Anatomy of the Infant and Child

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P. Puri (ed.), *Pediatric Surgery*,
https://doi.org/10.1007/978-3-662-43588-5_5

Abstract

There are key differences between the anatomy of the child and adult, most marked in newborn infants. These differences affect the accuracy of surface anatomical landmarks, surgical approaches and procedures, physiological and cardiorespiratory parameters and responses, and the ability to compensate for congenital malformations and/or the effects of surgical treatment. Anatomical differences in children that are particularly relevant to pediatric surgeons are discussed using a systems approach, focusing on growth and proportions, cardiovascular and respiratory systems, the abdominal wall and gastrointestinal tract, and the genitourinary, musculoskeletal, and nervous systems.

Keywords

Anatomy · Neonatal anatomy · Infant anatomy · Clinical anatomy

Introduction

A newborn infant more than triples in length, and its weight increases some 20-fold in the process of reaching maturity. During development, a few structures involute, while most change in size and/or position. Consequently, the anatomy of the child, and especially the infant, differs from adults (Table 1 and Fig. 1). This chapter summarizes the key differences between the anatomy of the child and adult that are *most relevant in pediatric surgery.*

Growth and Proportions

The growth of an individual from its earliest stage to maturity results in an increase in size and mass and includes cellular processes such as division, differentiation, and apoptosis (Sinclair and Dangerfield 1998). Growth is often proportional. Thus, the pelvis and lower limbs in a neonate are proportionately small (Diméglio 2006). However, growth may be differential. For example, the head of a full-term newborn infant accounts for about 25% of body length and 20% of body surface area, but corresponding figures in an adult are about 13% and 9%, respectively (Fig. 2). The ratio of body surface area to weight decreases with age: the surface area of a neonate is about 0.25m^2 compared to the average adult value of 1.73 m^2. Consequently, neonates are more vulnerable to heat loss.

The mean length of a full-term newborn measured from crown to heel is around 48–50 cm and birth weight 3.4 kg (normal range 2.7–4.6 kg), but there are variations between ethnic groups. The mean birth weight of a baby born in the United Kingdom to parents from the Indian subcontinent is about 400 g less (Kelly et al. 2009). Growth weight and height velocity are maximal in early infancy and peak again at puberty. Mean body weight at 3 years is around 13–15 kg and at 10 years is about 30–35 kg.

About 75–80% of a newborn's weight is water and 15–28% is fat (Standring 2008); by 1 year of age, total body water has decreased to adult values of around 60% of body weight.

Cardiovascular System

The Fetal Circulation

In the fetus, the lungs and airways are fluid filled, and the placenta regulates oxygen supply and carbon dioxide removal (▶ Chap. 12, "Pediatric Cardiovascular Physiology"). The fetus is

Table 1 Key anatomical differences between infants and adults

Cardiovascular system	Recent transition from fetal circulation
	Relatively large heart
	Potential for congenital heart defects
	Prominent thymic shadow on chest X-ray
Respiratory system	Obligate nose breathing
	Short neck with high larynx
	Ability to breathe whilst suckling
	Subglottis is the narrowest part of the airway
	Highly compliant chest wall
	Greater reliance on diaphragm for breathing
Abdomen	Relatively wide abdomen
	Short inguinal canal
	Propensity to inguinal hernias and undescended testes
	Small amount of intra-abdominal fat
	Proportionately large liver
	Poor radiological distinction between small and large bowel
	Small pelvic cavity
	Intra-abdominal bladder and body of uterus
	Proportionately large suprarenal glands
Musculoskeletal system	Proportionately large head, small pelvis, and lower limbs
	Open fontanelles
	Relatively underdeveloped face and mandible
	Horizontal auditory tube
	No spinal curvatures (other than shallow sacral curve)
	Absence of most secondary ossification centers
	Shallow and relatively larger acetabulum
	Relatively small gluteal muscles
Nervous system	Relatively large brain with full complement of neurons but
	incomplete myelination of axons
	Proportionately large cerebral ventricles
	Spinal cord terminates at lower level
Skin	Variable subcutaneous fat (with some brown fat)
	Thin skin, immature sweating
	Greater body surface area to weight ratio
	Head accounts for 20% of body surface area

relatively hypoxemic; the partial pressure of oxygen in the umbilical vein is around 4.7 kPa (35 mmHg) and SaO_2 80–90% (Murphy 2005). Oxygen delivery is maintained by a high concentration of fetal hemoglobin (which binds oxygen with greater affinity than adult hemoglobin) along with a relatively high cardiac output. Fetal blood is transported from the placenta via the umbilical vein to the left branch of the portal vein lying within the umbilical recess of the liver (Fig. 3). The ductus venosus arises from the posterior aspect of the left branch of the portal vein directly opposite the opening of the umbilical vein and passes superiorly and laterally between the left lobe and the caudate lobe of the liver to terminate in the left hepatic vein near its entry into the inferior vena cava (IVC). About 50–60% of umbilical venous blood flow passes directly through the ductus venosus, bypassing the hepatic circulation (Murphy 2005). A valve around the margin of the opening of the IVC into the right atrium directs this relatively well-oxygenated

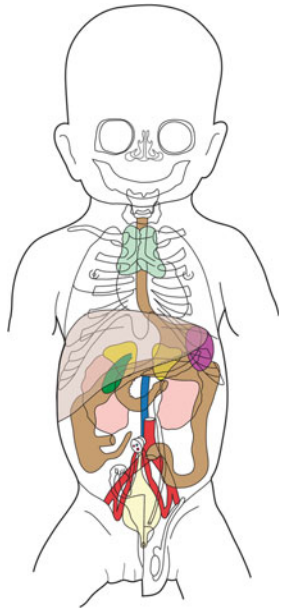

Fig. 1 Diagram illustrating the relative proportions of viscera in the newborn (Adapted from Crelin 1973, p. 75)

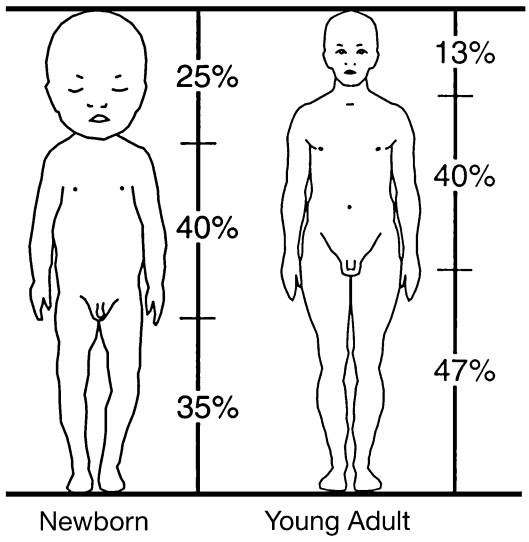

Fig. 2 The relative proportions of the head, trunk, and lower limbs in a neonate and adult (Adapted from Diméglio 2006, p. 40)

blood from the placenta through the foramen ovale into the left atrium. Better oxygenated blood is therefore ejected from the left ventricle to supply the fetal coronary circulation and brain. Desaturated systemic blood returning from the fetal superior vena cava and coronary sinus is directed preferentially to the right ventricle. However, a high pulmonary vascular resistance and the presence of a patent ductus arteriosus result in less than 15% of the fetal combined ventricular output reaching the lungs (Archer 2005). The ductus arteriosus shunts blood from the bifurcation of the pulmonary trunk into the aortic arch, just distal to the origin of the left subclavian artery. At term, the ductus arteriosus is about 8–12 mm long and 4–5 mm wide at its origin from the pulmonary trunk; the thoracic aorta by comparison measures about 5–6 mm in diameter (Standring 2008). The walls of the ductus arteriosus are rich in smooth muscle. Ductal patency is maintained by locally produced prostaglandins, which inhibit muscle contraction in response to oxygen.

