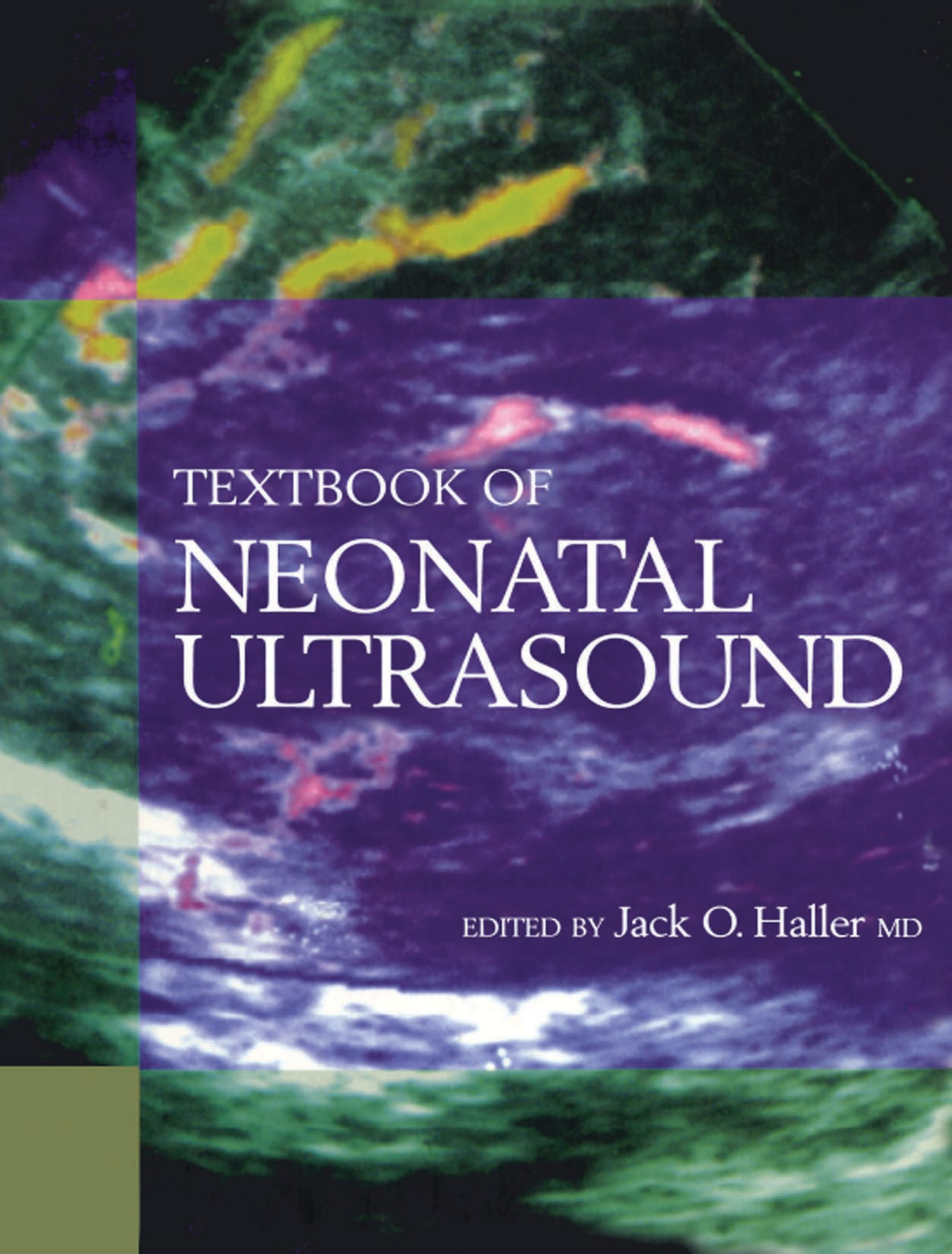

TEXTBOOK OF NEONATAL ULTRASOUND

EDITED BY Jack O. Haller MD

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informa
healthcare

New York London

First published in 1998 by Parthenon Publishing Group.
This edition published in 2011 by Informa Healthcare, Telephone House, 69-77 Paul Street, London EC2A 4LQ, UK.

