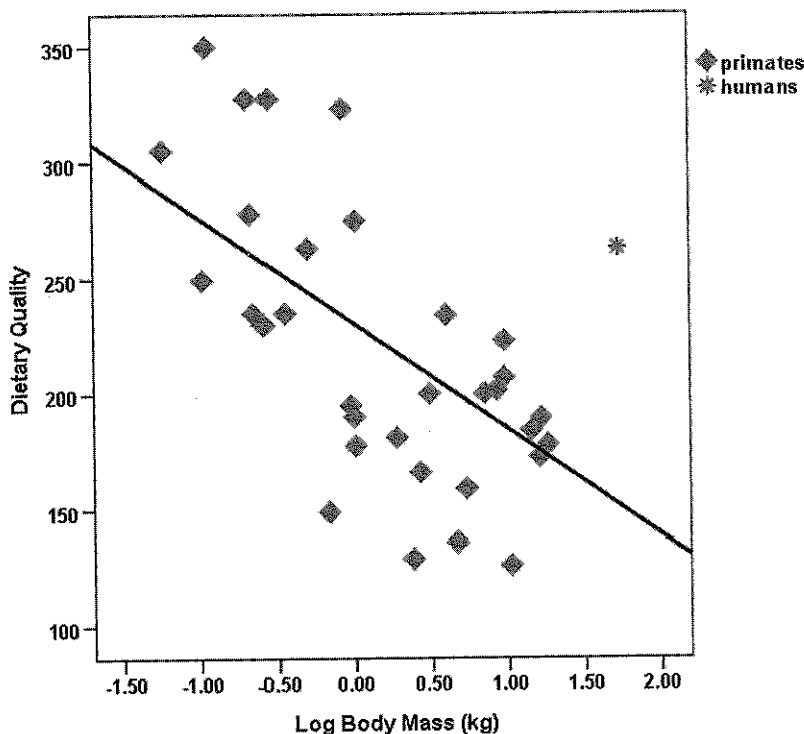
Figure 15.2 Plot of diet quality (DQ) versus log-body mass for 33 primate species. DQ is inversely related to body mass [$r = -0.59$ (total sample), -0.68 (non-human primates only); $p < 0.001$], indicating that smaller primates consume relatively high-quality diets. Humans have systematically higher quality diets than predicted for their size. (Source: *Adapted from Leonard et al.*[4]). This figure is reproduced in the color plate section.

The index ranges from a minimum of 100 (a diet of all leaves) to a maximum of 350 (a diet of all animal material).

There is a strong inverse relationship between DQ and body mass across primates, with smaller primates relying on energy-rich food such as insects, saps and gums, whereas large-bodied primates rely on low-quality plant foods, such as foliage. The diets of modern human foragers fall substantially above the regression line in Figure 15.2, implying that humans have systematically higher DQs than expected for a primate of this size. In fact, the staple foods for all human societies are much more nutritionally dense than those of other large-bodied primates. Although there is considerable variation in the diets of modern human foraging groups, recent analyses by Cordain and colleagues[12] have shown that modern human foragers derive fully 45—65% of their dietary energy intake from animal foods. In comparison, modern great apes obtain the bulk of their diet from low-quality plant foods. Gorillas derive over 80% of their diet from fibrous foods such as leaves and bark.[13] Even among common chimpanzees (*Pan troglodytes*), only

Table 15.2 Proportion of dietary energy intake derived from fat, protein and carbohydrates (CHO) in selected human populations, chimpanzees and gorillas

Species/group	Fat (%)	Protein (%)	CHO (%)	References
Humans (*Homo sapiens*)				
USA (2000)	33	14	53	Briefel and Johnson, 2004[15]
Modern foragers	28—58	19—35	22—40	Cordain et al., 2000[12]
Chimpanzee (*Pan troglodytes*)	6	21	73	Richard, 1985;[13] Tutin and Fernandez, 1992, 1993;[16,17] Popovich et al., 1997[5]
Gorilla (*Gorilla gorilla*)	3	24	73	Popovich et al., 1997[5]

about 5—10% of calories are derived from animal foods, including insects.[14] This higher quality diet means that we need to eat less volume of food to obtain the energy and nutrients we require.