Circulatory Changes After Birth

At birth, clamping of the umbilical cord increases peripheral vascular resistance and left-sided cardiac pressures and decreases right-sided cardiac pressures. The lungs inflate, and, as a result of this along with oxygen-induced pulmonary vasodilatation (mediated via nitric oxide), pulmonary vascular resistance falls dramatically. The ductus arteriosus also begins to close. Blood is therefore diverted from the pulmonary trunk into the pulmonary circulation. Increased venous return to the left atrium causes a rise in left atrial pressure. Right atrial pressure falls as a result of reduced venous return secondary to occlusion of the umbilical vein. These changes in atrial pressure force the free margin of the primary atrial septum to flatten against and subsequently adhere to the upper margin of the fossa ovalis, resulting in functional closure of the foramen ovale. A permanent seal usually develops during the first year of life.

Cardiovascular adaptation to neonatal life therefore requires the functional closure of three fetal conduits:

- *Foramen ovale*. Functional closure of the foramen ovale occurs immediately after birth

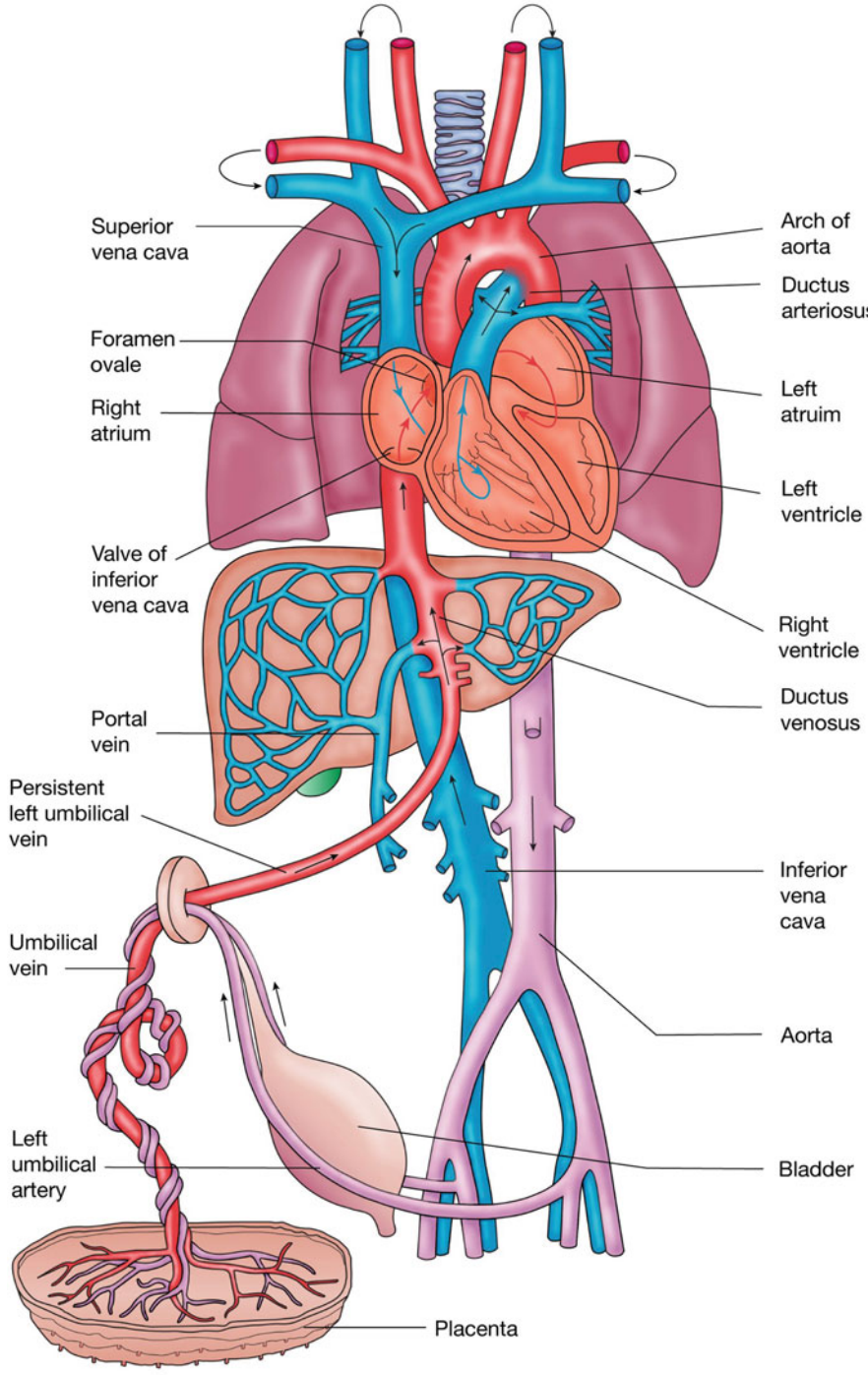

Fig. 3 The fetal circulation

consequent on differential atrial pressures; permanent anatomical closure usually follows in early infancy. Incomplete fusion of the primary atrial septum with the limbus of the fossa ovalis occurs in up to 25% of individuals (Hagen et al. 1984), resulting in a small potential atrial communication, a patent foramen ovale (PFO). Typically this has no consequences because of the flap-like arrangement of the opening and differential atrial pressures. However, a PFO may rarely be associated with paradoxical embolism (passage of an embolus from the venous system through an abnormal communication between the chambers of the heart causing a systemic arterial embolus, e.g., an embolic stroke) and an increased risk of decompression sickness in divers (Holmes et al. 2009). After closure of the foramen ovale, the valve of the IVC that was prominent in the fetus becomes flimsy or disappears.