Simultaneously published in the USA by Informa Healthcare, 52 Vanderbilt Avenue, 7th Floor, New York, NY 10017, USA.

Informa Healthcare is a trading division of Informa UK Ltd. Registered Office: 37–41 Mortimer Street, London W1T 3JH, UK. Registered in England and Wales number 1072954.

A CIP record for this book is available from the British Library.

ISBN-13: 9781850709022

Orders may be sent to: Informa Healthcare, Sheepen Place, Colchester, Essex CO3 3LP, UK
Telephone: +44 (0)20 7017 5540
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Typeset by Speedlith, Manchester, UK

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Foreword

As Editor of this text I have asked my friends, who are all superb pediatric radiologists in major medical centers, to contribute in areas of their expertise. These individuals have had many years of dedicated service to the care and diagnosis of neonatal conditions and many have developed an expertise in that area of speciality. It is to their expertise that I have sought their authorship.

This is a book for two particular audiences. First, it is intended to provide those concerned with the care and treatment of the neonate and young infant with an up-to-date text on the ultrasound manifestations of neonatal disease. Second, it is intended for those concerned with imaging the neonate, i.e. sonographers and radiologists, who rely on ultrasound to diagnose many of the neonatal conditions.

The book does not include echocardiography which really requires a text of its own.

It is my hope that the reader will enjoy this text and that it will prove useful in the day-to-day joy of taking care of the newborn.

Jack O. Haller

Dedication and acknowledgments

This book is dedicated to my Chairman of 22 years, Joshua A. Becker, M.D., who has supported, encouraged, and provided me with a superb academic environment that allows projects such as this one to be completed. He is the complete scholar, administrator and friend.

I want to thank Gloria Jorge and Barbara Roseman for their contributions to the technical aspects of this manuscript. Also, my colleagues Harris Cohen, M.D. and Rona Orentlicher, M.D. without whom I would not have had the time to complete this work.

Normal neonatal head ultrasound

1

Faridali G. Ramji and Thomas L. Slovis

Major technological advances have occurred since the late 1950s when ultrasound was first utilized by Leksell in the assessment of intracranial contents[1]. The amplitude mode (A-mode) scanning and static gray scale imaging are of only historical interest. The linear array units with large transducers have now been replaced by sector and linear, high frequency, small head transducers that comfortably fit over the fontanelle. The use of water baths and stand-off pads has been replaced by application of standard direct contact coupling gel used for all ultrasound scanning. The patient, who is often premature and in distress, is scanned by portable units brought to the nursery. The examination time has shortened and, in experienced hands, takes 5 to 10 minutes[2]. The resolution of images since Leksell's use of ultrasound in 1956 (A-mode sonography[1]), and the pioneering work of Kossoff and colleagues[3], and Garrett and colleagues[4] on ultrasound of the normal and hydrocephalic neonatal brain have markedly improved with the real-time gray scale imaging[5–43]. The inclusion of color and pulsed wave Doppler has added to the versatility of ultrasound in imaging through the cranium[44–55] and the understanding of vascular anatomy of the brain. Ultrasound has the distinct advantage over computed tomography or magnetic resonance imaging in its portability, being inexpensive, and non-invasive without sedation[10,18,19]. This makes it suitable for imaging neonates in intensive care units (NICU or ICU).

Embryology relevant to neurosonography

The formation of the central nervous system (CNS) in humans is extremely complex[56–59]. An in-depth discussion of its embryology is beyond the scope of this chapter. However, the key processes that lead to normal development are summarized here. Their inclusion and their understanding aids in the understanding of the normal development of the CNS as well as of congenital and developmental anomalies.

