THE DANDY-WALKER SYNDROME

Z.DOMINGO

A Dissertation in fulfillment of Part three of the MMed (Neurosurgery)

Submitted to the University of Cape Town

September 1992

Supervisor: Jonathan Peter MBChB, FRCS

Department of Paediatric Neurosurgery

Red Cross War Memorial Children's Hospital

Acknowledgement

I would like to thank Professor J.C. de Villiers and Dr. Jonathan Peter for their support and guidance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Dandy-Walker syndrome (DWS) has been defined as a congenital malformation of the structures of the posterior fossa characterised by cystic dilatation of the fourth ventricle, hypoplasia of the cerebellar vermis, enlargement of the posterior fossa, atresia of the foramina of Luschke and Magendie and associated hydrocephalus. Since its initial description definitions have been modified to include findings encountered in a particular case or series of cases.

This lack of uniformity of the diagnostic criteria has made the objective assessment of management and outcome difficult. It has also resulted in terms such as Dandy-Walker variant, mega cisterna magna, persistent Blake's pouch and prominent cisterna magna, being applied to posterior fossa cysts which do not fit in with the particular criteria used for the series described.

In an attempt to overcome this difficulty recent classifications based on the morphological characteristics of midline posterior fossa cysts have appeared in the literature. Although it is not disputed that the different posterior fossa cysts have a different embryogenesis and pathogenesis, their presentation to the clinician with symptoms and signs of hydrocephalus is similar and the clinician is faced with the same therapeutic dilemma, irrespective of the nature of the cyst.

This thesis presents the current understanding of the DWS and elaborates on the controversies regarding not only the definition of the syndrome but also in the management of this complex developmental anomaly. It is a clinical study on a limited number of patients and serves as a guideline to the clinician.

HISTORICAL OVERVIEW

Since its initial description more than one hundred years ago, the syndrome of hydrocephalus associated with a posterior fossa cyst has been the topic of many publications yet is still controversial and has many problems which are unanswered. Although the description of the syndrome has been attributed to Dandy and Walker, many authors have contributed to its understanding.

The association of hydrocephalus, hypoplasia of the cerebellar vermis and a posterior fossa cyst was first reported by Sutton in 1887[78]. Due to the inadequacy of this description and the misunderstanding of the pathogenesis, the first true description of this association of anomalies is credited to Dandy and Blackfan who in 1914 reported the association of hydrocephalus with cystic dilatation of the fourth ventricle and cerebellar anomalies in a thirteen month old infant[22]. This infant presented with the classical symptoms and signs of hydrocephalus. With the intraventricular administration of phenolsulfonphthalein Dandy and Blackfan were able to demonstrate that there was no communication between the ventricular system and the subarachnoid space. The infant was treated conservatively and died two months after the diagnosis was made. Autopsy revealed cystic dilatation of the fourth ventricle and

associated hypoplasia of the vermis. The aqueduct was dilated and the foramina of Magendie and Luschka were absent. The pathology of this syndrome was, therefore, attributed to atresia of the outlet foramina of the fourth ventricle.

By 1921 a further ten cases of hydrocephalus due to outlet obstruction were described by Dandy[21]. In this series of eight infants and two adults with hydrocephalus the aetiology of the outlet obstruction was classified as either congenital or post-meningitic. In the post-meningitic group the fourth ventricle was not dilated while congenital group had the classical features of the posterior fossa cyst. The outlet obstruction was confirmed either at surgery or at postmortem. Dandy felt that the only satisfactory treatment of any form of hydrocephalus was the treatment of the cause.

Three patients were operated on in an attempt to create an opening between the cystic dilatation of the fourth ventricle and the subarachnoid space. This was successfully performed in two patients, both adults, with post-meningitic outlet obstruction. The third patient was a three month old infant who died following puncture of the dilated fourth ventricle presumably from a rapid decompression of the hydrocephalus.

In 1942 Taggart and Walker described three cases of posterior fossa cysts associated with hydrocephalus and congenital atresia of the outlets of the fourth ventricle[79]. As in the case of Sahs published in 1941[72], all patients died following surgical attempt to relieve the obstruction by creating an opening between the fourth ventricle and the subarachnoid space. Autopsy examination revealed the presence of hydrocephalus in association with cystic dilatation of the fourth ventricle and dysgenesis of the vermis. The foramina of Magendie and Luschka were not seen. Histological examination of the cyst membrane was performed in one patient. It consisted of three layers: an internal layer of ependyma, an intermediate layer of glial tissue and an external layer of connective tissue which was continuous with the pia-arachnoid of the cerebellum.

The term "Dandy-Walker syndrome" was proposed by Benda in 1954[8]. His description was based on the reports of Dandy and Blackfan and Taggart and Walker. Although Benda gives a brief clinical description of the syndrome, the emphasis is on the neuropathological aspects of the Dandy-Walker syndrome as seen in the six patients in his series. The description of Benda included hydrocephalus, cystic transformation of the fourth ventricle and hypoplasia of the cerebellar vermis. Benda was able to demonstrate that the atresia of the outlets of the fourth ventricle was not an essential feature of this syndrome and in a few of his

patients there was passage of dye from the fourth ventricle into the subarachnoid space. Although the failure of the foramen of Magendie to develop in some cases was obvious, it was felt that this was not the main feature of the syndrome and that the main pathology consisted of a cyst in place of the posterior medullary velum with cleft formation of the cerebellum. As the clinical features and pathological findings formed a definite morbid entity and because the atresia of the outlet foramina of the fourth ventricle were not an essential part of the syndrome, Benda felt that the term "Dandy-Walker syndrome" should be applied to the entity so as to distinguish it from other developmental disorders of the cerebellum.