- *Ductus arteriosus*. In the full-term neonate with no congenital heart disease, the ductus arteriosus starts to close immediately after birth. Smooth muscle contraction within the ductus is probably mediated by several mechanisms: an increased arterial oxygen concentration, suppression of endogenous prostaglandin E2 synthesis, plasma catecholamines, and neural signaling. In addition, ductal blood flow is reversed as a result of increased systemic vascular resistance (due to the absence of the placental circulation) and decreased pulmonary vascular resistance. Functional closure of the ductus is complete within 3 days in more than 90% of term infants (Evans and Archer 1990). Structural closure occurs more gradually, leaving the fibrous ligamentum arteriosum connecting the bifurcation of the pulmonary trunk (near the origin of the left pulmonary artery) to the underside of the aortic arch. The prevalence of a patent ductus arteriosus persisting beyond 72 h of age is inversely related to gestational age and weight. It is relatively rare in term neonates but occurs in 80% of infants weighing less than 1200 g at birth (Dice and Bhatia 2007). Persistent ductal shunting is particularly common in preterm infants, especially those with respiratory distress syndrome (Evans and Archer 1990).
- *Ductus venosus*. Spontaneous closure of the ductus venosus begins immediately after birth (Meyer and Lind 1966) and is usually complete by about 17 days of age (Loberant et al. 1992; Fugelseth et al. 1997). Closure may be temporarily delayed in the presence of congenital heart disease, presumably as a result of elevated venous pressure. In the adult, a fibrous remnant, the ligamentum venosum, runs within the fissure separating the left lobe of the liver and the caudate lobe. Persistent patency of the ductus venosus is rare, but more common in boys, and may cause long-term problems such as hepatic encephalopathy (Stringer 2008).

The Heart

In the full-term neonate, mean systolic blood pressure in the first week of life is 70–80 mmHg (lower in preterm infants), heart rate is 120–140 beats/min, and cardiac output measured by Doppler ultrasound is about 250 mL/kg/min. As the pulmonary circulation is established, the work of the right side of the heart decreases and the left increases, resulting in changes in ventricular muscle thickness. At birth, the mean wall thickness of both ventricles is about 5 mm, whereas in adults the left ventricle is about three times as thick as the right (Standring 2008). The neonatal heart is relatively large in relation to the thorax, and it occupies a larger proportion of the lung fields on a chest radiograph compared to an adult (Fig. 4).

Congenital cardiac malformations (8 per 1000 live births (Archer 2005)) account for up to a quarter of all developmental anomalies. They include dextrocardia (isolated or part of situs inversus), isomerism, and structural defects (septal defects, abnormal atrioventricular or ventriculoarterial connections, and valvular anomalies). Ventriculoseptal defects are the most frequent, more often affecting the membranous part of the interventricular septum than the muscular part. A true atrial septal defect occurs when there is a failure of normal development of the septum

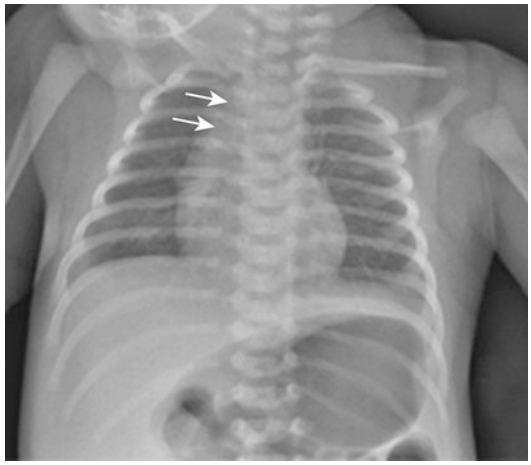

Fig. 4 Supine anteroposterior neonatal chest radiograph. Note the prominent superior mediastinal thymic shadow which is asymmetric on this rotated film (*white arrows*). Compared to an adult, the hemidiaphragms are relatively flat, the ribs are more horizontal, and the heart size is relatively large (although the transverse cardiothoracic ratio should still be less than 60% (Arthur 2001))

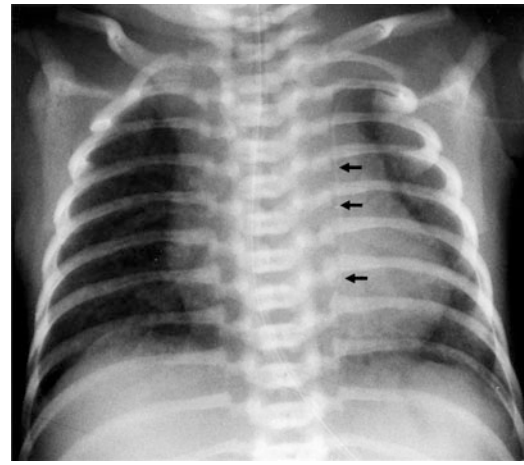

Fig. 5 A peripheral long line lying within a left-sided superior vena cava (*arrows*) in a neonate

primum and/or atrioventricular endocardial cushions. Coarctation of the aorta is often included within the spectrum of congenital heart disease even though it affects the aorta. Typically, there is narrowing or occlusion of the juxta-ductal segment of aorta just distal to the origin of the left subclavian artery although preductal (involving the aortic arch and its major branches) and even postductal coarctation can occur.

Central Veins

Central venous catheters in children are generally positioned such that the catheter tip lies just outside the cardiac silhouette on a chest radiograph, typically at the junction between the superior vena cava (SVC) and right atrium. This is in order to reduce the small but serious risk of atrial perforation and cardiac tamponade from migration of the catheter tip. The upper right atrium may be an acceptable position for the catheter tip in some cases, especially if it is envisaged that the catheter will be in place long enough for the child to grow substantially or if the catheter is to be used for hemodialysis. The catheter tip should not be positioned in the proximal SVC because it may migrate into the ostium of the azygos vein and cause venous thrombosis.

A persistent left-sided SVC is present in 0.3–0.5% of individuals; it usually drains into the right atrium either directly or via the coronary sinus (Iovino et al. 2012) (Fig. 5). This anatomical variant is usually asymptomatic, but its existence is important to recognize when inserting a central venous line from the left internal jugular or left subclavian vein since cardiac arrhythmias and coronary sinus thrombosis have been reported as complications.

The left brachiocephalic vein lies at a relatively higher level in the thorax and is potentially at risk of injury during tracheostomy.

Umbilical Vessels

The normal umbilical cord contains two relatively thick-walled umbilical arteries and, near the 12 o'clock position, one larger but thin-walled umbilical vein. The presence of a single umbilical artery may be associated with other congenital anomalies, particularly renal, vertebral, anorectal, and cardiovascular malformations (Martínez-Frías et al. 2008; Rittler et al. 2010), and an increased risk of perinatal mortality (Mu et al.

2008). However, routine karyotyping and renal sonography in an infant with an isolated single umbilical artery is not indicated (Mu et al. 2008; Deshpande et al. 2009).

At birth, the umbilical vessels constrict rapidly in response to a fall in umbilical cord temperature and hemodynamic changes. Occlusion of the umbilical artery is facilitated by the "folds of Hoboken," constriction rings along the length of the umbilical artery produced by oblique or transverse bundles of myofibroblasts (Röckelein et al. 1990). Numerous mediators of umbilical vessel vasoconstriction have been proposed, including bradykinin and endothelin-1, some of which are produced locally within the umbilical cord. Postnatally, the obliterated umbilical arteries become the paired medial umbilical folds or ligaments that are visible under the peritoneum of the anterior abdominal wall below the umbilicus; the proximal segment of each umbilical artery remains patent as the superior vesical artery. The intra-abdominal portion of the umbilical vein becomes the ligamentum teres. The urachus has normally involuted before birth leaving the median umbilical fold or ligament.

