Head growth and cranial assessment at neurological examination in infancy

Annotation

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The most dramatic increase in brain volume occurs in the last three months of fetal life and the first two years after birth. Concomitantly, the skull follows the volumetric increase in the cerebral hemispheres mostly by passive adaptation. The relationship between head and brain growth explains why the classical neurological assessment in infancy universally includes measurement of head circumference (HC). However, this crude information derived from HC measurement remains insufficient to qualify brain growth. One way to better document the relation between brain and skull could be to rely on the correlation between HC and body growth parameters, given a general agreement on the definition of proportionate and disproportionate head–body growth. Significant information with respect to the integrity of the underlying cerebral hemispheres can also be provided by systematic palpation of the main cranial sutures. In particular, the distension or overlapping of the squamous sutures which are strategically located at the junction of the cranial vault and the cranial base could be a valid marker of brain growth disorder.

The classification of head growth into normocephaly, microcephaly, or macrocephaly tends to be done at birth. However, a better knowledge of the many possible changes that can occur during the fast period of brain growth suggests that such a classification should be delayed. Among the changes that are worth considering to classify head growth, and that should be included in the growth profile analysis, is the persistence of cranial ridges.

Head circumference and fontanels: classical assessment

BASIC ANATOMICAL DESCRIPTION OF THE CRANIAL VAULT

The skull develops from mesenchyme. The cranial vault consists of six bony plates that are: anterior, frontal; posterior, occipital; between the two parietal bones; and inferior, the two temporal bones (Fig. 1). Strips of unmineralized dura, the sutures, join these plates. From a central spot in each bone forming the cranial vault, ossification spreads centrifugally toward these sutures (the parietal central spot may be prominent around term due to very active ossification). Ossification first takes place from around 9 to 10 gestational weeks[1] and increases with gestational age (GA) with wide individual variations in thickness (1 to 2mm at birth) At term, the cranial vault is firm, sometimes producing a 'ping-pong ball' sensation when touched along the upper edges of the parietal bones, due to the lag of calcification of these distal portions.

At birth, angles of the skull bones are not yet formed and, therefore, six membranous spaces, called fontanels, persist. The anterior fontanel (Fig. 1), the largest and the most systematically palpated, is diamond shaped. Its average anterio-posterior diameter is 1.5 to 2.5cm. Its closure begins by 3 postnatal months, due to the progressive in-growth of the edges of the membranous bones that form their borders.[2]

HEAD CIRCUMFERENCE ASSESSMENT

Measurement of the maximal occipito-frontal head circumference (HC) provides a simple, reproducible measurement of head size that correlates closely with brain volume.[3–5] HC increases strikingly before and after term birth: from 25cm at 28 weeks gestation it measures 35cm at term and 45cm by 8 postnatal months. This increase is so fast that using corrected age is recommended until the end of the second year of life.[6]

Reliability of HC measurements has been studied. The use of paper tape measures has proven to be more reliable than

cloth tape measures.[7] Intra- and inter-examiner reliability was tested using white, laminated, unmarked paper with a convenience sample of 50 term infants: 98 to 100% of the observed differences were less than 1cm.[8] Numerical value of HC is reported on a normative curve, the most commonly used being Nelhaus's curve.[9]

Different intrinsic factors may influence HC. Sex has been shown to be an important variable; at term, males tend to have HC that is 0.5cm larger than females.[10] Therefore, separate head growth curves for each sex must be used. In addition, racial comparisons in a North American sample showed that black neonates are consistently shorter and have lower birthweight than Hispanic and white neonates. Even though racial influences on HC have also been identified, the differences are not statistically significant; only the birthweight differences are statistically significant.[11] These results have been replicated in another sample of 3 million North American neonates.[12] Finally, at any age, there is a relationship between head size of normal children and that of their parents, depending on genetic programming for head growth. An adjustment of the child's head size value by the average parental value should be made in order to better define the range of normalcy.[13] It has been showed that while 16% of the apparently normal individuals had an 'abnormal' head size using Nelhaus's curve,[9] only 7% of the offspring had 'abnormal' head size when adjusted for parental head size.