Since 1954 the literature has been concerned with the controversies, not only in the treatment and outcome of the Dandy-Walker syndrome but also with the definition of the many variants[43,82]. The main difficulty is that the definition of the Dandy-Walker syndrome is not clearly established and varies according to the diagnostic technique employed. Although modern techniques of CT and MRI scanning have provided good anatomical definition of the posterior fossa cyst and associated central nervous system congenital anomalies, the CSF dynamics and the relationship between the cyst and the fourth ventricle, which was previously obtained with ventriculography, have been lost. In an attempt to resolve this issue recent literature has been

devoted to the classification of midline posterior fossa cysts[4,7]. It is hoped that this will help not only in the understanding of the Dandy-Walker cysts but also enable one to meaningfully compare the management and outcome of published series.

PATHOLOGY OF THE DANDY-WALKER SYNDROME

PATHOLOGY[13,14,20-22,25,30,31,33,45,51,70,72,85]

Posterior fossa cyst (Figure 1)

The posterior fossa cyst is the most obvious feature of the Dandy-Walker syndrome. It fills the posterior fossa and is continuous with the fourth ventricle. It is this communication with the fourth ventricle which differentiates the Dandy-Walker syndrome from arachnoid cysts of the fourth ventricle. The roof of the cyst is composed of a thin translucent membrane which extends from the superior vermis superiorly, to the medial edge of the cerebellar hemispheres laterally and to the calamus scriptorius inferiorly. Depending on the size of the cyst it may extend superiorly through the tentorial hiatus, posterior to the quadrigeminal plate and into the supra-tentorial compartment and inferiorly through the foramen magnum into the spinal canal. The histology of the cyst wall is also important as it differentiates Dandy-Walker cysts from arachnoid cysts. It is composed of a three layered membrane. The inner layer is ependyma and is continuous with the ependyma of the fourth ventricle. The outer layer is arachnoid. Between these two layers is a layer of neural tissue representing the compressed and dysgenetic inferior vermis. In parts this

layer may be extremely thin consisting of a few myelinated nerve fibres and glial remnants.

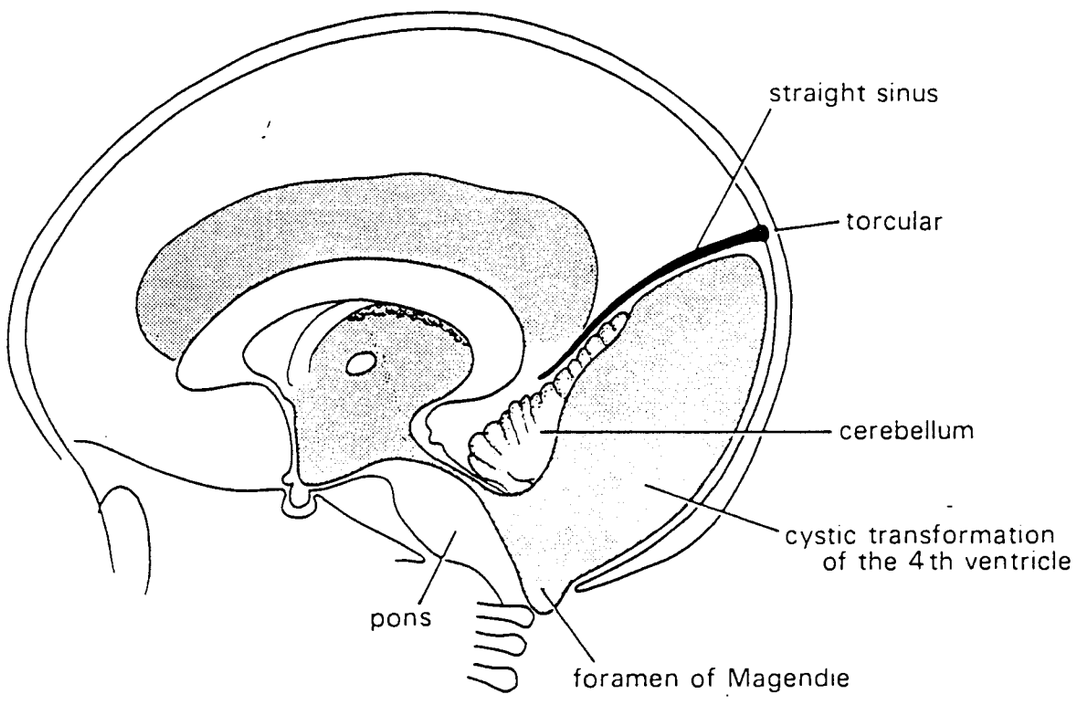


FIGURE 1: Diagram showing Dandy-Walker Cyst

Dandy-Walker Cyst showing antero-superiorly displaced hypoplastic cerebellar vermis, cystic transformation of the fourth ventricle, and associated hydrocephalus.