The umbilical vessels can be catheterized within 24–48 h of birth to provide vascular access for resuscitation, intravascular monitoring, fluid administration, blood transfusion, and/or parenteral nutrition (Anderson et al. 2008). The tip of an umbilical artery catheter is usually positioned above the diaphragm but below the ductus arteriosus ("high" position equivalent to T6–T9 vertebral level). Sometimes, the catheter tip is sited below the origin of the renal and inferior mesenteric arteries but above the aortic bifurcation ("low" position at L3–L4 vertebral level).

Arteries

The femoral artery is palpable midway between the anterior superior iliac spine and pubic tubercle in the neonate (Van Schoor et al. 2009); this is slightly more lateral than in an adult where its surface marking is midway between the anterior superior iliac spine and symphysis pubis (Hale et al. 2010). The renal arteries are at a slightly higher vertebral level in the neonate (T12-L1) (Standring 2008) compared to the adult (L1) (Mirjalili et al. 2012a), and the aortic bifurcation is similarly slightly more cranial (at the upper border of L4).

Respiratory System

Upper Airway

Relative to an adult, the newborn infant has a large head, short neck, small face and mandible, and large tongue (Crelin 1973). The entire surface of the tongue lies within the oral cavity, unlike in the older child and adult where its posterior third is in the oropharynx. Neonates are obligate nose breathers and do not begin to breathe orally until about 4 months of age. These features make infants more at risk of airway obstruction.

The neonatal nasopharynx curves smoothly backward and downward to join the oropharynx, rather than forming a right angle as in adults (Fig. 6). The hyoid bone and larynx are positioned higher in the neck. Consequently, the upper margin of the neonate's epiglottis (which is more

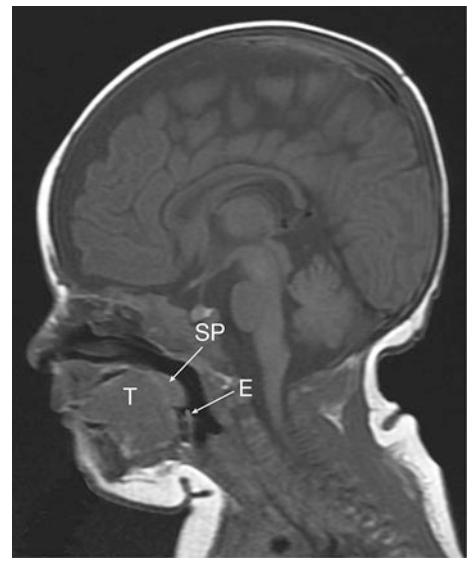

Fig. 6 Sagittal magnetic resonance image of the upper airway in a newborn. *T* tongue, *SP* soft palate, *E* epiglottis (Courtesy of Professor Terry Doyle)

horizontal than an adult's) extends to the level of the soft palate, and the posterior nares are in direct continuity with the larynx. This allows the infant to breathe while suckling. Ingested liquids pass lateral to the epiglottis via the piriform fossae. Despite immature coordination of swallowing and breathing, the risk of pulmonary aspiration is reduced by the high position of the larynx. The higher more anterior position of the larynx also means that it is easier to intubate the trachea with a straight-bladed laryngoscope. As the infant grows, the larynx descends, and the epiglottis loses contact with the soft palate.

The narrowest part of the infant's upper airway (about 3.5 mm in a term neonate) is the subglottis at the level of the cricoid cartilage, rather than the vocal cords as in adults (Fayoux et al. 2008). Mucosal edema in this region is more likely to compromise the airway (▶ Chap. 43, "Stridor in the Newborn"). As endotracheal tube cuffs tend to lie at this level, uncuffed tubes are preferred in neonates and young children. The internal diameter (mm) of an appropriate uncuffed endotracheal tube from about 1 year of age can be estimated from the formula (age/4) + 4 (O'Meara and Watton 2012).

The thyroid cartilage is shorter, lies nearer the hyoid bone, and has a less well-developed laryngeal prominence in children. Although the thyroid cartilage is slightly smaller in girls from birth (Fayoux et al. 2008), gender differences in laryngeal shape and size only begin to become apparent at about 3 years of age (Crelin 1973) and do not become well established until puberty. Adult men have a much more noticeable laryngeal prominence than women because the thyroid laminae are larger and meet at a more acute angle (mean 75° in men compared to 90° in women) (Jotz et al. 2014).

In 3–8-year-olds, upper airway lymphoid tissue is particularly prominent. At this age, adenotonsillar hypertrophy may cause airway obstruction, particularly when sleeping at night (obstructive sleep apnea).

Trachea

The trachea is short, measuring as little as 3 cm in premature neonates, making positioning of an endotracheal tube critical. The tip of the tube is usually best sited between the clavicles, 1–2 cm above the carina, which corresponds to the vertebral body of T1. As in adults, the trachea starts at the level of the sixth cervical vertebra but bifurcates at a relatively higher level (approximately T4) than in adults (approximately T5/T6 vertebral level (Mirjalili et al. 2012b)). The trachea is abnormally short in DiGeorge syndrome (Wells et al. 1989). The trachea is rich in elastic tissue (Kamel et al. 2009) and readily deformable, especially in neonates where the cartilage rings are soft. The right main bronchus is wider and steeper than the left, and the carina is more likely to lie slightly to the left of the middle of the trachea. An inhaled foreign body is therefore more likely to enter the right lung (Tahir et al. 2009).

Bronchial Tree

The bronchial tree is largely developed by the 16th week of intrauterine life; thereafter, conducting airways (down to the level of the terminal bronchioles) mostly increase in size rather than number (Jeffery 1998). Respiratory bronchioles develop and form alveoli as gestation progresses; type 2 pneumocytes begin surfactant production at about 26 weeks' gestation. At birth, 85% of alveoli have formed. Lung growth is especially rapid during infancy and is largely due to continuing alveolar development. It is generally agreed that most alveoli are formed by 2 years of age and simply increase in size thereafter (Thurlbeck 1982; Hislop 2002), but there is evidence to indicate that some alveoli continue to be formed in early childhood (Burri 2006).

Intermittent cyclical fetal "breathing" movements are detectable from about 11 weeks' gestation. Fluid produced by the fetal lungs is essential for normal growth and development of the lungs; there is a net egress of fluid from the lungs, which is either swallowed or mixes with the amniotic fluid. Fetal lung fluid production decreases a few days before term delivery switching to net reabsorption during labor. Before the infant takes his/her first breath, the terminal bronchioles and

alveoli are still filled with fluid. At birth, a newborn infant delivered by caesarean section has more lung fluid than an infant delivered vaginally. For the alveoli to expand adequately, surface tension must be reduced; this is achieved by the release of surfactant from type II pneumocytes lining the alveoli. Surfactant also prevents alveolar collapse on expiration, which explains why very premature infants with inadequate surfactant production develop respiratory distress. Remodeling of the pulmonary vessels begins immediately after birth leading to reduced pulmonary vascular resistance.

The small size of both the upper and lower airways in infants and children makes them more susceptible to obstruction than their adult counterparts.

Thorax and Mechanics of Breathing

The neonatal thorax has the shape of a truncated cone and is more rounded in circumference than an adult's. In an adult, the compliance of the chest wall and lung are similar, but a neonate's chest wall is up to five times more compliant than its lungs (Standring 2008). Consequently, it is easily deformable, as is readily apparent in an infant with chest wall recession associated with respiratory distress. The greater compliance of the chest wall in children means that serious visceral injuries can occur following blunt trauma without radiologic evidence of rib fractures.