Various definitions of normal limits are found in the literature. In Europe, the 3rd, 10th, and 25th centiles below the mean and the 75th, 90th and 97th centiles above it are alternatively used to determine this cut-off point. The 5th and 95th centiles have been more routinely retained in North America. Finally, the World Health Organization recommends the use of standard deviations (SD) to determine normal limits. The choice of different criteria leads to significant differences in the detection of abnormal growth patterns.[14] Considering that fetal growth has been changing over the years for various reasons, systematic updating of the data should be done every 5 to 10 years. Therefore, one should choose the most recent growth curve that best reflects the populations demographics.[15]

Repeated measures will allow consideration of the head growth velocity changes during age intervals (i.e. in increments) – a set of mathematical models have been proposed.[16,17] Such a monitoring of growth rates allows early recognition of abnormal growth.[18] However, no clear cut-off point that defines abnormal growth has been identified.

FONTANEL ASSESSMENT

Mean anterior fontanel size ([length + width] ÷ 2]) has been studied during the first year of life,[19] resulting in the definition of a small fontanel when the size is 2SD below the mean and a large fontanel when the size is 2SD above the mean. However, the extreme variability in its size takes away some of its practical significance. Occasionally children thought to have a small or absent anterior fontanel are found to have an anterior intra-fontanel bone.[20] The clinical appreciation of the tension of the dura at the level of the anterior fontanel allows the estimation of the intra-cranial tension, when the infant is quiet and in semi-recline; due to pitfalls in the interpretation of the size of the anterior fontanel (if small, it may seem depressed; if large, it may seem full), only a pulsatile, bulging fontanel is a reliable sign of increased intra-cranial pressure. Time of closure is extremely variable; before 6 months is considered early, whereas after 18 months is considered late.

HEAD AND BODY PROPORTIONALITY AT BIRTH: GESTALT VERSUS STATISTICAL APPROACH

A symmetrical rate of head and body growth is often called 'proportionate', whereas an asymmetrical one is often called 'disproportionate'. When disproportion is found, the pattern observed may provide etiological clues: as an example, the fetus araignée (spider-like) is characterized by a very large head in comparison with a slim, dehydrated body can be encountered in pre-eclampsia. Such a disproportionality (asymmetry) is believed to be the result of the brain-sparing effect. An asymmetry detrimental to HC is usually the result of fetal brain damage: hypoxic–ischemic, toxic, or resulting from viral infection. Despite the well-recognized interest in this identification of proportionate and disproportionate growth, a global appraisal (gestalt) approach is still commonly used in daily pediatric practice to relate head and body proportionality.

Some epidemiologists consider the concept of symmetric and asymmetric intra-uterine growth retardation (IUGR) as probably an artefact resulting from the failure to appreciate the normal relationship between birthweight and body proportionality.[21] Others accept that adaptive sparing in length and head growth in IUGR does in fact occur[22] but also suggest that there is no evidence for the bimodality that would characterize symmetrical and asymmetrical IUGR. In fact, the difficulty comes from the frequent succession of initial sparing and later deficit in brain volume, depending on the severity and time at onset of the placental insufficiency: when the restriction occurs in the last 3 months of pregnancy, sparing by redistribution of supplies of blood and nutrients may operate, and so head growth is maintained for several weeks. This may later be overwhelmed, and then deficit of head growth occurs due to hypoxic–ischemic brain damage. Taking into account this succession of adaptation and failure is basic for obstetrical management of these risk pregnancies but impossible to identify at birth regardless of the refinement of the head–body proportionality measure. Moreover, when the restriction of supplies to the fetus occurs as early as 26 weeks gestation or before, the sparing effect does not operate.[23]