Table 15.2 presents comparative data on *macronutrient* (i.e. fat, protein and carbohydrate) intakes of selected human groups, compared to those of chimpanzees and gorillas living in the wild. The dietary information for human populations was derived from US national data[15] and from a recent review of the diets of present-day hunter—gatherers (foragers) by Cordain et al.[12] Data for chimpanzees and gorillas were derived from foraging studies in the wild[5,13,16,17] and compositional analysis of commonly consumed food items.[5] Today's foraging societies derive between 28 and 58% of their daily energy intakes from dietary fat. Groups living in more northern climes (e.g. Inuits) derive a larger share of their diet from animal foods, and thus have higher daily fat intakes. Conversely, tropical foraging populations generally have lower fat intakes because they obtain more of their diet from plant foods. In comparison, Americans and other populations of the industrialized world fall within the range seen for hunter—gatherers, deriving about one-third of their daily energy intake from fat.[15]

In contrast to the levels seen in human populations, the great apes obtain only a small share of calories from dietary fat. Popovich and colleagues[5] estimate that western lowland gorillas derive approximately 3% of their energy from dietary fats. Chimpanzees appear to have higher fat intakes than gorillas (about 6% of dietary energy), but they are still well below the low end of the modern forager range. Thus, the higher consumption of meat and other animal foods among human hunter—gatherers is associated with diets that are higher in fat and more dense in energy.

Beyond the energetic benefits associated with greater animal consumption, the human diet also provides higher levels of key fatty acids that are critical to brain development. Mammalian brain growth is dependent upon sufficient amounts of two long-chain polyunsaturated fatty acids (LC-PUFAs): docosahexaenoic acid (DHA) and arachidonic acid (AA).[6,7] Species with relatively large brain sizes have greater requirements for DHA and AA.[7] Since mammals have a limited capacity to synthesize these fatty

acids, dietary sources of DHA and AA appear to be limiting nutrients that constrained the evolution of larger brain size in many mammalian lineages.[7,18] Cordain and colleagues[6] have shown that the wild plant foods that make up the diets of most large-bodied primates contain little or no AA and DHA. In contrast, animal foods (e.g. fish, mammalian muscle tissue and organ meat) provide moderate to high levels of these fatty acids.

The link between brain size and dietary quality is seen in Figure 15.3, which shows relative brain size versus relative dietary quality for the 31 different primate species for which metabolic, brain size and dietary data are available. Both the brain size and diet quality measures have been standardized relative to body weight. There is a strong positive relationship ($r = 0.63$, $p < 0.001$) between the amount of energy allocated to the brain and the caloric density of the diet. Across all primates, larger brains require higher quality diets. Humans fall at the positive extremes for both parameters, having the largest relative brain size and the highest quality diet. Thus, the high costs of the large,
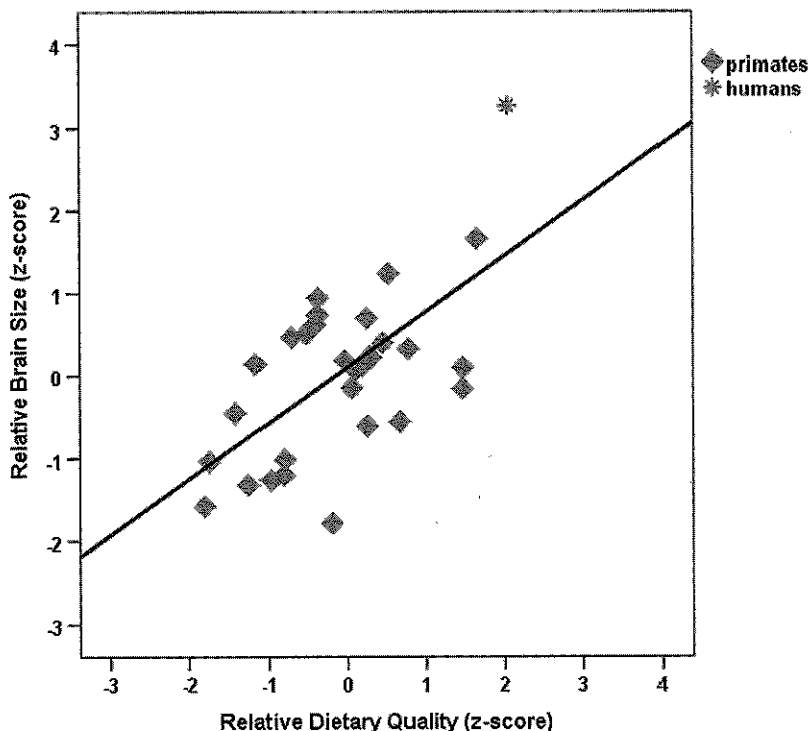
Figure 15.3 Plot of relative brain size versus relative diet quality for 31 primate species (including humans). Primates with higher quality diets for their size have relatively large brain size ($r = 0.63$, $p < 0.001$). Humans represent the positive extremes for both measures, having large brain:body size and a substantially higher quality diet than expected for their size. (Source: *Adapted from Leonard et al.[4]*). This figure is reproduced in the color plate section.