(from: Mori K. Anomalies of the Central Nervous System)

The patency of the outlet foramina has been the subject of debate in the past. Until the publication of Benda in 1954 it was believed that there was no communication between the cyst and the subarachnoid space due to atresia of the foramina of Luschka and Magendie. This was thought to be an essential pathological feature of the syndrome. Patency has been clearly demonstrated in 50%-82% of clinical and pathological series. Thus atresia of the foramina of Luschka and Magendie, once considered to be the hallmark of the Dandy-Walker syndrome is absent in the majority of patients and no direct correlation has been demonstrated between patencty of the outlets of the fourth ventricle and the degree of hydrocephalus.

The choroid plexus of the fourth ventricle is displaced anteriorly and inferiorly and is usually hypoplastic.

Cerebellum

The cerebellar hemispheres are hypoplastic and are displaced posteriorly and laterally by the large cyst. The nuclei of the cerebellum may also be deformed or absent.

The degree of vermian involvement depends on the severity of the Dandy-Walker syndrome. The inferior vermis lies within the cyst wall and is usually dysplastic consisting of a few neural and glial elements. The superior vermis is preserved

but is displaced superiorly by the cyst. It may also be rotated superiorly making identification on axial CT scans difficult. This superior displacement may impinge on the quadrageminal plate within the tentorial hiatus with resultant secondary aqueduct stenosis.

Posterior fossa dura and venous sinuses

The posterior fossa is large and there is elevation of the tentorium and the venous sinuses. Whether these changes are primary or secondary is not clear. It is likely that the changes are secondary to enlargement of the fourth ventricle with inhibition of the downward migration of the transverse sinuses and confluence of sinuses. In contrast to the Arnold-Chiari malformations where the dural structures are abnormal, in the Dandy-Walker syndrome, except for the elevated position of the sinuses and the tentorium, the dural structures are normal.

Vascular anatomy

Knowledge of the arterial and venous anatomy has been gained from carotid and vertebral angiography which was an important diagnostic modality prior to the development of CT scanning.

Features on cerebral angiography

*bowing of the anterior cerebral arteries - indicative of hydrocephalus

*elevation of the middle cerebral artery - due to dilatation of the temporal horns

*posterior cerebral arteries -displaced upwards and laterally due to increased pressure in the posterior fossa

*Vein of Galen - often duplicated and elongated.

*Internal cerebral veins - separated

*Thalamic vessels - displaced laterally

*Torcular - elevated

*Lateral sinuses - elevated

*Superior cerebellar arteries - displaced anterio-superiorly

*Superior vermian vessels - may be absent

*Posterior inferior cerebellar artery - all segments are displaced laterally by the dilated fourth ventricle. The vermian segment may be absent or hypoplastic

The large number of vascular abnormalities seen on angiography are a consequence of the posterior fossa cyst and the hydrocephalus and do not represent abnormalities in the development of the intracranial vasculature. The only abnormality which is of clinical importance is the high position of the lateral sinuses as this may influence the

positioning of ventriculo-peritoneal shunts. Opening into the lateral sinus as a consequence of the low positioning of the burrhole for ventricular shunt insertion may have disasterous consequences particulurly in an infant.

Hydrocephalus

The association between hydrocephalus and the Dandy-Walker syndrome is variable. It is difficult to establish the exact incidence of hydrocephalus in the Dandy-Walker syndrome as the majority of patients seen in clinical practice have presented to the practitioner because of symptomatic hydrocephalus. The hydrocephalus may be a consequence of the following:

Fourth ventricular outlet obstruction: It has been well established that the outlets of the fourth ventricle are patent in up to 68% of patients. In those patients where the outlets are obstructed, this must play an important role in the pathogenesis of the hydrocephalus.

Aqueduct obstruction: Patency of the aqueduct has been demonstrated in clinical and pathological studies in 87% of patients with the Dandy-Walker syndrome. In those cases where occlusion has been demonstrated the pathology includes:

*aqueduct stenosis or forking

*functional occlusion due to herniation of the superior vermis

*functional occlusion due to herniation of the posterior fossa cyst

Incompetence of the subarachnoid pathways: Hydrocephalus in the absence of aqueduct or outlet obstruction would imply that there must be some obstruction in the subarachnoid pathways or some deficit in the absorptive capacity. This could explain the high failure rate following direct surgical treatment of the posterior fossa cyst.

Associated central nervous system anomalies

Associated anomalies have been noted in up to 68% of post-mortem studies and 40% of clinical studies. Associated anomalies include

*agenesis of the corpus callosum

*non-specific gyral anomalies

*heterotopias

*polymicrogyria

*agyria and macrogyria

*occipital meningoceles

*malformations of the inferior olive

*cerebellar folia abnormalities

*infundibular hamartomas

*diverticular cysts of the third ventricle

EMBRYOLOGY OF THE POSTERIOR FOSSA STRUCTURES

The embryogenesis of the Dandy-Walker syndrome remains obscure and the key to its understanding, lies in the normal development of the posterior fossa structures and their temporal relationships.

