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Anatomical and Physiological Characteristics of Early and Preschool-Age Children

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Abstract Early childhood (infancy to preschool age) is marked by rapid and non-linear growth, with striking anatomical and physiological differences compared to adults. This review synthesizes literature on pediatric anatomy and physiology for children ~0–6 years old. Key findings include disproportionate growth of the head and brain (brain weight ~25% of adult size at birth, body weight ~5%), rapid postnatal brain development and myelination, and open cranial sutures/fontanels. Bone tissue in children is highly vascular and elastic, with thick periosteum and growth plates enabling rapid lengthening; bone is more porous and flexible than in adults. Skeletal muscles constitute ~25% of a newborn's body weight (vs ~40–43% in adults) and have higher tone and lower strength; muscle fibers thicken and increase in number with age. The pediatric airway is smaller in diameter with a relatively larger tongue and long floppy epiglottis, predisposing infants to airway obstruction. Respiratory physiology is distinct: neonates have lower functional residual capacity and higher metabolic O_2 demand, and newborn lungs contain ~150 million alveoli (about half the adult number). Cardiovascularly, the child's heart is less compliant and output is heart-rate–dependent; heart rate is high (e.g. 140–160 bpm in neonates) while blood volume and blood pressure are low relative to adults. These system-specific trends reflect developmental priorities (e.g. rapid neural growth early, later musculoskeletal strengthening) and imply unique clinical considerations. In conclusion, pediatric anatomy and physiology undergo dramatic changes through early childhood, underscoring that "a child is not a small adult.

Keywords Pediatric development, Anatomy, Physiology, Infancy, Preschool, Growth, Organ systems

1. Introduction

Children in the first years of life exhibit unique anatomical and physiological features that differ fundamentally from adults. Rapid growth occurs during infancy and early childhood, but the pattern is heterogeneous ("heterochronous"), with spurts and plateaus in different organs and tissues. For example, brain growth and craniofacial development are accelerated after birth, while sexual maturation occurs much later. This review presents a detailed account of anatomical proportions and organ function in early and preschool-age children, highlighting key differences from adult physiology. Understanding these differences is crucial for pediatric healthcare, as well as for designing age-appropriate medical devices and therapies. This article is based on a synthesis of pediatric literature, including textbooks and recent clinical reviews, and draws on the provided foundational content. Our objective is to describe system-by-system features of the nervous, skeletal, muscular, respiratory, and cardiovascular systems (among others) in young children, and to discuss the developmental trends these differences imply.

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2. Methods

We performed a narrative review of pediatric anatomy and physiology, focusing on infancy through preschool age. Relevant sources were identified via searches in medical databases (e.g. PubMed, Google Scholar) using keywords like "child anatomy early childhood," "pediatric physiology differences," and "infant growth development." The Russian-language manuscript "Анатомо-физиологические особенности детей раннего и дошкольного возраста" served as a conceptual guide, supplemented by published reviews and textbooks. Data on growth charts, organ proportions, and age-specific physiology were extracted from authoritative references. Key findings are presented by organ system, with citations to peer-reviewed studies where available. No original experimental or human subject research was conducted; the article is based on secondary literature synthesis.

3. Results

Growth and Body Proportions

Infants grow extremely rapidly but unevenly. From birth to 2 years, body weight roughly triples, and height increases from about 50 cm to 75 cm in the first year. By age 4, total length is roughly twice that at birth [1]. The head and brain are disproportionately large: at birth the brain is ~25% of adult size while body weight is ~5%, and infant head length is about 25% of body length (nearly twice the adult ratio). The brain's postnatal growth is rapid (half of adult volume by age ~1–2 years) and cortical gyrification (sulci and gyri) deepens in early childhood. In contrast, other body regions (e.g. limbs, genital organs) grow more slowly initially. Newborns typically lose some weight after birth then regain it, doubling birth weight by ~5–6 months and tripling it by 1 year [1].

These growth patterns reflect prioritization of neural development early, with skeletal and muscular systems gaining later.

Nervous System

The infant nervous system is structurally and functionally immature. The neonatal brain is high in water content and low in myelination; its gray and white matter are poorly differentiated at birth. Myelination of major pathways (e.g. pyramidal tracts) continues postnatally, generally completing in different regions between 2 and 7 years of age. The cerebral cortex undergoes intense growth of dendrites and synapses in the first years, with corresponding deepening of sulci and expansion of cortical surface. As a result, the newborn's head is soft and compliant: fontanels (e.g. posterior by ~2 months, anterior by 12–18 months) and wide sutures allow cranial expansion with little resistance. The skull bones are thin and deformable. Early reflexes (sucking, grasping, Moro, Babinski, etc.) are strong but gradually replaced by higher cortical control; neonates rely on midbrain and brainstem for vital functions as the cortex is underdeveloped. Sensory organs also differ: taste is relatively well developed (infants prefer sweet flavors), while the olfactory sense is still maturing. Neurophysiologically, infants have high cerebral blood flow and metabolic rate per brain mass, but lower intracranial pressure (ICP) and blood pressure (BP) norms than adults. Importantly, children cannot be treated as "small adults" in brain or spinal injuries, since their cranial anatomy and hemodynamics are fundamentally different. For example, the infant's large head (relative to body) and pliable skull mean impacts distribute force differently; the airway and chest protection are also less robust. Overall, neural development is rapid early on, with most cortical areas reaching near-adult synaptic density by the toddler years.