Neurulation (primary and secondary)

Brain development begins with dorsal induction at approximately day 14 post-fertilization with the formation of the neural plate (primary neurulation) on the dorsal aspect of the embryo[56]. At day 21 post-fertilization, the neural folds begin to fuse at its midpoint converting the neural plate into a neural tube. The fusion and closure proceeds like a zipper with the cranial end of the neural tube or anterior neural pore closing on day 24 and the caudal end or posterior neural pore closing at 26 days post-fertilization[56]. The neural tube will give rise to the brain and spinal cord and the hollow portion of the neural tube will be converted into the ventricular system of the brain and the central canal of the spinal cord. Secondary neurulation results from interactions of notochord and mesoderm in formation of the dura, pia, vertebrae, and skull.

Ventral induction – formation of brain vesicles

In the beginning of the fourth week post-fertilization, the cranial end of the neural tube undergoes expansion, flexion, and fusion of the neural pores giving rise to three primary brain vesicles: the forebrain or prosencephalon, the midbrain or mesencephalon, and the hindbrain or rhombencephalon[56] (Figure 1). The rapidly growing embryo, especially at the cranial end, undergoes two ventral flexions resulting in a midbrain or mesencephalic flexure at the region of the future midbrain and the cervical flexure at the junction of the hindbrain and the spinal cord (Figure 2). At about the fifth week, the prosencephalon develops into two vesicles, the telencephalon anterior and the diencephalon posterior (Figures 1 and 2).

Adult derivatives

Neuronal proliferation, differentiation, histogenesis and cellular migration, as well as neuronal

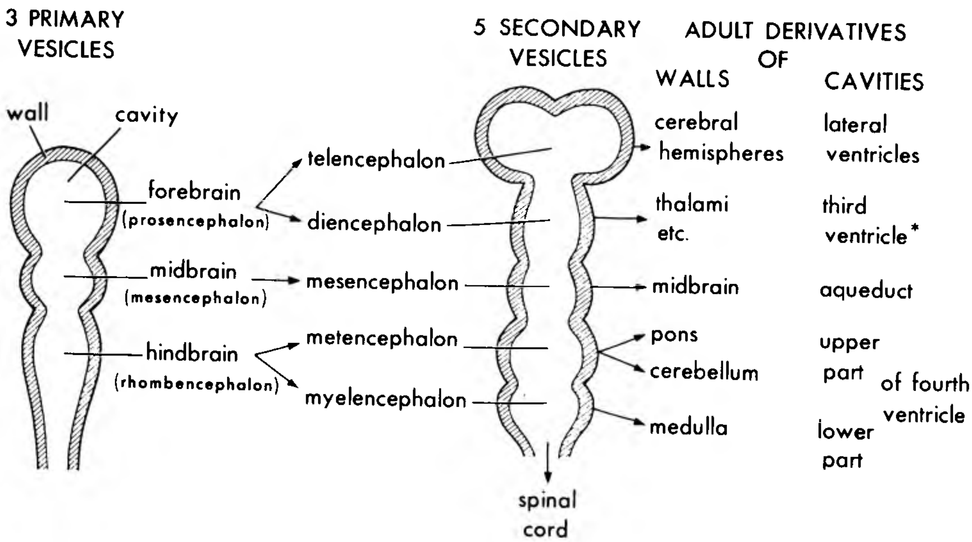

Figure 1 Diagrammatic representation of brain vesicles with their wall and cavity and their adult derivatives. *The anterior part of the third ventricle forms from the cavity of the telencephalon but most of the third ventricle is derived from the cavity of the diencephalon.The fourth ventricle results from the cavity of the rhombencephalon and the aqueduct results from the cavity of the mesencephalon. (With permission[56])