metabolically expensive human brain are partially offset by the consumption of a diet that is more dense in energy and fat than those of other primates of similar size.

This relationship implies that the evolution of large human brains would have necessitated the adoption of a sufficiently high-quality diet (including meat and energy-rich fruits) to support the increased metabolic demands of *encephalization*. Evidence from the human fossil record is consistent with this model: the first major burst of evolutionary change in *hominid* brain size occurred with the emergence and evolution of early members of the genus *Homo* between about 1.7 and 2.0 million years ago (mya) (Table 15.3).[4] Before this, our earlier hominid ancestors, the australopithecines, showed only modest brain size evolution from an average of 400 to 510 g over a 2-million-year span from 4 to 2 mya. With the evolution of the genus *Homo* there was rapid change, with brain sizes of, on average, around 600 g in *Homo habilis* (at 2.4–1.6 mya) and 800–900 g in early members of *Homo erectus* (at 1.8–1.5 mya). Although the relative brain size of *H. erectus* has not yet reached the size of modern humans, it is outside the range seen among other living primate species.

The evolution of *H. erectus* in Africa is widely viewed as a major adaptive shift in human evolution.[19,20] Indeed, what is remarkable about the emergence of *H. erectus* in East Africa at 1.8 million years is that there were (1) marked increases in both brain and body size, and (2) the evolution of human-like body proportions at the same time as (3) a reduction in face and tooth sizes.[21,22] These trends clearly suggest major energetic and dietary shifts: (1) the large body sizes necessitating greater daily energy needs; (2) bigger brains suggesting the need for a higher quality diet; (3) and the facial and dental changes suggesting that they were consuming a different mix of foods from their australopithecine ancestors.

The archeological record provides evidence that this occurred with *H. erectus*, as this species is associated with stone tools and the development of the first rudimentary

Table 15.3 Geological age, brain size, and estimated male and female body weights of selected fossil hominid species

Species	Geological age (mya)	Brain size (g)	Body weight (kg) Male	Female
Australopithecus afarensis	3.9–3.0	438	45	29
Australopithecus africanus	3.0–2.4	452	41	30
Australopithecus boisei	2.3–1.4	521	49	34
Australopithecus robustus	1.9–1.4	530	40	32
Homo habilis	1.9–1.6	612	37	32
Homo erectus (early)	1.8–1.5	863	66	54
Homo erectus (late)	0.5–0.3	980	60	55
Homo sapiens	0.4–0.0	1350	58	49

mya: million years ago.
Source: Data derived from Leonard et al.[4]

hunting and gathering economy. Meat appears to have been more common in the diet of *H. erectus* than it was in the australopithecines, with mammalian carcasses probably being acquired through both hunting and scavenging.[23,24] Increasingly sophisticated stone tools (i.e. the Acheulean industry) emerged around 1.6—1.4 mya, improving the ability of these hominids to process animal and plant materials.[25] These changes in diet and foraging behavior would not have turned our ancestors into carnivores; however, the addition of even modest amounts of meat to the diet (10—20% of dietary energy) combined with the sharing of resources that is typical of hunter—gatherer groups would have significantly increased the quality and stability of the diet of *H. erectus.*