Since the 1980s, different attempts have been made to replace the gestalt approach with a more rigorous approach using different statistical models. As weight is universally and validly measured, it has been for a long time the only parameter used to define growth at birth. To select babies whose heads are out of proportion to their bodies,[24] the HC^3:BW ratio has been proposed as HC^3 is directly related to brain weight (BW). This type of index gives an easy to compute and readily understandable figure. Indices using birth length tend not to be used due to the major imprecision of length measurement. As a complementary assessment, mid arm circumference measurement (MAC) has been used to qualify the nutritional status of newborn infants.[25] It must be measured carefully: with the arm held extended and prone, the measurement is made at the midpoint between the shoulder and the elbow, taking care not to crease the skin during the measurement. The recorded value should be the mean of 3 measurements. A standard, easy to use curve of the MAC:HC

ratio is available from 25 to 42 weeks' gestation.[26]

Finally, each anthropometrical measurement can also be used to calculate the *z* score relative to its GA. Scores are calculated using the formula $z=(X-M)/SD$, where X is one particular measurement of an individual child and M is the mean value for this measurement; both M and SD are based on specific sex and GA subgroups. The *z* score thus indicates the number of SDs by which a measurement deviates from the reference mean.

In fetal life, the difference in *z* scores between each couple of parameters obtained by ultrasound measurements (HC, MAC, femoral length [FL]) measures the presence of asymmetry and its degree in a cohort of small for GA fetuses.[27] One SD and 2SDs of the differences of *z* scores were proposed as cut-off values for the definition of asymmetry. Equivalent standards have not been yet defined for extrauterine measurements.

Cranial sutures: a complementary assessment

BASIC ANATOMICAL DESCRIPTION OF CRANIAL SUTURES

As seen in Figure 1, the two parietal bones are separated at the midline by the sagittal suture. The lambdoid suture is at the junction of these parietal bones with the occipital bone while the coronal suture is found at the junction of the frontal bone. Inferiorly, the squamous sutures are at the junction of the lower edge of the parietal bones with the temporal bones. The metopic suture is located at the junction of the right and left parts of the frontal bone. At an immature stage (fetal and neonatal), every suture is a 1 to 2mm wide membranous zone, easily followed by palpation with the tip of the fingers and is visible to the eye as well as radiologically.

Later in infancy, every suture (temporo-parietal excepted) will show more and more complex indentations with a puzzle-like interweaving between each bone and the next (Fig. 2), and progressive solidification of the system occurs. The temporo-parietal suture (or squamous), however, will show a different pattern of evolution: the edge of both the parietal and the squamous part of the temporal bone becomes oblique and forms a fairly large zone of contact (1 to 2cm high). This

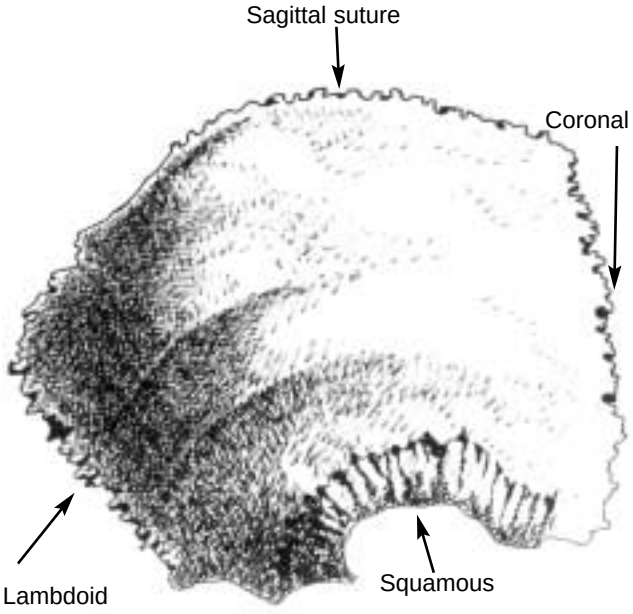

Figure 2: *External view of one parietal bone. Sagittal, coronal and lambdoid sutures become dentate within first years of life and will solidify in a puzzle-like interweaving. Squamous suture is anatomically different: oblique edges of parietal and temporal bones form a 1 to 2cm zone of contact.*