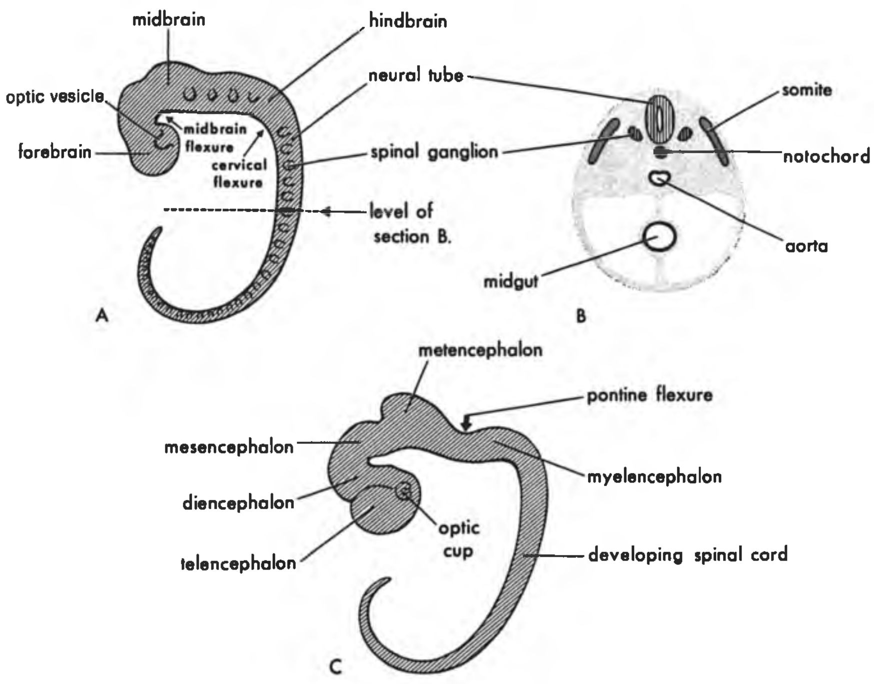

Figure 2 Diagrammatic representation of developing brain at the end of the fifth week. A and B depict the rapid growth, expansion, and flexion that occur at the cranial end of the neural tube. The development of the pontine flexure (C) separates the rhombencephalon into its two components, metencephalon superiorly and myelencephalon inferiorly. (With permission[56])

organization, result with subsequent myelination and maturation of the myelin. All are required in formation of the normal CNS. The telencephalon will become the cerebral hemispheres with their lateral ventricles and slit-like third ventricle, and the diencephalon gives rise to the thalamus and hypothalamus and contributes to the formation of neurohypophysis of the pituitary gland[56]. The adenohypophysis or the glandular portion arises from the oral ectoderm or stomoderm. The mesencephalon will give rise to the midbrain. The rhombencephalon gives rise to the myelencephalon and metencephalon. The myelencephalon forms the medulla oblongata, and the metencephalon the pons and the cerebellum.

Technical considerations, indications and hazards of neurosonography, and anatomy

The sonograms are performed using the highest frequency sector and linear-array transducers (usually 7–10 MHz) which gives optimal resolution of the anatomy. The acoustic windows to intracranial structures are the anterior[24], posterior and posterolateral fontanelles, and the foramen magnum[5] or over other sutures such as the metopic suture[28]. If necessary, scanning through the thin squamosal portion of the temporal bone could be utilized when fontanelles are closed[5,18,24]. Placing the transducer just medial and caudal to the mastoid process allows improved visibility of structures in the posterior fossa[60]. Standard acoustic coupling gel is placed over the surface of the head. The commonly used acoustic window is the anterior fontanelle with images carried out in coronal, modified coronal, sagittal and modified sagittal planes. Imaging is modified because we must scan through a fixed point, such as the anterior fontanelle[6].

Image quality should be maximized and may require the adjusting of many technical parameters. This includes the transmit zone enhancement, depth compensation, persistence, pre- and post-processing adjustments, and the number of focal zones[5]. We obtain both video tape and gray scale hard copy for documentation, but the most recent innovation is the filmless department with all reading from the monitor and storage via optical disk (or tape).