## 15.3 HUMAN BRAIN GROWTH: PATTERNS AND METABOLIC CONSEQUENCES

Large adult human brain size is achieved primarily by extending the rapid, proliferative period of brain growth through the first year after birth. Thus, human infants are born *altrically* (relatively underdeveloped for their age) with a brain size that is a much smaller proportion of final adult size than in other primates. This pattern is evident in Figure 15.4, which shows the relationship between adult brain size and newborn (neonate) brain size in humans and 31 other primate species.[26] On average, adult brain sizes in non-human primates are about 2.3 times the size of those of newborns. Among humans, this ratio is significantly larger — about 3.5 — with brain size increasing from about 400 g at birth to 1400 g in adulthood.[8,9]

Figure 15.5 presents the growth velocities in brain size (g/year) and body size (height; cm/year) for boys and girls under the age of 10 years.[27,28] Growth in both the brain and body is most rapid under the age of 1 year; however, growth rates in the brain decline much more rapidly, such that by 5—6 years of age, children are close to reaching their adult brain sizes.

The high metabolic costs of our large developing brain create nutritional constraints for human infants. During infancy and early childhood, the energy demands of large brains are extreme because brain growth is most rapid and brain:body weight ratios are much larger than in adulthood. These points are highlighted in Table 15.4, which presents age changes in brain size (g), body size (kg), RMR (kcal/day) and percentage of RMR allocated to brain metabolism from birth to adulthood. Whereas brain metabolism accounts for 20—25% of resting needs in adults, in an infant of under 10 kg it is using upwards of 60%.[1]

Figure 15.6 shows the consequences of rapid early life growth in brain and body size for total daily energy requirements in children under 10 years, based on the World Health Organization's most recent recommendations on human energy needs.[29] Total energy needs are standardized per kilogram of body weight, and reflect the combined costs of RMR, growth and activity. Note that during the first few months after birth,
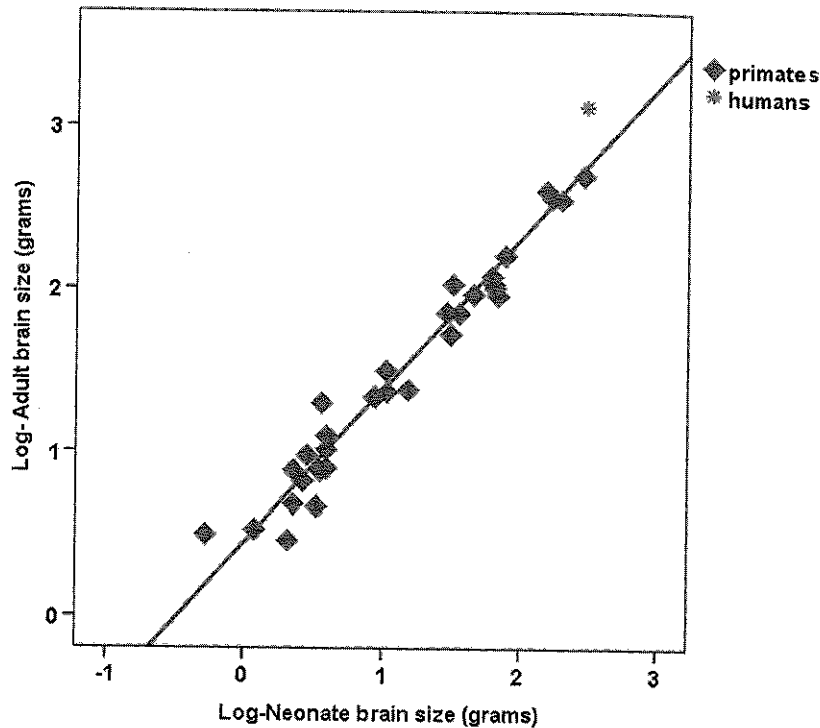
Figure 15.4 Log—log plot of adult brain size (g) versus neonate brain size (g) for humans and 31 other primate species. Brain growth of human infants is much faster than in other primate species. Consequently, adult human brain sizes average about 3.5 times those of newborns, compared to 2.3 times newborn size in other primates. (Source: *Data derived from Barton and Capellini.*[26]). This figure is reproduced in the color plate section.
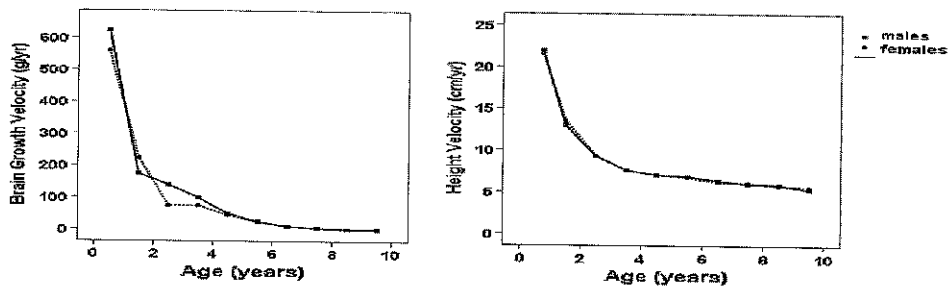