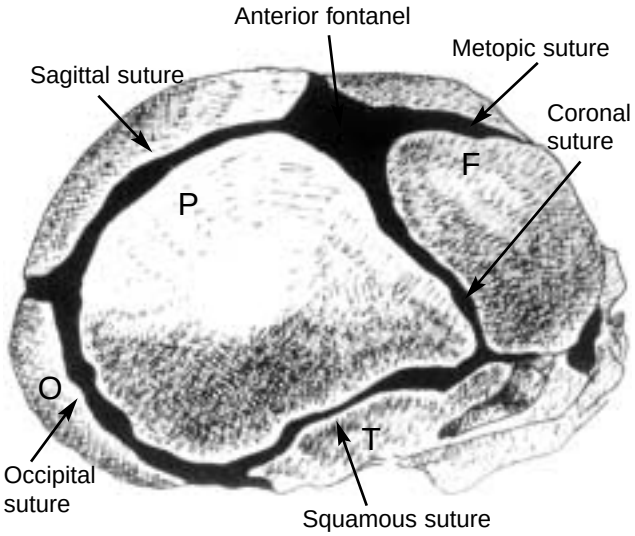

Figure 1: *Skull bones, sutures and fontanels in fetus and neonate. Every suture is made of a 1 to 2mm wide membranous zone. F, frontal bone; P, parietal bone; O, occipital bone; T, temporal bone.*

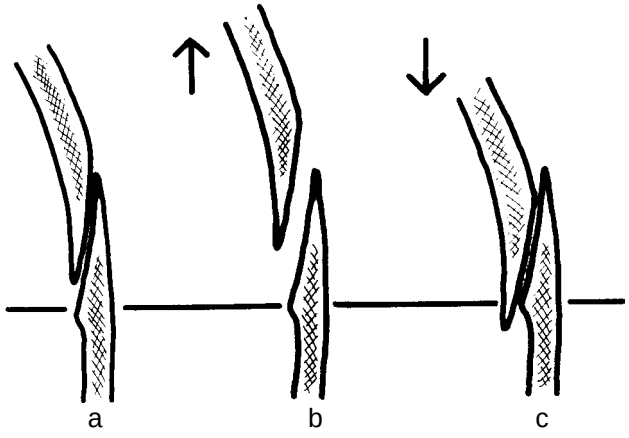

Figure 3: *Junction between cranial vault and cranial base on a vertical section of a squamous suture. (a) in normal situation, oblique edge of temporal bone acts as a console, to sustain parietal bone; (b) with increasing intra-cranial pressure, parietal edge slips upward and distension occurs between 2 edges; (c) with decreasing intra-cranial pressure, parietal bone slips downward, and temporal edge becomes ridge-like.*

set-up between cranial vault and cranial base looks like a console, a bracket, sustaining the convex parietal wall (Fig. 3a). When the parietal bone slips up, due to an increase in cranial pressure, separation between the two edges will be felt (Fig. 3b); when the parietal bone slips down, due to insufficient hemispheric growth, the overlapping of the temporal bone forms a ridge (Fig. 3c).

Before going into the neurological significance of changes observed in cranial sutures, two warnings are worth mentioning: (1) variations such as distension or overlapping can be induced by nutritional or hydration status; therefore, it is mandatory to check the weight curve, to look for edema or signs of dehydration; (2) cranial ridges on one or every suture may also be due to impaired genetic programming of skull development, that is, primary cranio-synostosis. Such genetic abnormalities will not be considered here.

SIGNIFICANCE OF DISTENDED SUTURES

The neonatal cranial vault shows a unique capacity to passively adapt to changes in intra-cranial pressure. This capacity explains the physiological modifications easily observed after most cephalic deliveries: in the first hours of life, overlapping of every suture is observed, depending on the degree of intra-partum moulding. Twelve hours later or so, some degree of distension, especially of the sagittal suture is physiological, due to a mild degree of brain edema following any cephalic delivery. After 3 or 4 days, every suture is normally 'edge to edge'.