The clinical indications of head ultrasound in the neonate, premature or term, have been summarized in Table 1[2,61]. Although no known deleterious effects have resulted or have been reported from diagnostic ultrasound, nevertheless, there may be hazards from the procedure of performing the neurosonogram on the premature neonate, and this requires mention[62]. The hazards include inadvertently moving the endotracheal tube, spread of infection due to inadequate cleaning of the transducers and/or the operator's hands, hypothermia may result during the procedure, and bradycardia from application of too much pressure on the fontanelle with the transducer. Precautions suggested include: (1) minimizing head and neck movement, (2) minimizing pressure applied on the fontanelle, (3) using prewarmed coupling gel which is removed after scanning to minimize heat loss due to evaporation, (4) careful handwashing, and (5) wiping the transducer with 70% isopropyl alcohol or 2% alkalinized glutaraldehyde between studies[62].

It is important that every patient's head ultrasound is carried out in a standard manner and the same anatomical landmarks[13] are imaged such that normal and abnormal anatomy can be correlated from one patient to another. This also allows all technologists performing neonatal head ultrasound to be consistent even when one patient is scanned by several technologists during the course of a hospital stay. In the coronal plane we obtain eight ultrasound images, all acquired by radially sweeping the transducer from anterior to

Table 1 Clinical indications for ultrasonic intracranial evaluation[2,61]

Premature infants
In all less than 1500 g or < 32 weeks gestation
Suspected intracranial bleeding
As follow-up to any detected abnormality, i.e. enlarged ventricles, parenchymal injury
Secondary to bleeding
Secondary to hypoxia/apnea
Premature or full-term infants
Large or rapidly enlarging head size, or increased intracranial pressure
Seizures
Cranial bruits
Meningomyelocele patient/CNS anomaly
Following central nervous system infection
subdural collection
ventriculitis
parenchymal changes (abscess, other)
Traumatized or asphyxiated infant
Follow-up on surgical procedures or shunt placement (ECMO)
Low Apgar
Older child
Through craniotomy site for evaluation of ventricular size

posterior cranium (Figure 3). In the sagittal plane there are five images obtained, one in the midline and two in the parasagittal region on each side of the midline (Figure 3). Four additional images are obtained with the linear array transducer, one coronal and three sagittal for improved resolution and detection of small subependymal hemorrhage.

Scanning in the coronal plane

In the coronal plane, the following images are obtained (Figures 4 and 5).

(1) The transducer is angled forward, anterior to the frontal horn, such that bright echoes result from the orbital roof and ethmoid complex (Figures 4 and 5). The anterior part of the cerebral hemispheres gives fine but low level echoes and the echogenic midline falx oriented vertically in the interhemispheric fissure is demonstrated (Figures 4a and 5). The bony reflective echoes give a 'steer's head' appearance[13] (Figure 4a).

(2) The second coronal plane is slightly posterior to the first plane such that the 'steer's head' changes to a 'mask' appearance[13] (Figure 4b). This results from the lesser wing of the sphenoid giving rise to the echogenic upper portion of the mask; the lower portions of the mask are reflections resulting from the greater wings of the sphenoid forming the anterior floor of the temporal fossa (Figure 4b). The central portions of the mask are formed by dense echoes resulting from the planum sphenoidale. The echogenic falx in the interhemispheric fissure forms a prominent vertical landmark where the anterior cerebral artery pulsations are noted. Short horizontal echoes arising from the brain surface are visible just off the midline and, of these, the most prominent is that resulting from the cingulate sulcus with the cingulate gyrus just below it. The slit-like semi-lunar shaped hypoechoic regions on either side of midline are the frontal horn of the lateral ventricles with the caudate nucleus abutting and indenting each lateral wall (Figure 5).

(3) The third coronal landmark is the sylvian fissure between the frontal lobe and the temporal lobe which appear as 'Y' shaped[13] (Figures 4 and 5). The echogenicity is not as pronounced as bone and results from the combination of pulsating branches of the middle cerebral artery and the