Figure 15.5 Growth velocities of (a) brain size (g/year) and (b) height/length (cm/year) for children 0—10 years of age. Growth rates for both brain and body size are most rapid early in life. Rates of brain growth, however, decline more rapidly than body growth such that by 5—6 years of age, children are approaching their adult brain sizes. (Source: *Brain growth data are from Leigh;*[27] *height growth data from Baumgartner et al.*[28])

Table 15.4 Body weight, brain weight, resting metabolic rate (RMR) and percentage of RMR allocated to brain metabolism (BrMet) for humans from birth to adulthood

Age	Body weight (kg)	Brain weight (g)	RMR (kcal/day)	BrMet (%)
Newborn	3.5	400	161	73
3 months	5.5	650	300	64
18 months	11.0	1045	590	53
5 years	19.0	1235	830	44
10 years	31.0	1350	1160	34
Adult male	70.0	1400	1800	23
Adult female	50.0	1360	1480	27

Source: All data are from Holliday.[1]
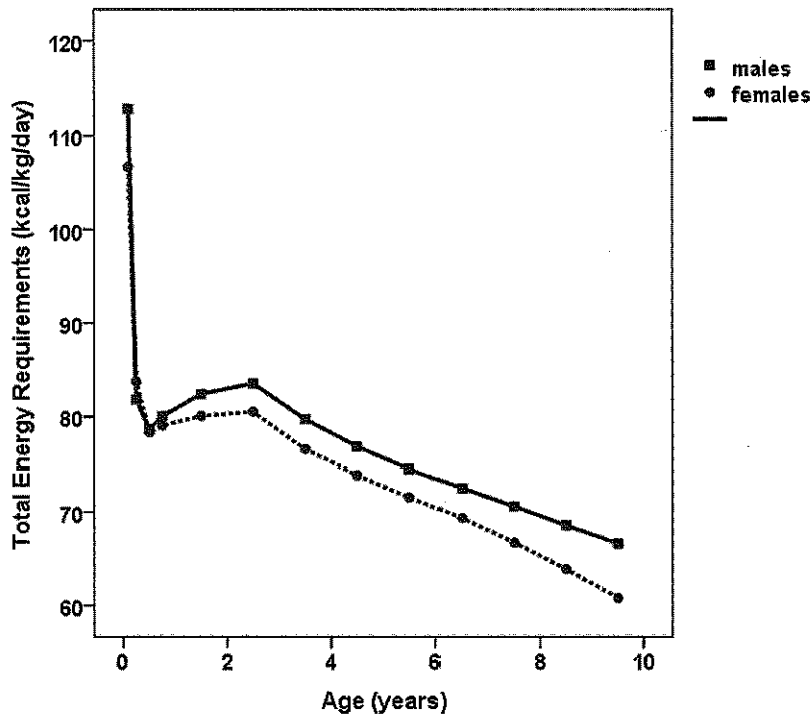
Figure 15.6 Total daily energy requirements (kcal/kg/day) for children 0–10 years of age. Rapid rates of growth in brain and body size contribute to very high energy requirements early in life (>100 kcal/kg/day). By age 10 years, weight-specific energy requirements decline by 40% (65–70 kcal/kg/day), and by adulthood, they are less than half those observed in early infancy. (Source: *Data from FAO/WHO/UNU.*[29])