Besides these physiological variations around the time of birth, any distension of sutures (5mm or more) has to be considered as a sign of raising intra-cranial pressure. The diagnosis of hydrocephalus is discussed according to the clinical context. Daily measurement of HC will show a fairly vertical curve clearly crossing centiles on a standard chart. Due to this ability to modulate intra-cranial volume, cerebral signs and symptoms of intra-cranial hypertension are usually not as marked as later in life. However, it is worth mentioning that the ability to open sutures varies individually and with GA. Consequently, some infants (mainly premature babies) will show overt cranial signs and moderate cerebral signs; on the other hand, other infants (mainly term or postterm infants) will not show much separation of sutures but overt clinical signs in relation with intra-cranial hypertension such as: sunset sign, yawning, lethargy, irregular breathing, apnoeic spells, bradycardia, vomiting, and arching posture.

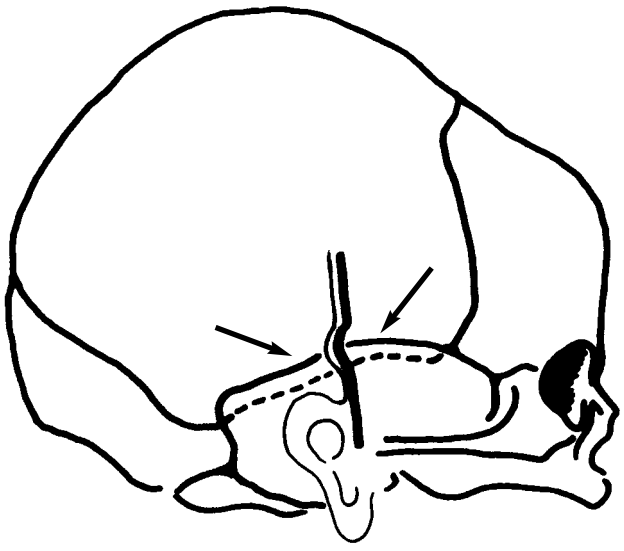

Figure 4: *Squamous ridge on a profile view of skull. A prominent ridge occurs above ear when edge of temporal bone is overlapping parietal bone.*

SIGNIFICANCE OF OVERLAPPING SUTURES

As seen above, the volumetric increase of cerebral hemispheres with maturation is the most important stimulus for the expansion of the cranial vault. This tight link is well illustrated in very severe cases of cerebral atrophy following hypoxic–ischemic encephalopathy over a 2 to 3 month period, HC gradually decreases by 2SD from its initial value, where it tends to stabilize. At the same time, all cranial sutures develop a prominent ridge, mimicking craniosynostosis. A tendency of decreased rate of head growth in full term newborns with hypoxic–ischemic encephalopathy may predict microcephaly before its actual occurrence.[28]

In cases of a prenatal hypoxic–ischemic encephalopathy, when the insult occurs at least several weeks before birth, the presence at birth of cranial ridges on every suture can be a precious clue to prenatal damage (most often undetected before birth).[29] Other morphologic signs may be associated: a high-arched palate due to the defective fetal sucking and a tightly clenched fist with an adducted thumb due to damage in the motor control system. When indicated by these signs, early MRI (i.e. within the first few days of life) often shows a brain damage that is clearly prenatal. The diagnostic value of these signs is linked to their presence at birth. If not identified soon after birth, they will be of no value later in dating the insult as any intra-partum insult could have provoked identical signs after a few weeks. Much litigation can be avoided by the routine practice of a careful cranial assessment.

PARTICULAR SENSITIVITY OF THE SQUAMOUS SUTURE

Arthur Parmelee[30] was the first to draw attention to the squamous suture, as being more revealing to clinicians than the other sutures when distended in the neonatal period: 'The lower margin of the parietal bone is, in my experience, always in contact with the temporal bone and greater wing of the sphenoid except in cases of hydrocephalus. A widened squamous suture, I believe, is a reliable sign of hydrocephalus and is of value early when comparative measurements are still equivocal' (p70). This means that due to its location at the junction of cranial vault and cranial base, as discussed above, the squamous suture is the last to open with raising intra-cranial hypertension.[31] As an image, the cranial vault first opens as a chestnut envelope, with distension occurring on every suture, the squamous excepted. It is only with ongoing intra-cranial hypertension that the whole cranial vault is moving up, that is, the squamous sutures separate.