The respiratory rate of a full-term newborn is about 40–44 breaths/min. The ribs are more horizontal and contribute less to chest expansion. Infants rely mainly on diaphragmatic breathing. The diaphragm is relatively flat at birth (Fig. 4) and becomes more dome shaped with continuing growth. Diaphragmatic contraction tends to pull the ribs inward; concomitant outward movement of the abdomen (thoracoabdominal paradox) is a normal finding in newborns.

The work of breathing is greater in an infant than an adult and greater still in a preterm infant. This is due to numerous factors including greater chest wall compliance. Furthermore, neonates, and particularly those that are premature, have a much smaller proportion of fatigue resistant type I muscle fibers in their diaphragmatic and intercostal muscles as compared to older infants (Keens et al. 1978).

The neonatal thymus is variable in size at birth but typically large (up to 5 cm wide and 1 cm thick). It is a prominent feature on a chest X-ray (Fig. 4). The thymus overlies the trachea, great vessels (especially the left brachiocephalic vein), and upper anterior surface of the heart. After the first year of life, it becomes progressively smaller and less vascular, and the lymphoid tissue is increasingly replaced by fat.

Abdominal Wall and Gastrointestinal Tract

Abdominal and Pelvic Cavities

The infant's abdomen is relatively wide and protuberant because the diaphragm is flatter and the pelvic cavity smaller. The distance between the costal margin and iliac crest is proportionately greater. For these reasons, transverse supraumbilical incisions provide good surgical access in young children. The rectus abdominis muscles may be relatively wide apart in an infant creating divarication, which resolves with growth.

The infant's peritoneal cavity is relatively shallow anteroposteriorly because there is no lumbar lordosis and the paravertebral gutters are poorly developed. There are numerous anatomical differences between the child and adult that are relevant to pediatric laparoscopy: working spaces are smaller; the position and size of some organs such as the bladder and liver are different; the relatively shallow peritoneal cavity means that the great vessels may be more at risk of injury when inserting a trocar; the abdominal wall is more compliant and the peritoneum more elastic; and the inferior epigastric vessels are relatively larger. The greater omentum is delicate and membranous, rarely extending much below the level of the umbilicus. The neonate has less fat in the gut mesenteries and around the viscera.

The inguinal canal in the newborn is short and more vertically orientated because the superficial

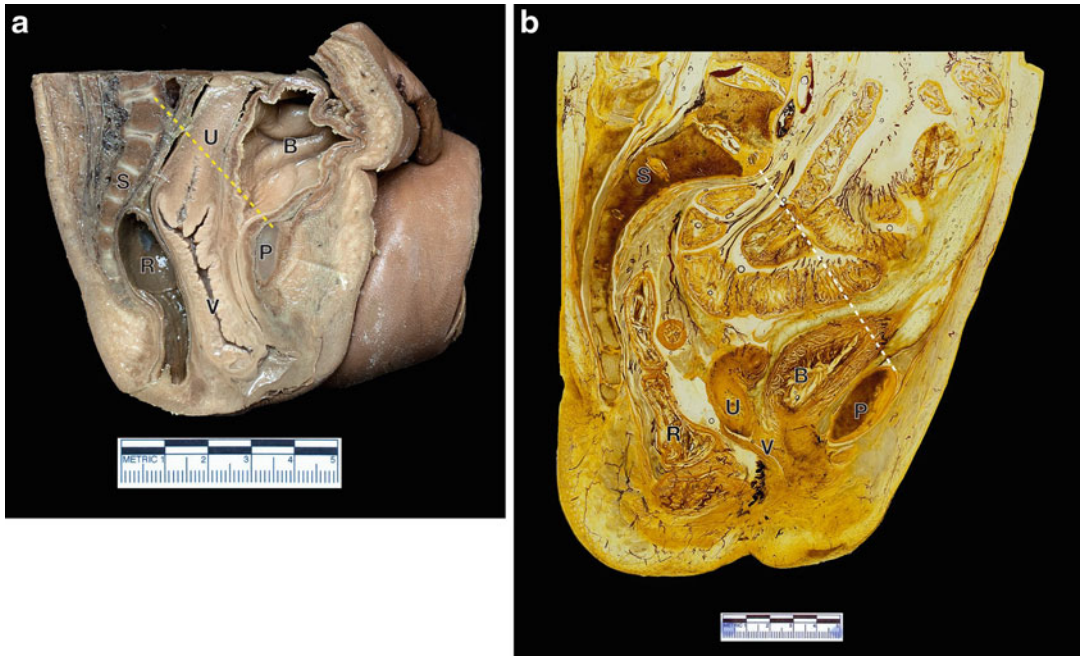

Fig. 7 Midline sagittal section of a plastinated neonatal (**a**) and adult (**b**) female pelvis. Note the relative positions of the bladder (*B*) and uterus (*U*), the curvature of the sacrum (*S*), and the angle of the pelvis (*dotted line* between sacral promontory and pubic bone [*P*]). *V* vagina, *R* rectum (Courtesy of the W.D. Trotter Anatomy Museum, University of Otago)

inguinal ring lies just medial to the deep ring. Despite its length, the canal can still be opened via a short incision in its anterior wall (the external oblique aponeurosis) when repairing an inguinal hernia, even in premature infants. The canal lengthens with growth.

Compared to an adult, the true pelvis (the part below the pelvic brim) in the neonate is small, both relatively and absolutely. It is also more circular in cross section, orientated more vertically, and has a less pronounced sacral curve. The urinary bladder, ovaries, and uterus are all partly intra-abdominal, and the rectum occupies most of the true pelvis (Fig. 7).

Gastrointestinal Tract

At term, the newborn esophagus is about 8–10 cm long from the level of the cricoid cartilage to the diaphragm (Crelin 1973); the upper and lower esophageal sphincters each extend over about 1 cm (Gupta and Jadcherla 2006). Lower esophageal sphincter pressure is particularly low during the first month or two of life. The narrowest part of the upper digestive tract is where the cricopharyngeus muscle blends with the upper esophagus, a potential site of esophageal perforation during the passage of a nasogastric tube (Gander et al. 2009).

The anterior surface of the stomach is overlapped by the left lobe of the liver, which extends close to the spleen. The capacity of the neonatal stomach is approximately 30–35 mL at term but reaches 100 mL by the fourth week. The newborn stomach is typically very small in infants with isolated esophageal atresia. Gastric emptying is relatively slow and poorly coordinated in the first few weeks of life, even though the gastric muscle layers are developed. Gastric acid is present on the first day of life in most premature infants of at least 27 weeks' gestation, although basal acid output is low during the first 24 h (Marciano and Wershil 2007).

The small bowel of the infant is distributed more horizontally because of the shape of the abdominal cavity and position of the bladder. The mean length of the small intestine from the duodenojejunal flexure to the ileocaecal junction is around 160 cm when measured along its antimesenteric border in vivo in the full-term neonate (Struijs et al. 2009) but is considerably longer when measured at autopsy (Weaver et al. 1991). Mean length is nearer 100 cm at about 30 weeks' gestation (Struijs et al. 2009). The mesentery contains relatively little fat, making identification of mesenteric blood vessels much easier. In older children, lymph nodes are readily identifiable in the small bowel mesentery and may be prominent in the absence of disease.

