Growth of cranial vault, cranial base and nasomaxillary complex
• Development of the calvaria is dependent upon the presence of the brain. It comprises the frontal bones, the parietal bones, and the squamous parts of the temporal and occipital bones.
The cranial vault is made up of a number of flat bones that are formed directly by intramembranous bone formation, without cartilaginous precursors. From the time that ossification begins at a number of centers that foreshadow the eventual anatomic bony units, the growth process is entirely the result of periosteal activity at the surfaces of the bones. Remodeling and growth occur primarily at the periosteum-lined contact areas between adjacent skull bones, the cranial sutures, but periosteal activity also changes both the inner and outer surfaces of these plate-like bones.
At birth, the flat bones of the skull are rather widely separated by relatively loose connective tissues. These open spaces, the fontanelles, allow a considerable amount of deformation of the skull at birth. This is important in allowing the relatively large head to pass through the birth canal.
• After birth, apposition of bone along the edges of the fontanelles eliminates these open spaces fairly quickly, but the bones remain separated by a thin periosteum-lined suture for many years, eventually fusing in adult life.
• Despite their small size, apposition of new bone at these sutures is the major mechanism for growth of the cranial vault. Although the majority of growth in the cranial vault occurs at the sutures, there is a tendency for bone to be removed from the inner surface of the cranial vault, while at the same time new bone is added on the exterior surface. This remodeling of the inner and outer surfaces allows for changes in contour during growth.
FIGURE 2-23 The fontanelles of the newborn skull (pink).
Additional figure:
Superior view of the cranium showing bone growth.

a. Bone condensation within ectomeninx (embryo ~ 8 weeks).
b. Sutures and fontanelles (foetus ~ full-term).
c. Patent sutures allow the bones to grow around their edges and the cranium to enlarge.
Cranial base

• In contrast to the cranial vault, the bones of the base of the skull (the cranial base) are formed initially in cartilage and are later transformed by endochondral ossification to bone. This is particularly true of the midline structures. As one moves laterally, growth at sutures and surface remodeling become more important, but the cranial base is essentially a midline structure.
• Growth of the cranial base is influenced by both neural and somatic growth patterns, with 50 per cent of postnatal growth being complete by the age of 3 years. As in the calvarium, there is both remodelling and sutural infilling as the brain enlarges, but there are also primary cartilaginous growth sites in this region — the synchondroses.
• Of these, the spheno-occipital synchondrosis is of special interest as it makes an important contribution to growth of the cranial base during childhood, continuing to grow until 13–15 years in females and 15–17 years of age in males, fusing at approximately 20 years.
Fig. 3: The bones that form the base of the skull
• Thus the middle cranial fossa follows a somatic growth pattern and enlarges both by anteroposterior growth at the sphenoo-occipital synchondrosis and by remodelling.

• The anterior cranial fossa follows a neural growth pattern and enlarges and increases in anteroposterior length by remodelling, with resorption intracranially and corresponding extracranial deposition.
• There is no further growth of the anterior cranial fossa between the sella turcica and foramen caecum after the age of 7 years. Therefore, after this age the anterior cranial base may be used as a stable reference structure upon which sequential lateral skull radiographs may be superimposed to analyse changes in facial form due to growth and orthodontic treatment.

• The Sella-Nasion line is not as accurate because Nasion can change position due to surface deposition and the development of the frontal sinuses.
Fig. 6.7 Effect of variations in the position of nasion on angles SNA, SNB and ANB:
• The spheno-occipital synchondrosis is anterior to the temporomandibular joints, but posterior to the anterior cranial fossa, and, therefore, its growth is significant clinically as it influences the overall facial skeletal pattern (Fig. 4.10). Growth at the spheno-occipital synchondrosis increases the length of the cranial base, and since the maxillary complex lies beneath the anterior cranial fossa while the mandible articulates with the skull at the temporomandibular joints which lie beneath the middle cranial fossa, the cranial base plays an important part in determining how the mandible and maxilla relate to each other.
Fig. 4.10 Anteroposterior growth at the sphenoo-occipital synchondrosis affects the anteroposterior relationship of the jaws.
• For example, a Class II skeletal facial pattern is often associated with the presence of a long cranial base which causes the mandible to be set back relative to the maxilla.
• In the same way, the overall shape of the cranial base affects the jaw relationship, with a smaller cranial base angle tending to cause a Class III skeletal pattern, and a larger cranial base angle being more likely to be associated with a Class II skeletal pattern (Fig. 4.11).
• The cranial base angle usually remains constant during the postnatal period, but can increase or decrease due to surface remodelling and differential growth at the sphenooroccipital synchondrosis.
Fig. 4.11 View (a) Low cranial base angle associated with Class III skeletal pattern. View (b) Large cranial base angle associated with a Class II skeletal pattern.
Nasomaxillary complex