Rhombencephalon

The first critical step in the development of the rhombencephalon is the formation of the pontine flexure (stages X111-XV1). This is due to differential growth within the rhombencephalon and occurs during days 28 to 39. (figure 2,3)

Cerebellar hemispheres (figure 4,5)

At five weeks a thickening occurs bilaterally in the alar plate of the rhombencephalon forming the rhombic lips. These are the primordia of the cerebellar hemispheres.

FIGURE 2: Pontine Flexure at 49 days

(from: Netter F. The Ciba collection of Medical Illustrations)

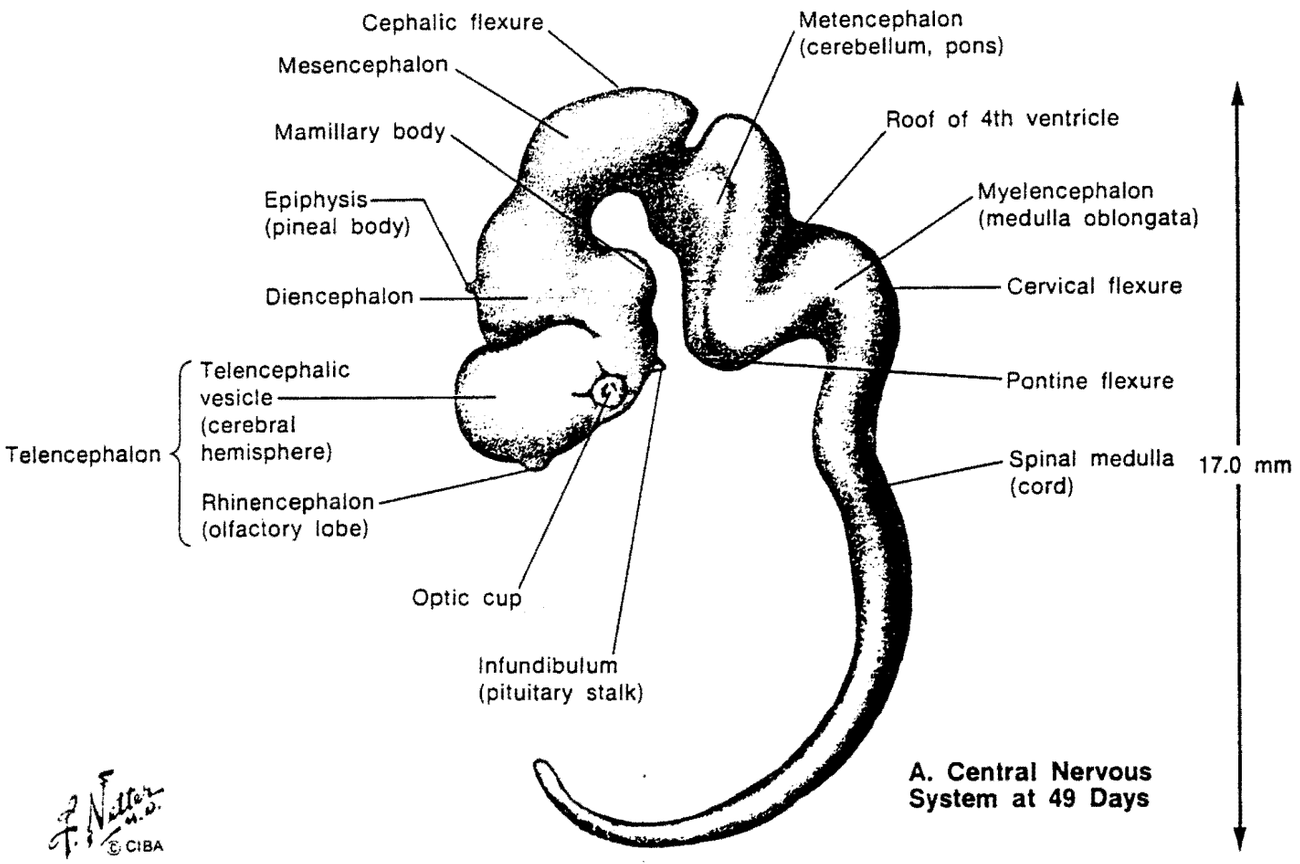


FIGURE 3: Development of Flexures of the brain

Longitudinal and cross sectional diagrams relating the development of flexures of the brain with some important landmarks for cerebellar morphogenesis.

(from: Lemire RJ, et al. Normal and abnormal development of the human nervous system)