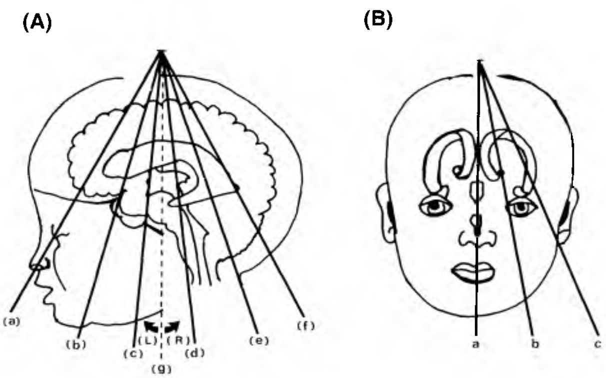

Figure 3 Planes of transfontanelle cranial ultrasound. (A) coronal sections: plane (a) anteriorly to the frontal horn of the lateral ventricles. Plane (b) through the frontal horn of the lateral ventricles. Plane (c) at or just anterior to the foramen of Monro. Plane (d) section just posterior to the foramen of Monro. Plane (e) through the body of the lateral ventricles and plane (f) through the atria or trigone of the lateral ventricles. Plane (g) are angled coronal scans on each side at the level of the foramen of Monro and arrows indicate angulation left (L) or right (R). (B) sagittal sections: plane (a) sagittal plane in the midline. Plane (b) and (c) are 15° and 30° parasagittal angulation, respectively. (Reprinted with permission[2,13])

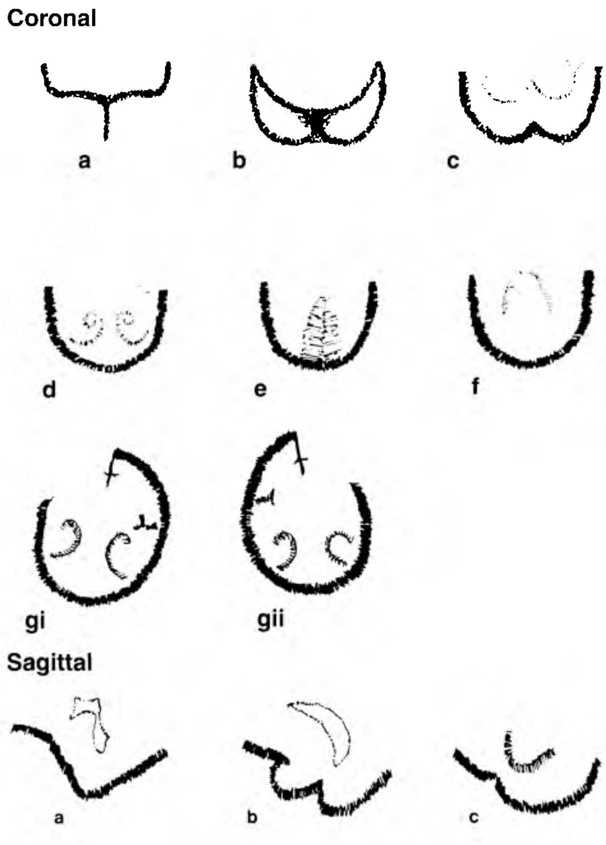

Figure 4 Diagrammatic representation of bony landmarks seen during the performance of a transcranial ultrasound in the coronal and sagittal planes. The bony and parenchymal features represented are referred to in the relevant text and sonographic planes are depicted in Figure 3. gi, angulation to left; gii, angulation to right. (Modified with permission[13])