The mean length of the colon from the ileocaecal junction to the upper rectum in the term infant in vivo is about 55 cm (Struijs et al. 2009; Mirjalili et al. 2017). Compared to adults, the caecum and ascending and descending colon are relatively short and the transverse colon, sigmoid colon, and rectum relatively long. The caecum tapers to a proportionately wider appendix with a relatively wider orifice. The mean length of the large bowel increases to about 73cm at 4–6 years and 95cm at 9–11 years (Mirjalili et al. 2017). In children, the transverse colon is the longest segment and contributes approximately 30% of the total length of the large bowel. The cecum is located in the right upper quadrant in a substantial minority of infants but is in the right lower quadrant in almost all school age children. In infants, the anal canal has well-defined anal columns and prominent anal sinuses (Shafik 1980); stasis within these sinuses may be a cause of perianal sepsis, particularly in male infants, although other factors are probably also involved (Nix and Stringer 1997).

Neonatal small bowel has few circular folds (valvulae conniventes), and the neonatal colon has no haustra. It is therefore difficult to distinguish the small and large bowel on plain abdominal radiographs of the newborn. Their relative position (central small bowel vs. peripheral large bowel) and caliber are a rough guide, but a contrast study may be required to accurately differentiate small from large bowel.

Liver, Gallbladder, and Spleen

The neonatal liver weighs about 120 g at term and comprises about 4% of body weight (as compared to 2% in the adult); it more than doubles in weight during the first year. The relatively large liver fills much of the upper abdomen. Its inferior border extends 1–2 cm below the costal margin, and the left lobe overlaps the stomach and extends more laterally. The premature baby's liver is particularly fragile and vulnerable to injury (e.g., from an abdominal retractor). The neonatal gallbladder is more intrahepatic, and its fundus may not extend below the inferior border of the liver; a more adult type configuration is evident after 2 years of age.

The tip of the newborn's spleen is often palpable just below the left costal margin. Normal values for spleen lengths at different ages in childhood have been established using ultrasound (Megremis et al. 2004). The tail of the pancreas is in contact with the splenic hilum in more than 90% of cases, a much greater proportion than in adults (Üngör et al. 2007). Accessory spleens are found at autopsy in about 14% of fetuses and neonates as compared to 10% of adults (Cahalane and Kiesselbach 1970), but it is uncertain whether this is a true difference in prevalence.

Genitourinary System

Genitourinary anomalies are among the commonest congenital malformations, and so it is especially important to understand the normal anatomy of the newborn.

Kidneys and Suprarenal Glands

By 8 weeks of gestation, the urethra is patent, and the fetal kidneys are beginning to make urine. Fetal urine output increases steadily during pregnancy and accounts for the majority of amniotic fluid in the second half of pregnancy (Maged et al. 2014). At birth the kidneys are about 4–5 cm in

length compared to a mean length of 11 cm in adults. The renal pelvis measures less than 5 mm anteroposteriorly, and fetal lobulation of the kidneys is still present. Individual nephrons are composed of (i) a renal corpuscle consisting of a central glomerulus surrounded by a capsule and concerned with plasma filtration and (ii) a renal tubule that produces urine by selective reabsorption of the filtrate. At birth there are about one million renal corpuscles in the cortex of each kidney. Postnatally, nephron mass increases, but no new nephrons are made. The glomerular filtration rate (GFR) is low in newborns, particularly in the premature infant, but doubles by 2 weeks of age in the full-term infant and reaches adult values (120 mL/min per $1.73m^2$) by 1–2 years (Lissauer and Clayden 2007).

The suprarenal glands are relatively large at birth with a proportionately thick cortex. Their average combined weight is 9 g compared with 7–12 g in the adult. Both glands become smaller in absolute and relative terms in the neonatal period due to shrinkage of the suprarenal cortex (Kangarloo et al. 1986).

Bladder and Ureter

The bladder is mostly intra-abdominal at birth (Fig. 7) with its apex midway between the pubis and the umbilicus in the unfilled state. Manual expression of urine (Credé's maneuver) and suprapubic aspiration are therefore relatively easy. The bladder does not achieve its adult pelvic position until about the sixth year (Standring 2008). The apex of the bladder is continuous with the median umbilical fold or ligament which represents the obliterated urachus. A urachal remnant (sinus, cyst, patent urachus, etc.) is a consequence of incomplete involution. The intravesical segment of the ureter (intramural and submucosal portions) lengthens from about 0.5 cm in neonates to 1.3 cm (the adult value) by 10–12 years of age. An abnormally short submucosal tunnel is one of the causes of vesicoureteric reflux (VUR) in preschool children; this type of VUR tends to resolve spontaneously with growth (Godley and Ransley 2010).

Genitalia and Reproductive Tract

During development the testis "descends" from the urogenital ridge, and by about the sixth month of gestation, the testis lies adjacent to the deep inguinal ring; it is connected to the developing scrotum by the gubernaculum. About 1 month later, the testis begins its inguinoscrotal descent accompanied by a tongue of peritoneum, the processus vaginalis. About 4% of boys born at term have an undescended testis(es); this figure is higher in premature infants. By 3 months of age, the prevalence of cryptorchidism has fallen to 1.5%. Further spontaneous testicular descent does not occur after 6 months of age. The precise timing and process of closure of the processus vaginalis are uncertain (Godbole and Stringer 2010). Surgical studies have shown that a patent processus vaginalis is present in around 60% of contralateral groin explorations *in infants with a unilateral inguinal hernia* in the first 2 months, falling to around 40% after 2 years of age. Autopsy studies have indicated that the processus is patent in about 80% of newborns, decreasing to about 15–20% in adults. Boys with cryptorchidism have higher patency rates.

The prostate and seminal vesicles are well developed at birth. The penis and scrotum are relatively large, and the scrotum has a broad base and relatively thick walls. The inner surface of the prepuce (foreskin) begins to separate from the glans penis in the fetus, but only 4% of newborns have a fully retractile foreskin. By 6–7 years of age, about 8% of uncircumcised boys will still have a nonretractile foreskin, but this figure decreases to about 1% by 17 years of age (Oster 1968), emphasizing that the natural history of the foreskin is one of spontaneous separation.

In female infants, the ovary lies in the lower part of the iliac fossa and only descends into the ovarian fossa within the true pelvis during early childhood as the pelvis deepens. At birth the ovaries are relatively large and contain the full

complement of primary oocytes, each surrounded by a single layer of follicular cells forming the primordial follicles. Of the seven million oocytes estimated to be present in the female fetus, only one million remain at birth, and this number decreases further to approximately 40,000 by puberty.

In the term infant, the uterus is about 3–5 cm long, and the cervix forms two-thirds or more of its length (Fig. 7). Female newborns have a relatively prominent clitoris (mean length of 4 mm (Oberfield et al. 1989)) and labia. The vagina is about 3 cm long and is relatively thick walled with a fleshy hymen. After withdrawal of maternal hormones, the uterus and vagina diminish in size.