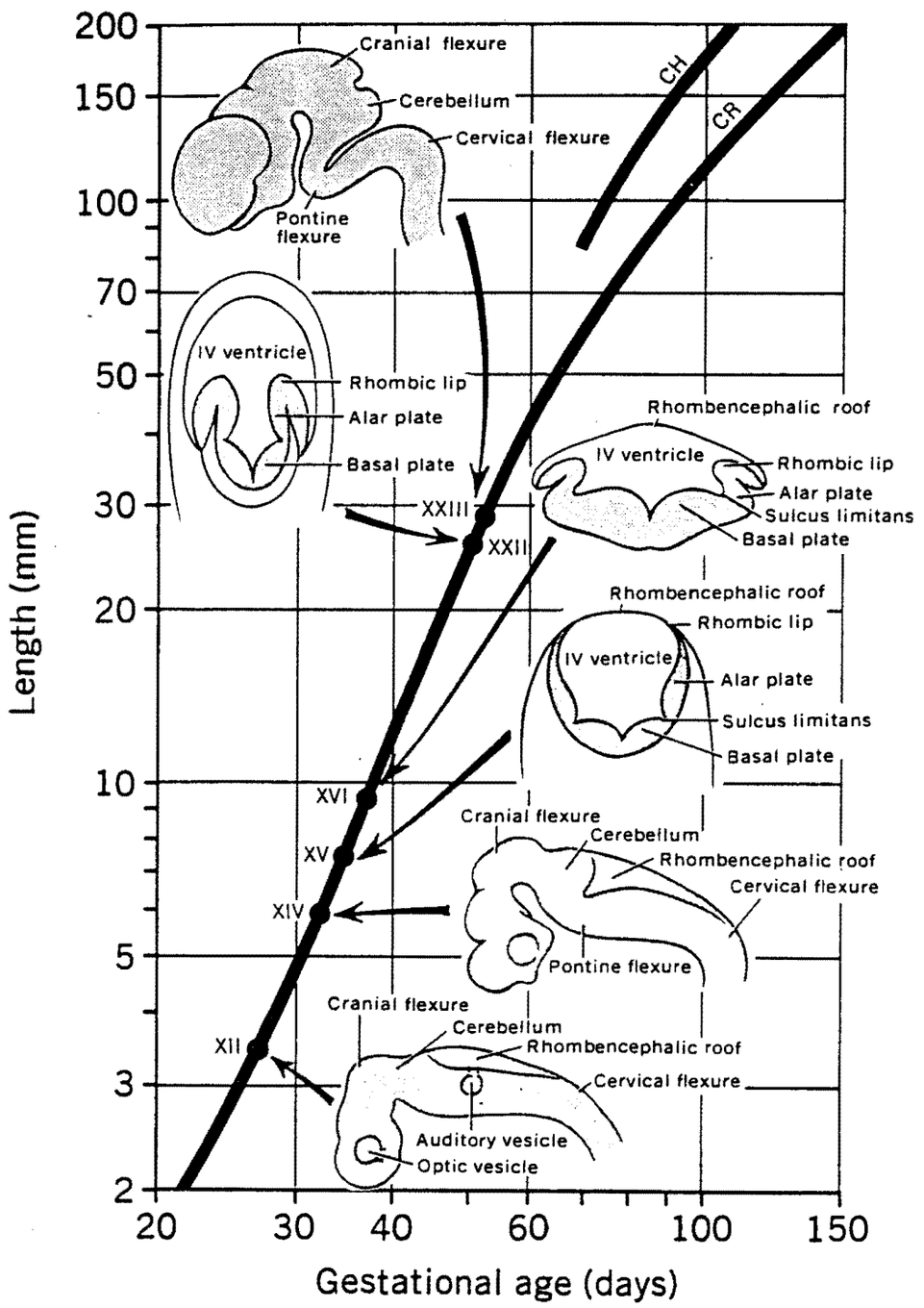


FIGURE 4: Development of Cerebellum

Sagittal sections through the roof of the metencephalon, showing the development of the cerebellum:
a. 8 weeks b. 12 weeks c. 13 weeks d. 15 weeks

(from Langman Medical Embryology)