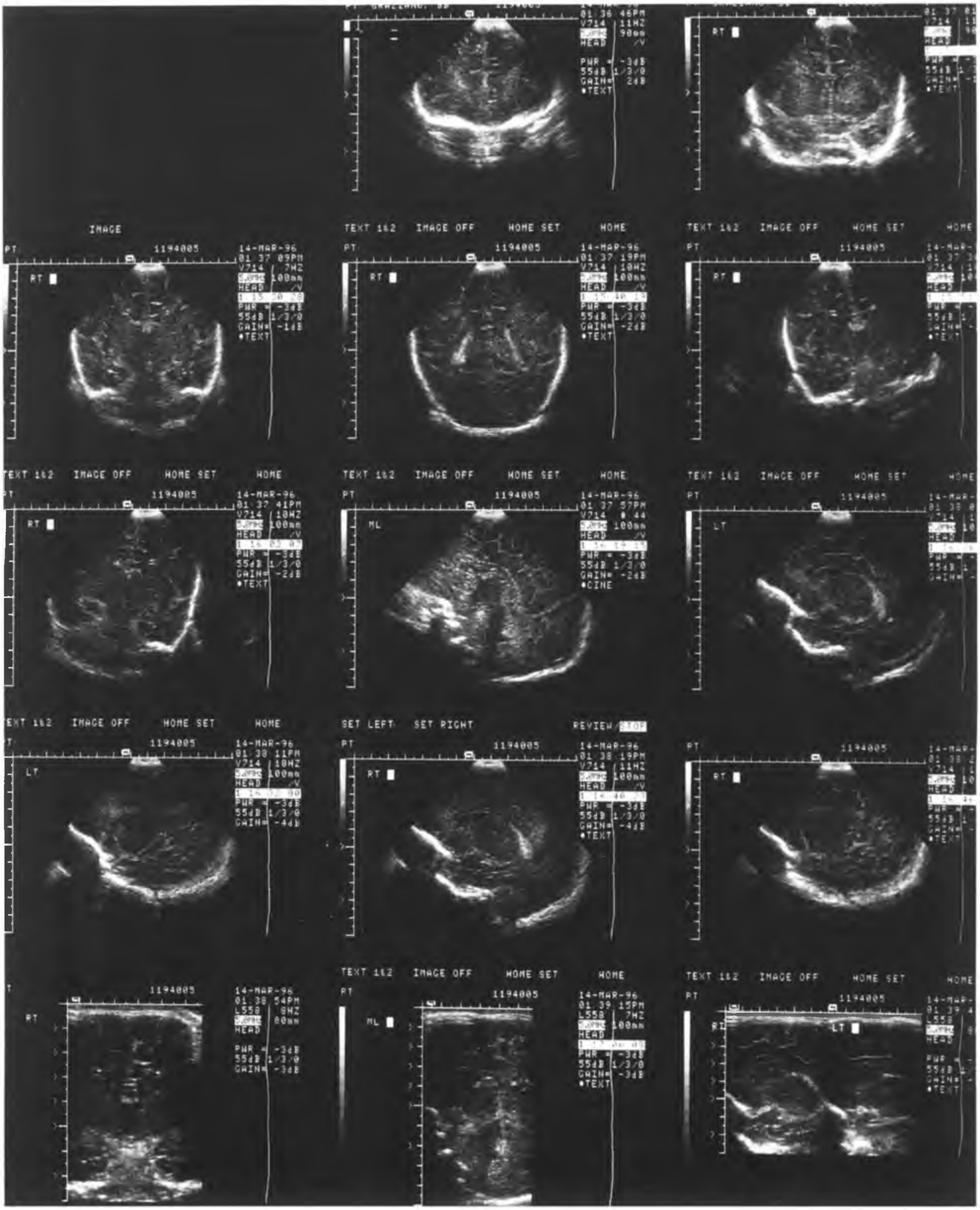

Figure 5 A standard head ultrasound. The first blank square is the patient's relevant data and the clinical history. This is followed by six coronal images using a sector transducer, two of which are in the angled coronal planes. The five sagittal images using sector transducer are then acquired. This is followed by obtaining one in the coronal and three in the sagittal planes using a high resolution linear transducer specifically in the midline and at the level of the caudothalamic grooves (the last picture is a composite dual image at each caudothalamic groove). Performing the sonogram in this manner allows for one film consisting of all the patient data plus 14 images. (See Figure 19 for details of individual images)