Musculoskeletal System

Skull and Face

The skull vault is formed by intramembranous ossification, the facial skeleton is derived from neural crest membrane bones, and the skull base and some bony pharyngeal arch derivatives (e.g., hyoid bone and ossicles) by endochondral ossification (Standring 2008). During birth, the margins of the frontal and parietal bones are able to slide over each other. In the first 2 days of life, palpable overriding of the bones of the vault is common. Persistent ridging of suture lines may indicate craniosynostosis. Growth at the coronal suture is mostly responsible for fronto-occipital expansion of the skull; premature fusion causes brachycephaly if bilateral and plagiocephaly if unilateral. The latter must be distinguished from asymmetric flattening of the back of the skull (deformational plagiocephaly) in premature babies secondary to postnatal gravitational molding. Growth at the metopic and sagittal sutures increases skull breadth, the metopic suture fusing at around 18 months of age, and the sagittal suture at puberty. Premature fusion of the sagittal suture (sagittal craniosynostosis) is the most common form of craniosynostosis and produces an elongated skull. This must be distinguished from the long thin head (dolichocephaly) sometimes seen in premature babies secondary to postnatal molding as a consequence of head positioning.

Serial measurements of head circumference give an indication of brain growth; 80% of adult head size is achieved by 5 years of age. Abnormal head enlargement may be familial or indicate hydrocephalus, while poor head growth may reflect neurological impairment from a variety of causes or malnutrition.

Fontanelles are formed where several skull vault bones meet. The two most prominent are the anterior fontanelle overlying the superior sagittal venous sinus at the junction of the metopic and sagittal sutures (the bregma) and the posterior fontanelle at the junction of the sagittal and lambdoid sutures (the lambda) (Sundaresan et al. 1990). The size of the anterior fontanelle at birth is very variable; if unduly large, it may be an indication of congenital hypothyroidism or a skeletal disorder (Davies et al. 1975). The timing of closure of the fontanelles is also variable, but the anterior fontanelle is obliterated by 2 years of age in 95% of children (Acheson and Jefferson 1954) and the posterior by 2 months of age (Bickley and Szilagyi 2009).

Postnatal growth of the skull is associated with disproportionate growth of the facial skeleton and mandible, both of which are small in comparison to the skull vault at birth (Fig. 8). The bony external ear canal is not developed, and the mastoid process is absent at birth. Consequently, the facial nerve is potentially at risk of injury (e.g., from obstetric forceps) where it emerges from the stylomastoid foramen. At birth, the two halves of the mandible are united by a fibrous symphysis that fuses in early childhood. The mandibular rami are at a more obtuse angle to the body of the mandible. The mandible changes shape as the teeth erupt and the muscles of mastication and chin develop.

The maxillary and ethmoid sinuses are present at birth, but the sphenoid sinus is poorly developed, and the frontal sinuses are absent (Crelin 1973). The auditory tube is almost horizontal, increasing the risk of middle ear disease; it becomes more vertical during childhood. The hard palate is short, only slightly arched, and ridged by transverse folds which

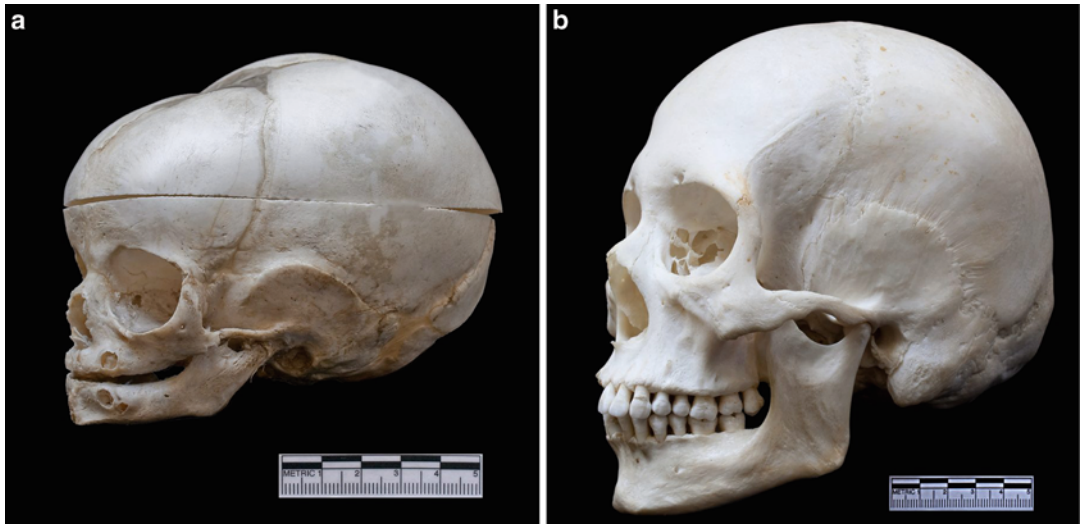

Fig. 8 Comparison of a neonatal (**a**) and adult male (**b**) skull. Note the relatively small size of the face and mandible in the neonate, the cranial vault sutures, and the anterior fontanelle. The mastoid process has not developed at birth (Courtesy of the W.D. Trotter Anatomy Museum, University of Otago)

assist with suckling. The nasolacrimal duct which drains tear secretions from the conjunctival sac to the inferior meatus of the nasal cavity is relatively short and wide at birth but may be obstructed due to incomplete canalization, leading to excessive tearing, discharge, and infection.

Vertebral Column, Pelvis, and Limbs

Apart from a mild sacral curve, the vertebral column in the neonate lacks the fixed spinal curvatures present in adults. After birth, the thoracic curvature develops first, and then, as the infant learns to control its head, sit, stand, and walk, curvatures in the cervical and lumbar spines develop which help to maintain the center of gravity of the trunk when walking. The sacral promontory "descends" and becomes more prominent.

The pattern of cervical spine injuries is different in children, reflecting anatomical differences, namely, a relatively large head, more flexible neck, and less well-developed cervical muscles (Knox 2016). Most cervical spine injuries in children under 8 years of age affect the intervertebral discs and ligaments of the upper cervical spine (occiput-C2), whereas older children tend to injure the subaxial region of the cervical spine (C3-C7), a pattern more similar to adults (O'Meara and Watton 2012; Leonard et al. 2014; Ribeiro da Silva et al. 2016). Moreover, children are more likely to have a subluxation without fracture of the cervical spine or a spinal cord injury without radiographic abnormality. Consequently, *clinical assessment* of the injured child with a potential cervical spine injury is essential, even in the presence of normal cervical spine radiographs.

The anatomy of the sacral hiatus and caudal canal varies between individuals but also varies with age. When performing a caudal anesthetic block, neonates are more at risk of inadvertent dural puncture than older children and adults because the termination of the dural sac is nearer the sacral hiatus and the sacrum is more cartilaginous providing less rigid bony definition (Lees et al. 2014).

In the fetus, hemopoiesis occurs in the liver, spleen, and bone marrow, but after birth it is largely restricted to the bone marrow of the vertebrae, ribs, sternum, proximal long bones, and diploe of the skull.