the energy demands for the developing infant are extraordinary — averaging more than 100 kcal/kg/day in both boys and girls. By the age of 9 years, the energy requirements have declined by about 40% to 70 kcal/kg/day in boys and 65 kcal/kg/day in girls. Once adulthood is reached, daily energy requirements are about 35—40 kcal/kg/day in women, and between 40—50 kcal/kg/day for men.

The high nutrient density and digestibility of breast milk help to support the rapid growth of the brain during early postnatal life. Human breast milk provides about 70 kcal, 4.2 g of fat, 7.3 g of carbohydrate (mostly as the sugar lactose) and 1.3 g of protein per 100 g consumed.[30] The energy and macronutrient content of breast milk varies across populations, with heavier women tending to produce milk with higher fat content.[31] However, the degree of variation in macronutrient composition tends to be small relative to the degree of variation observed in maternal body weight and composition. Consequently, mothers who are marginally nourished may show physiological accommodations (such as utilizing their own fat and muscle stores or reducing their RMRs) during lactation that allow them to produce sufficient quality and quantity of breast milk to support the developing infant.[32]

Breast milk also contains significant amounts of the key essential fatty acids — DHA and AA — that are critical for promoting brain growth. Indeed, greater intakes of these LC-PUFAs are associated with improved brain growth, cognitive development and immune function.[33] In addition, since humans have a limited capacity to synthesize these essential fatty acids, variation in DHA and AA concentrations in breast milk are strongly associated with maternal dietary patterns.[34] Consequently, current dietary guidelines encourage pregnant and lactating women to consume foods containing these LC-PUFAs.[33]

15.4 BRAIN GROWTH AND BODY COMPOSITION

In addition to the nutritional resources provided by breast milk, distinctive aspects of infant body composition help to support the energy demands of the developing brain. Human infants are born with the highest body fat levels of any mammalian species, and continue to gain fat during their early postnatal life.[35,36] These high levels of adiposity in early life thus coincide with the periods of greatest metabolic demand of the brain.

Figure 15.7 shows changes in percentage body fatness during the first 48 months of life based on longitudinal data collected by Dewey and colleagues.[36] From birth to around 9 months, infant body fatness increases from 16% to about 26%. Thus, during early postnatal life, human infants continue to store additional energy as body fat to support their rapidly growing brains. Between 12 and 48 months of age, the period during which children transition from breast milk to solid foods, percentage body fat declines to about 16%.

For young children growing up in impoverished conditions in the developing world, obtaining sufficient energy and nutrients to sustain rapid rates of growth in both the brain
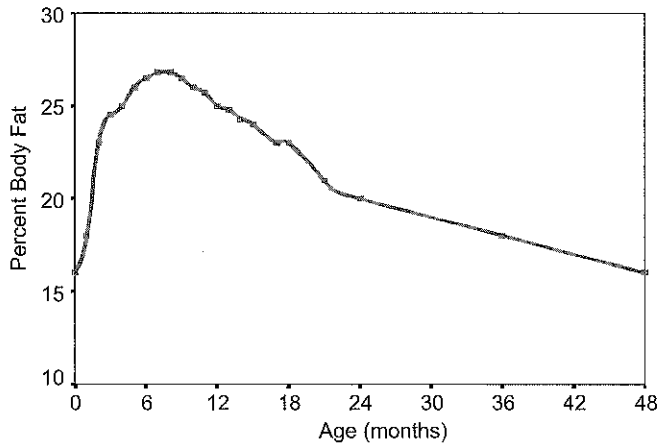
Figure 15.7 Changes in percentage body fatness of human infants from birth to 48 months. Body fatness increases from 16 to 26% during the first 9 months, and then declines to ~16% by 4 years of age. (Source: *Data from Dewey et al.[36]*). This figure is reproduced in the color plate section.