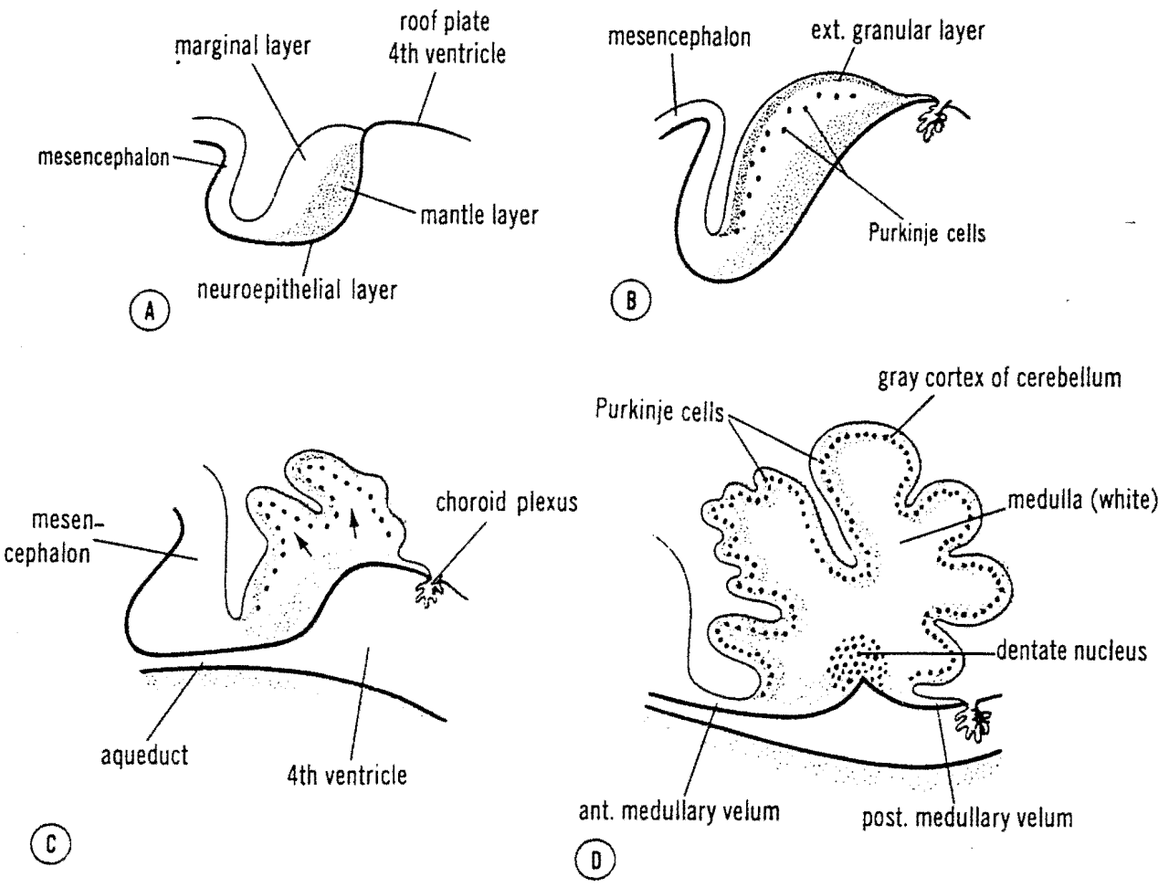
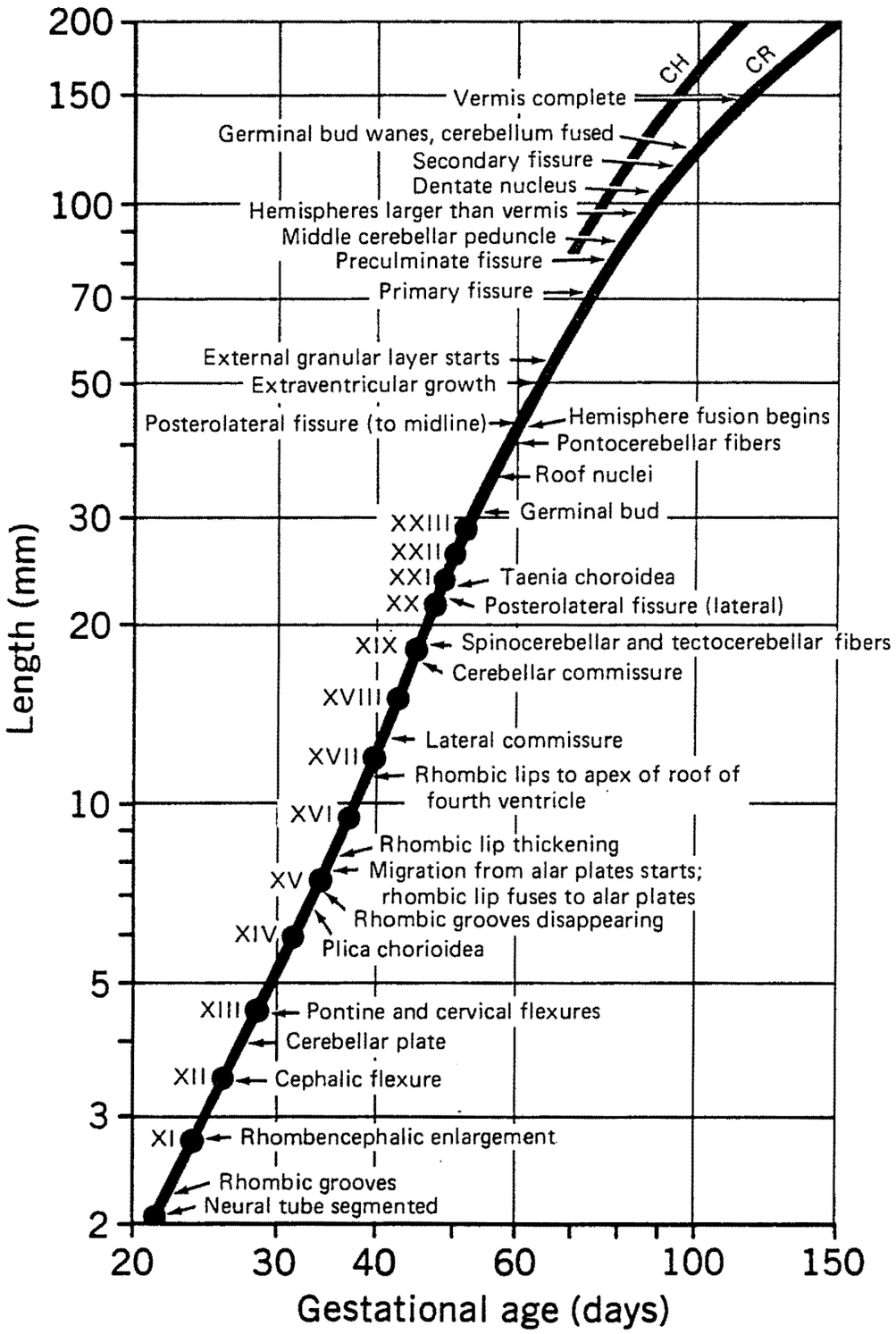


FIGURE 5: Development of Cerebellum correlated with CR length and gestational age

(from: Lemire RJ, et al. Normal and abnormal development of the human nervous system)



The glia and neurones of the cerebellum migrate by two pathways to their final destination.