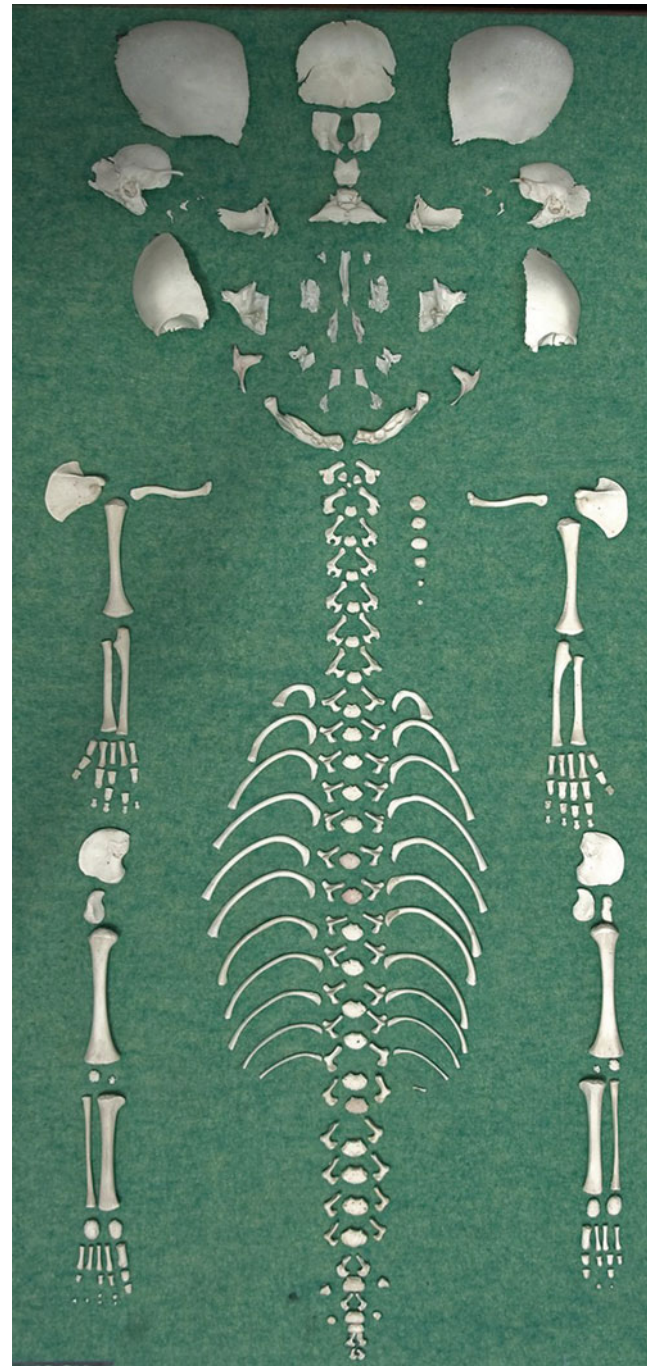

Fig. 9 The bony skeleton of a newborn baby. There are no carpal bones at birth, there are separate ossification centers for the hip, and secondary centers of ossification in the long bones are absent except for the lower end of the femur and upper end of tibia (Specimen prepared by Professor J.H. Scott in 1895. Courtesy of the W.D. Trotter Anatomy Museum, University of Otago)

Of the 800 or so ossification centers in the human skeleton, just over half appear after birth; these include most secondary ossification centers (Fig. 9). Cartilage is abundant at birth. None of the carpal bones have ossification centers at birth and the only secondary centers of ossification in the long bones are in the femoral and tibial condyles and humeral head (Crelin 1973). The iliac crest, acetabular floor, and ischial tuberosity are all cartilaginous.

The acetabulum is relatively large and shallow at birth and has a characteristic Y-shaped triradiate cartilaginous epiphyseal plate at the site of union between the ilium, ischium, and pubis. Nearly one-third of the neonatal femoral head lies outside the acetabulum, making the hip joint easier to dislocate. Developmental dysplasia of the hip affects about 1 in 100 live births and is more common in girls. The neonatal femoral neck is short, and the femoral shaft is straight. The proximal femoral growth plate in early infancy is intra-articular so that infection in the proximal femoral metaphysis may cause a septic arthritis. The lower limb muscles in the newborn are relatively underdeveloped, and the gluteal muscle mass is small. The thighs tend to be abducted and flexed, the knees flexed and the foot dorsiflexed and inverted. In congenital talipes equinovarus (club foot), maldevelopment of the talus causes inversion and supination of the foot and adduction of the forefoot.

Nervous System

At term, the neonatal brain weighs between 300 and 400 g and accounts for about 10% of body weight (compared to 2% in the adult) (Crelin 1973). Brain growth is especially rapid during the first year of life, when the brain reaches 75% of its adult volume. In the term infant, the number of neurons is already established at birth; brain growth is due to an increase in size of nerve cell bodies, development of additional neuronal connections, proliferation of neuroglia and blood vessels, and myelination of axons. Myelination is at its peak in the first 6 months of life but continues until maturity (Standring 2008). The arrangement of sulci and gyri at birth is similar to the adult, although the central sulcus is slightly further forward and the cerebral ventricles are proportionately larger. Mean head circumference at term is 34 cm.

The termination of the spinal cord, the conus medullaris, may extend as low as the level of the L3 vertebra in the neonate, whereas in the adult, it is usually around the lower border of L1. The conus is readily visualized by ultrasound scan in the first 3 months of life. The supracristal plane between the upper limits of the iliac crests is slightly higher (L3/4 rather than L4); a lumbar puncture in the newborn should not be performed above this level to avoid the risk of injuring the spinal cord.

Skin and Subcutaneous Tissue

Body fat is laid down in the fetus from about 34 weeks' gestation and, with appropriate intrauterine nutrition, increases until term. Plantar fat pads give the neonate a flat-footed appearance. Brown fat is a modified form of adipose tissue in the newborn concentrated at the back of the neck, in the interscapular region, and in pararenal areas. It is composed of adipocytes with mitochondria that have large and numerous cristae adapted to heat production. Despite this specialized fat, the neonate's ability to regulate temperature is poorly developed.

At birth, breast tissue is similarly developed in girls and boys. It may appear prominent due to the influence of maternal hormones, even leading to the secretion of a small amount of fluid (witch's milk). Supernumerary nipple(s) may be found along the mammary ridges (milk lines) which extend on each side from the axilla to the groin.

Neonatal skin is relatively thin. The ability to see peripheral veins is very dependent on the thickness of the subcutaneous tissues. Common sites for peripheral venous cannulation include: the dorsal arch veins of the hands and feet, the cephalic vein at the wrist, the volar aspect of the wrist (where the veins are small and fragile), the cubital fossa, the saphenous vein immediately anterior to the medial malleolus or behind the medial aspect of the knee, and the superficial temporal vein anterior to the ear.

Conclusion

There are key differences between the anatomy of the child and adult that affect the utility of traditional surface anatomical landmarks, surgical

approaches and procedures, and the interpretation of normal physiological and cardiorespiratory parameters and responses. Pediatric surgeons need to be aware of these differences.

Cross-References

- ▶ Pediatric Cardiovascular Physiology
- ▶ Stridor in the Newborn

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