and body can be particularly challenging.[37,38] Research on children in the developing world suggests that chronic, mild to moderate undernutrition has a relatively small impact on a child's fatness. Instead of taking away the fat reserves, nutritional needs appear to be down-regulated by substantially reducing rates of growth in height/length, producing the common problem of infant/childhood "growth stunting" or growth failure that is ubiquitous among impoverished populations of the developing world.[39]

Figure 15.8 shows an example of this process based on growth data collected from young girls of the indigenous population of lowland Bolivia (the Tsimane').[40] Note that early in life the stature of Tsimane' girls closely approximates the US median, but by the
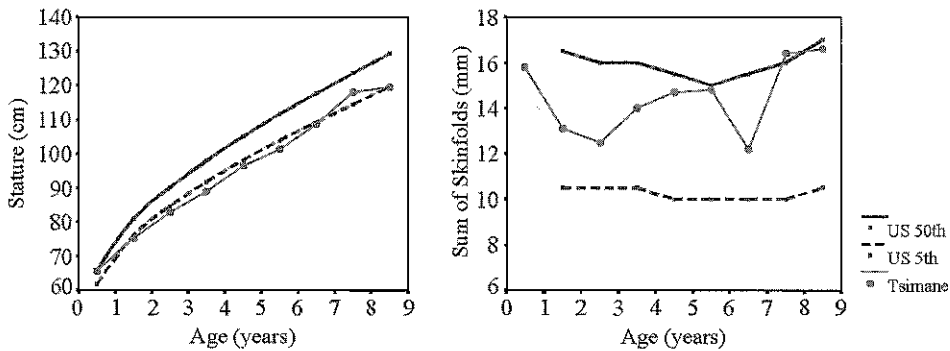
Figure 15.8 Patterns of physical growth in stature (cm) and body fatness (as sum of triceps and subscapular skinfolds, mm) in girls of the Tsimane' of lowland Bolivia. Growth of Tsimane' girls is characterized by marked linear growth stunting, whereas body fatness compares more favorably to US norms. (Source: *Data from Foster et al.[40]*). This figure is reproduced in the color plate section.

age of 3—4 years it has dropped below the 5th centile, where it will track for the rest of life. In contrast, body fatness (as measured by the sum of the triceps and subscapular skinfolds) compares more favorably to US norms, tracking between the 15th and 50th US centiles. The problem of early childhood growth failure is the product of both increased infectious disease loads and reduced dietary quality, which is particularly acute during the weaning period.

Recent work has suggested a mechanism to explain how body fatness is preserved under conditions of early-life growth stunting. Working among impoverished populations of Brazil, Hoffman and colleagues[41] found that children who were growth stunted had significantly lower RMRs and rates of fat metabolism than their "non-stunted" peers. Under resting conditions, the stunted children derived only 25% of the energy needs from fat, compared to 34% in the non-stunted group. These researchers hypothesize that the impaired fat metabolism of the stunted children is associated with a reduction in insulin-like growth factor-1 (IGF-1) that is commonly observed with poor childhood growth.[41,42] IGF-1 has been shown to increase cellular lipid metabolism;[43] hence, significant reductions in IGF-1 during growth can be expected to result in decreased fat consumption.