collagen of the leptomeninges. The appearance of the sylvian fissure may serve as a clue to gestational age and will be discussed later. This ultrasound image is at or just anterior to the foramen of Monro. The slit-like anechoic frontal horns of the lateral ventricles are again visualized but situated slightly more posterior than on the previous image and have more of a 'boomerang' shape than the semi-lunar shape[13] (Figure 5). In the midline between the ventricles lies the echogenic septum pellucidum and, often in the premie with fluid between the two walls, the anechoic cavum septum pellucidum. Inferolateral to the frontal horn lies the head of the caudate nucleus which is of medium echogenicity. Lateral to the caudate are the anterior limb of the internal capsule and the lentiform nucleus (comprised of globus pallidus medially and putamen laterally). In the near field above the roof of the frontal horns is the genu of the corpus callosum, which is composed of homogeneously packed axons and appears hypoechoic except at its surface which is echogenic due to pial tissue. In the midfield below the septum pellucidum is the slit-like foramen of Monro.

(4) This section is just posterior to the foramen of Monro and, when there are no abnormalities identified, could be combined with the image prior to it. However, the image behind the foramen of Monro shows the anechoic bodies of the lateral ventricle and the echogenic choroid plexus lie on the floor of the ventricle. The third ventricle may not be visible in the coronal plane or it may appear as a slit-like structure in the midline below the lateral ventricle. On either side of the third ventricle is the thalamus, which is of medium echogenicity. Further lateral are the medial extensions of the sylvian fissure. Prominent landmarks on this image in the far field are the C-shaped structures composed of parahippocampal gyrus and the medial gyrus of the temporal lobe (Figure 4d). In the midline between the temporal lobes are the cerebral peduncles. A normal temporal horn of the lateral ventricle is rarely seen on this plane[19].

(5) Further posterior angulation results in a landmark composed of an echogenic inverted 'V' formed by the cerebellum medially and the tentorium laterally[13] (Figure 4e). The sonolucent normal lateral ventricle is not prominent but outlines the echogenic choroid plexus. In the midline the quadrigeminal plate cistern may be visible as a small echogenic area, containing vessels and leptomeninges.

(6) The sixth image is posterior to the previous image. The very bright echoes in the far field are from the calvarium. In the midfield, the glomus of choroid plexus appear as divergent echogenic bands located in the trigone of the lateral ventricle (Figures 4 and 5). Around the choroid may be the anechoic cerebrospinal fluid (CSF) of the lateral ventricle but generally the choroid plexus on this image fills the lateral ventricle.

(7) Coronal angled images are routinely obtained and are quite helpful in detecting extra-axial fluid over convexities of the brain. This view is performed by obtaining an image on each side with the transducer in the coronal plane but angled to the left or right at the level of the foramen of Monro (Figures 3, 4 and 5). These images can be acquired at any time in the study. One additional image is obtained in the coronal plane through the foramen of Monro with a linear array transducer. The linear transducer provides better resolution (see Figures 4 and 5), especially for detecting subtle bleeds.

Scanning in the sagittal plane

In the sagittal plane, the following images are routinely obtained (Figures 4 and 5).

(1) The midline sagittal image is one of the most important, especially in ruling out any congenital anatomical abnormalities and in defining the posterior fossa. The superior sagittal sinus, which is the most superior portion of the falx cerebri, can be assessed as it lies under the anterior fontanelle. Visualization requires color Doppler and this will be addressed later with vascular anatomy. The cingulate gyrus is identified and is limited superiorly by the cingulate sulcus and inferiorly by the callosal sulcus (Figure 5). The gyrus consists of hypoechoic gray matter and slightly echogenic white matter centrally. The corpus callosum is a hypoechoic structure, the thickness of which may vary with age. The cavum septum pellucidum is seen below the corpus callosum in most premature infants. The massa intermedia or the thalamic adhesion (intrathalamic connection) and the foramen of Monro are seen easily. The third ventricle is best seen on this image with its chiasmatic and infundibular recesses anteriorly and pineal and habenular recesses posteriorly. Further inferior and posterior are the aqueduct of Sylvius and posterior fossa with the fourth ventricle. Posterior to the fourth ventricle is the midline cerebellum – the echogenic vermis. The triangular tip of the roof of the fourth ventricle is called the fastigium. The cisterna magna lies posterior and inferior to the cerebellum and should be identified

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