Skeletal System

Children's bones differ markedly from adult bones. They contain more porous, collagen-rich matrix and have wider Haversian canals. The long bones have thick growth (epiphyseal) plates that allow lengthening; these cartilage layers remain until the second decade. The periosteum (outer covering) is very thick and osteogenic in children, facilitating rapid remodeling. Bones are more elastic and deformable: minor bending (greenstick) or buckling (Torus) fractures are common rather than complete breaks. The thick periosteum restrains fragment displacement and promotes healing. Pediatric bone heals quickly, often better than adult bone, as the plentiful stem cells in growing bone actively generate new tissue [2]. The ratio of cartilage to ossified bone is higher in infancy, which explains why newborn skulls have fontanels and why their vertebrae are not yet fused. Over the preschool years, vertebral and limb bone morphology gradually assumes the adult configuration (e.g. the cervical spine curvature is set by age ~7, lumbar by ~12). In summary, the pediatric skeleton is characterized by ongoing endochondral ossification, open growth plates, and a structure that is lighter and more resilient (though relatively weaker) than in adults. These features underlie the ease of bone growth and the predisposition to certain pediatric fracture patterns [2].

Muscular System

Muscular development is also age-dependent. At birth, skeletal muscle makes up roughly 25% of an infant's body mass, rising to about 40–45% in a mature adult. Newborn muscles are relatively small in cross-section and less powerful. Infants exhibit a physiological hypertonia: muscle tone (especially flexor tone) is high in the first months, causing limbs to be flexed at rest; this gradually normalizes by about 6–12 months. As an infant matures, muscle fibers thicken (hypertrophy) and in some studies may even increase in number (hyperplasia). Gross motor milestones (lifting head, rolling, sitting, crawling, walking) appear in a cranial-to-caudal sequence linked to neuromuscular maturation. Initially, axial and neck muscles gain strength before limb muscles; proximal (shoulder/hip) muscles develop before distal (hands/feet) muscles. Overall, a young child's muscles produce less absolute force and faster fatigue than an adult's, reflecting lower muscle mass fraction and incomplete neuromuscular control [3].

Respiratory System

The pediatric respiratory anatomy and function show important differences. The airway is small in diameter: an infant's narrowest point is the subglottic cricoid region (unlike the adult glottis). Key pediatric airway features include a relatively larger tongue, a more anterior and cephalad larynx, and a long, floppy, omega-shaped epiglottis [4]. Notably, infants have an obligate nasal-breathing tendency because of a low soft palate and enlarged epiglottis that together separate nasopharynx and hypopharynx. These traits predispose children to airway obstruction (from secretions, edema or positioning) much more readily than adults. The large occiput of infants also tends to flex the neck when supine, worsening airway compromise. Pulmonary mechanics differ as well. Newborn rib cages are very compliant and ribs are almost horizontal, so infants have a lower functional residual capacity (FRC). The diaphragm is higher and chest wall more flexible, so infants breathe predominantly by diaphragmatic motion. Respiratory muscles are less efficient (higher proportion of fatigue-prone fibers). Metabolic oxygen demand is 2–3 times higher per kg in infants, so ventilation-perfusion matching must be efficient; however, infants have fewer alveoli and a smaller total lung volume. At birth, the lungs contain roughly 150 million alveoli – only about half the adult number – with the remainder forming in early childhood. Therefore, children have higher airway resistance (resistance $\propto 1/\text{radius}^4$) and tire more quickly under stress. These anatomical and physiological differences mean pediatric patients are prone to rapid desaturation during apnea or airway obstruction. However, the extensive potential for alveolar growth suggests some capacity for recovery if early lung injury is avoided.

Cardiovascular System

Cardiac anatomy and hemodynamics also vary with age. A child's heart is large relative to body size (e.g. it comprises a larger percentage of body weight in early childhood than in adults). The neonate's myocardium is less compliant and contains fewer contractile elements per mass. Consequently, cardiac output is almost entirely heart-rate dependent: infants cannot appreciably increase stroke volume because ventricular filling is limited [5].