(a) neurones of deep cerebellar nuclei and Purkinje layer migrate radially outward via the wall of V4 during the ninth to eleventh week

(b) neurones of granular cortex migrate tangentially to the rhombic lips forming the external granular layer during the eleventh to thirteenth weeks. Here they proliferate until 16/52 and then migrate inwards to form

1. basket/stellate cells of the outer (molecular) layer
2. inner granular layer

Thus by the end of the first postnatal year the external granular layer has disappeared completely.

Vermis

The vermis forms by the fusion of the developing cerebellar hemispheres. This fusion starts superiorly at nine weeks and continues inferiorly. By fifteen weeks the entire vermis has formed.

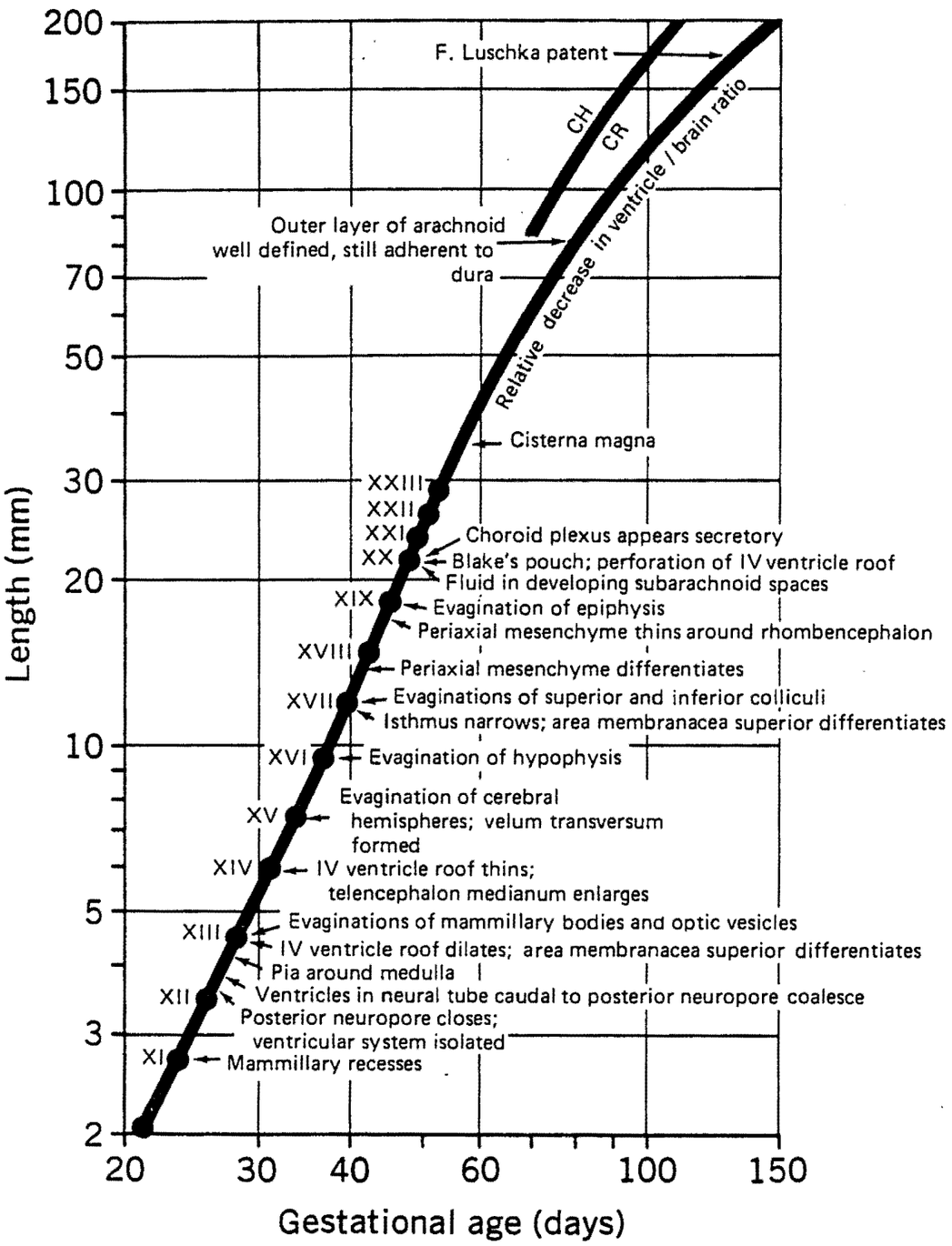
Roof of the fourth ventricle (figure 6)

The developing pontine flexure causes the roof of the rhombencephalon to thin during days 28-33. The rhombic roof is also transversely creased by this buckling. The crease divides the roof into two areas. The area membranacea superior, which forms the posterior medullary velum, and the area membranacea inferior. Within this crease the choroid plexus developes.