• The maxilla derives from the first pharyngeal arch and ossification of the maxillary complex is intramembranous, beginning in the 6th week i.u.
• The maxilla is the third bone to ossify after the clavicle and the mandible.
• The main ossification centres appear bilaterally above the future deciduous canine close to where the infraorbital nerve gives off the anterior superior alveolar nerve. Ossification proceeds in several directions to produce the various maxillary processes.
Postnatal growth of the maxilla follows a growth pattern that is thought to be intermediate between a neural and a somatic growth pattern.
Clinical orthodontic practice is primarily concerned with the dentition and its supporting alveolar bone which is part of the maxilla and premaxilla.

However, the middle third of the facial skeleton is a complex structure and also includes, among others, the palatal, zygomatic, ethmoid, vomer, and nasal bones. These articulate with each other and with the anterior cranial base at sutures.
• The maxilla develops postnatally entirely by intramembranous ossification. Since there is no cartilage replacement, growth occurs in two ways:
  (1) by apposition of bone at the sutures that connect the maxilla to the cranium and cranial base.
  (2) by surface remodeling. In contrast to the cranial vault, however, surface changes in the maxilla are quite dramatic and as important as changes at the sutures.
Growth at sutures

- Maxilla is attached to the cranium by:
  1. Fronto-nasal suture
  2. Frontomaxillary
  3. Zygomaticomaxillary
  4. Zygomaticotemporal
  5. Pterygopalatine suture
Sutures are oblique and parallel to each other. This allows the downward and forward repositioning of maxilla as growth occurs at these sutures. As growth of surrounding soft tissue occurs, the maxilla is carried downwards and forward. This leads to opening up of space at the sutural attachments. New bone is formed on either side of the suture. Thus the overall size of the bones on either side increases. Hence a tension related bone formation occurs at sutures.
Fig. 5: The nasomaxillary complex as it emerges from beneath the cranium
Maxillary tuberosities

• Much of the anteroposterior growth of the maxilla is in a backward direction at the tuberosities which also lengthens the dental arch, allowing the permanent molar teeth to erupt.

• A forwards displacement of the maxilla gives room for the deposition of bone at the tuberosities.
Maxillary tuberosity

• Maxillary arch grows in 3 directions
  – Posteriorly deposition on posterior surface of maxillary tuberosity
  – Laterally- deposition on buccal surface of tuberosity
  – Downward- deposition along alveolar ridge
• Endosteal surface is resorptive for growth of maxillary sinus
Zygomatic arch

- The zygomatic bones are also carried forwards, necessitating infilling at sutures, and at the same time they enlarge and remodel. In the upper part of the face, the ethmoids and nasal bones grow forwards by deposition on their anterior surfaces
Zygomatic arch

• Resorption at anterior surface and deposition at the lateral and posterior surfaces
• As a result the zygomatic arches move posteriorly and bilaterally outwards
• Downward growth occurs by
  1- vertical development of the alveolar process and eruption of the teeth.
  2- also by inferior drift of the hard palate, i.e. the palate remodels downwards by deposition of bone on its inferior surface (the palatal vault) and resorption on its superior surface (the floor of the nose and maxillary sinuses).
  3- These changes are also associated with some downward displacement of the bones as they enlarge, again necessitating infilling at sutures.
FIGURE 2-29  Remodeling of the palatal vault (which is also the floor of the nose) moves it in the same direction as it is being translated: bone is removed from the floor of the nose and added to the roof of the mouth. On the anterior surface, however, bone is removed, partially canceling the forward translation. As the vault moves downward, the same process of bone remodeling also widens it. (Redrawn from Enlow DH, Hans MB: Essentials of facial growth, Philadelphia, 1996, W B. Saunders.)
• Lateral growth in the mid-face occurs by displacement of the two halves of the maxilla, with deposition of bone at the midline suture.
• Internal remodelling leads to enlargement of the air sinuses and nasal cavity as the bones of the mid-face increase in size.
Despite being translated anteriorly, in fact much of the anterior surface of the maxilla is resorptive in order to maintain the concave contours beneath the pyriform fossa and zygomatic buttresses.
• Maxillary growth slows to adult levels on average at about 15 years in girls and rather later, at about 17 years, in boys.