The normal neonatal heart rate is high (around 120–160 beats/minute in full-term neonates), and it gradually decreases to adult rates by the end of early childhood. In fact, adults respond to stress primarily by increasing heart rate (due to sympathetic tone), whereas neonates have a predominance of vagal tone and are more susceptible to bradycardia under stress. Blood pressure norms are also age-specific: children have lower baseline arterial pressures than adults, rising steadily through childhood. For example, a normal systolic BP might be 70–80 mmHg in a neonate but ~90–100 mmHg by 2–3 years. Blood volume is relatively small in infants, about 75–80 mL/kg (versus ~70 mL/kg in adults), meaning that even a small hemorrhage causes proportionately greater volume loss. Pediatric vessels are more elastic; systemic vascular resistance is higher at birth due to closure of the placenta after birth. The fetal shunts (ductus arteriosus, foramen ovale, ductus venosus) normally close in the days after birth, but for a time the infant's circulation remains transitional and less stable. In summary, children compensate for circulatory challenges primarily through tachycardia (until a point) and have narrower safety margins for blood loss or fluid shifts compared to adults. Other organ systems (digestive, renal, endocrine, immune) also differ in infancy, but a few highlights include: the gastrointestinal tract grows rapidly (with digestive enzyme systems maturing by ~3–4 years), the kidneys have low concentrating ability (premature infants lack mature nephrons), and the skin has a higher water content and surface area:mass ratio, making infants prone to dehydration and heat loss. Collectively, these system-level features illustrate that an early-childhood child is anatomically and physiologically distinct from an adult.

4. Discussion

The anatomical and physiological traits of early childhood form a coherent developmental pattern. Critically, the priorities of growth change over time: brain and head growth dominate in the newborn period, whereas somatic growth (bones, muscles) and immune development continue through the preschool years. The disproportionately large infant head and high brain metabolic rate mean that neural development drives whole-body demands in the first 1–2 years. This explains why the brain reaches ~75% of adult volume by age 2. Once neural systems have laid down sensory, motor, and cognitive capabilities, growth focus shifts to the musculoskeletal and organ systems. Bone growth plates allow continued height increase until adolescence, muscle bulk increases gradually, and visceral organs (heart, lungs, kidneys) enlarge and mature functionally. Functionally, many pediatric homeostatic mechanisms are "immature" or governed by developmental constraints. For example, thermoregulation is delicate in infants because of high body-surface-area ratio and low subcutaneous fat. The combined effect of small absolute blood volume and flexible vasculature means infants maintain blood pressure differently. The high resting heart rate and limited stroke volume increase (as shown in statPearls) reflect an adult-level sympathetic response threshold that has yet to mature. In the respiratory system, the adaptive significance of newborn airway anatomy (e.g. nasal breathing reflex, laryngeal shape) may relate to the need to feed and breathe simultaneously, but also complicates sedation and airway management. Importantly, recognizing these differences has practical implications. Clinicians must interpret vital signs (heart rate, BP, respiratory rate) against age-based norms, not adult values. Drug dosing and fluid resuscitation must account for higher metabolic rates and body water content. Pediatric fractures and bone injuries follow different patterns due to the elastic skeleton. Developmental milestones in gross and fine motor skills directly follow the anatomical maturation of muscles and nerves.

Across systems, a unifying theme is that children's physiology is in flux. Many reference values (for lab tests, imaging, etc.) evolve with age. The potential for plasticity (e.g. bone remodeling, ongoing alveologenesis [6]) is greater in early life, offering both resilience and vulnerability: injuries or exposures in infancy can have long-term consequences (e.g. on neurodevelopment or lung function), yet recovery potential may also be higher if managed correctly. Research in pediatric pathology or critical care often emphasizes that findings in adults cannot simply be scaled down; they must be studied in the context of these developmental norms. In interpreting our results, one limitation is the focus on broad patterns rather than individual variation. Socioeconomic factors, nutrition, and genetics can modulate growth and development. Also, much of pediatric physiology is age-continuous: a 1-year-old differs from a 3-year-old, who differs from a 7-year-old. For brevity, this review aggregates "early childhood" as a group, but in practice each year has its own profile. Finally, while we drew on the provided Russian manuscript for structure, we corroborated points with international literature to ensure accuracy.

5. Conclusions

Young children differ fundamentally from adults in anatomy and physiology. Early infancy is characterized by rapid brain and head growth, developing reflexes and sensory pathways, and flexible skeletal structures. Muscle mass and functional capacity are initially low but increase steadily. Respiratory and cardiovascular systems operate at high rates (heart rate, respiratory rate) with low absolute volumes, reflecting immature mechanics and a heavy reliance on compensatory mechanisms. These developmental features result in a high degree of plasticity but also require that pediatric care be tailored to age-specific norms. In summary, pediatric physiology follows distinct trends (e.g. rapid early neural maturation followed by musculoskeletal growth) that underscore the axiom that children are not just small adults but a dynamically evolving population.

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