In developmental studies, the systematic clinical practice to palpate the squamous suture just above the ears (Fig. 4) has been initiated by Saint-Anne Dargassies.[32] During the first few months of life, one can feel the edge to edge status at the squamous suture site in normal development. The response of the squamous suture to a moderately deficient

brain growth appears different from the other sutures.[33] While every other suture is staying edge to edge, the parietal bone slips down and the temporal bone overlaps the parietal bone externally, thus creating a squamous ridge. Being the first to overlap, the squamous ridge can be interpreted as an early and indirect neurological sign reflecting subtle brain damage. This squamous ridge may indeed constitute an accessible marker of moderate perinatal brain damage. Its inclusion among minor neurological signs has been justified by our recent results on its predictive value for non-optimal developmental outcome.[33–35]

Head growth profiles and categorization at 2 years corrected age

In ideal conditions, head growth follows a smooth progression in the same range on the standard chart as body growth and with adequate head–body proportionality and suture status. However, various deviant situations can be identified during the two first years of follow-up. Due mainly to the unique and temporary capacity of the skull to adapt to the brain volume, catch-up growth or decline can be observed. However, facing the lack of a universal definition of catch-up growth or decline, each clinical or investigative team has to define its own standards to classify these parameters. Discrepancies between these home made classifications prevent any valid comparison between various cohort studies.

Our own definitions are as follows: (1) decline – decrease of 1 or 2SDs or more, not followed by a catch-up; (2) a catch-up – increase of 1 or 2SDs or more, whether or not preceded by a postnatal decline. The catch-up after decline is defined as complete when returning to the initial range or incomplete when showing a trend (1SD) but not reaching the initial value.

In order to include all observations concerning suture status and head growth characteristics, it seems wise to wait until after the most rapid head growth period, at around 2 years for corrected age. Stabilization of head growth profile is usually reached at this stage. Several categories are emerging: microcephaly, macrocephaly, and normocephaly.

MICROCEPHALY

Absolute microcephaly

There are two types of absolute microcephaly: (1) primary is defined as 2SD below mean since birth; (2) secondary is defined as 2SD below mean, postnatally acquired. From a semantic point of view, it is interesting to note that the term 'microcephaly' (literally small head) is used to designate both a small head and a small brain ('micrencephaly', literally small brain is rarely used)

Relative microcephaly postnatally acquired

A continuous decline of more than 50 centiles between birth and 18 months in infants whose HC at birth was above the 52nd centile is one definition proposed under the term of 'relative microcephaly'.[28] Another proposal is a drop of more than 2SD, under the term of 'suboptimal head growth'.[36]

Macrocephaly

It is currently defined by 2SD above the mean. Mostly of genetic origin, this sign is nearly always present from birth, with edge to edge sutures. Genetic influence is very common. From a semantic point of view, the term 'macrocephaly' (enlarged head) is not synonymous of 'megalencephaly' (enlarged brain), as the brain may or may not fill the skull, as shown on MRI.

Normocephaly

Two SD below or 2SD above the mean crudely defines it. Based on this review, it becomes easy to understand that such definition of normal head growth is not synonymous with normal brain growth.

Conclusion

The classical assessment considers mainly the HC measurement. This parameter may be misleading when used without complementary assessments such as estimation of head–body proportionality and appraisal of cranial sutures. These two variables may appear superfluous when dealing with overt brain damage. However, they become essential, and are possibly the only cue, in cases of more subtle brain damage as these children rarely reach HC below 2SD. Therefore, our claim is that this complementary assessment should be considered essential for early identification of children at higher risk of unfavourable long-term outcome.

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