Overall, key aspects of human growth and development of body composition are shaped by the very high metabolic demands of brain metabolism early in life. Human infants are born altricially and, unlike other primates, continue rapid brain growth into early postnatal life.[9,10] To provide energy reserves for the high metabolic demands of large, rapidly growing brains, human infants are born with high body fat levels, and continue to gain fat during the first year of postnatal life. Furthermore, under conditions of chronic nutritional stress, human infants show the capacity to preserve brain metabolism by (1) down-regulating linear growth, (2) reducing fat oxidation, and (3) increasing fat storage. These adaptive responses are evidenced in the preservation of body fatness among "growth-stunted" children, and in the tendency of stunted children to gain weight and body fatness later in life.[44]

15.5 SUMMARY

The evolution of large human brain size has had important implications for the biology of our species. Humans expend a much larger share of their resting energy budget on brain metabolism than other primates or non-primate mammals. Comparative analyses of primate dietary patterns indicate that the high costs of large human brains are supported, in part, by diets that are relatively rich in energy and fat. Compared to other large-bodied apes, modern humans derive a much larger share of their dietary energy from fat. Among living primates, the relative proportion of metabolic energy allocated to the brain is positively correlated with dietary quality. Humans fall at the positive end of this relationship, having both a very high-quality diet and a large brain.

The human fossil record indicates that major changes in both brain size and diet occurred in association with the emergence of the genus *Homo* between 2.0 and 1.7 mya in Africa. With the evolution of early *H. erectus* 1.8 mya, there is evidence of an important adaptive shift: the evolution of the first hunting and gathering economy, characterized by greater consumption of animal foods and sharing of food within social groups. *Homo erectus* was human-like in body size and proportions, and had a brain size beyond that seen in non-human primates, approaching the range of modern humans. In addition, changes in the face and teeth of *H. erectus*, coupled with its more sophisticated tool technology, suggest that these hominids were consuming a higher quality and more stable diet that would have helped to fuel the increases in brain size.

Humans achieve their large brain sizes through a growth pattern that is distinct from that of other primates. In humans, very rapid brain growth that is typical of the fetal period is extended through the first year of postnatal life. The rapid rates of growth in both brain and body size contribute to very high daily energy requirements during infancy and early childhood. To accommodate these high metabolic demands, human infants are born with high levels of body fat and continue to gain fat during the first year of life.

Under conditions of nutritional stress, human infants and toddlers preserve body fat reserves for brain metabolism by reducing rates of linear growth. This process of "linear growth stunting" is also associated with reduced rates of fat oxidation and increased rates of fat storage. Thus, humans appear to show important adaptations in fat metabolism to accommodate the high energy demands of the brain early in life.

Ongoing research is providing new insights into variation in patterns of brain growth and its behavioral correlates, as well as differences in the metabolic costs of brain growth. For example, recent population-based studies of normal brain growth using magnetic resonance imaging (MRI) are now allowing researchers to explore more directly the biological and behavioral correlates of differences in brain development.[45] Similarly, through the use of positron emission tomography (PET scans), researchers can quantify patterns of variation in the metabolic costs of the brain and other organs by measuring rates of blood flow and glucose uptake.[46] Thus, the broader use of newer medical imaging techniques is expanding our understanding of brain growth and function, and providing key insights into the evolution of human brain size and behavioral complexity.

GLOSSARY

Allometry (scaling): The change in size of one biological measure with respect to another (often body size).

Altricial: Being relatively "underdeveloped" for one's chronological age.

Encephalization: Brain size in relation to body size. In general, primates are more encephalized than other mammals.

Hominids: Living humans and our fossil ancestors that lived after the last common ancestor between humans and apes.

Macronutrients: Dietary compounds required in large amounts, which can be used as sources of energy (calories). These include proteins, fats and carbohydrates.

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INTERNET RESOURCES

Becoming human: http://www.becominghuman.org/
Better brains for babies: http://www.fcs.uga.edu/ext/bbb/
Brain net: http://www.brainnet.org/
CDC growth charts: http://www.cdc.gov/growthcharts/clinical_charts.htm
MRI study of normal brain development: http://www.brain-child.org/home.htm
My Plate (USDA dietary guidelines): http://www.choosemyplate.gov/
Resources for the study of the brain: http://brainmuseum.org/
World Health Organization breastfeeding: http://www.who.int/topics/breastfeeding/en/
WHO child growth standards: http://www.who.int/childgrowth/en/index.html
Zero to three (National Center for Infants, Toddlers & Families): http://www.zerotothree.org/

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SECOND EDITION

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