The roof eventually perforates in the midline on day forty-seven and on day forty-eight forming the foramen of Magendie. This is due to active differentiation of the roof and not due to the production of CSF, as was previously thought, as CSF is only produced a few days later.

FIGURE 6: Development of Ventricular system correlated with CR length and gestational age

(from: Lemire RJ, et al. Normal and abnormal development of the human nervous system)



Choroid plexus and CSF formation

During stage XX the roof of the rhombencephalon becomes uniquely differentiated. Caudal to the plica choroidea the roof of the fourth ventricle perforates forming the foramen of Magendie. The timing of this critical event has been a source of heated debate in the past and continues to be controversial. It is this failure of consensus which has resulted in the many theories regarding the pathogenesis of the Dandy-Walker syndrome.

Stages XX-XX11 are critical to the normal development of the ventricular pathways and the flow of cerebro-spinal fluid. Three events are closely related in time

1. perforation of the roof of the fourth ventricle
2. development of secretory epithelium in the choroid plexus
3. formation of the subarachnoid space

Histological studies clearly show that it is not the build-up of CSF pressure that results in the perforation of the roof of the fourth ventricle but an active process of differentiation in the roof of the fourth ventricle . The development of the foramen of Magendie has been extensively studied. Blake described a closed pouch that evaginates from the caudal part of the fourth ventricle and persists in some species but is lost in man.

The development of the foramina of Luschka is less well described but both foramina are usually patent at birth. The size of the lateral foramina is usually inversly proportional to the size of the foramen of Magendie. Alexander found the foramina of Luschka to be symmetrically non-patent in 20% of normal humans.

The choroid plexus of the fourth ventricle appears on day forty-three and forty-four. The production of CSF only occurs after perforation of the roof of the fourth ventricle making the hydrodynamic theories less probable.

EMBRYOGENESIS OF THE DANDY-WALKER SYNDROME

THEORIES[3,7,12,26-28,36,37,48,57,62,63,71,74,]

There are five main theories regarding the formation of the Dandy-Walker syndrome.

1. Atresia of the foramina of Magendie and Luschka

This theory was proposed by early authors such as Dandy, Taggart and Benda. The atresia was confirmed by early post-mortem reports.

It is postulated that with congential atresia of the outlets of the fourth ventricle, and the on-going production of CSF, the forth ventricle dilates. As a secondary event there is maldevelopment of the vermis and cerebellum as well as the development of hydrocephalus. Occasional cases where no hydrocephalus has developed has been attributed to an abnormally small choroid with less CSF production as well as the possibility that the cyst wall may act as a semi-permeable membrane. It has also been postulated that blood vessels may absorb some of the CSF resulting in the failure to develop hydrocephalus despite the outlet obstruction.

Both clinical and pathological studies by the following authors have found the outlets of the fourth ventricle patent in 50%-82% of patients.

Gibson (1955)

D'Agnostino (1963)

Hart (1972)

French (1983)

Hirsch (1984)

Raimondi (1984)

2. Dysraphism of the corpus cerebelli

Although Benda stated that atresia of the outlets of the fourth ventricle is important in the pathogenesis it was also suggested that failure of fusion of the cerebellar hemispheres, very much like spinal dysraphism, may explain the development of the Dandy-Walker syndrome. The absence of an associated cranium bifidum is not explained. He does not expand on this theory and it does not explain the pathology seen in the Dandy-Walker syndrome.

3. Hydrodynamic theory

In 1957 Gardner, the main proponent of the hydrodynamic theory, claimed that the Dandy-Walker syndrome, Chiari malformations, arachnoid cysts and syringomyelia were different manifestations of the same developmental anomaly ie. failure of development of the outlets of V4. Depending on the elasticity of the roof of the fourth ventricle it either:

- stretched to form a Dandy-Walker cyst
- remained intact resulting in the herniation of the contents of the posterior fossa and the formation of a Chiari malformation
- ruptured, forming an arachnoid cyst

There is no histological/embryological evidence presented to support this theory.

In 1959 Brodal and Hauglie-Hansen published two cases with clinical, anatomical and pathological evidence as well as experimental work done in mice which does not support the theory of Gardner. They postulated that the syndrome occurs prior to the formation of the outlets of the fourth ventricle. As the result of some undetermined process there is an increase in intraventricular pressure. This causes bulging of the area membranacea superior with the resultant poor development of the vermis.

In 1972 Hart presented 28 cases of the Dandy-Walker syndrome and concluded that due to the associated CNS and systemic anomalies, the developmental errors occured long before the development of the foramina of Luschka and Magendie and that it was the accumulation of the pre-choroidal CSF that resulted in the development of the Dandy-Walker syndrome. This evidence is against the hydrodynamic theory of Gardner.

4. Neuroschisis

This theory was proposed by Padget(1970/1972) following the discovery of neural tube clefts and overlying blebs in human and monkey embryos. It is argued that these represent partial ruptures of the neural tube with neuroschistic bleb formation. This theory was postulated for most cases of dysraphism including the Dandy-Walker syndrome.

In the case of the Dandy-Walker syndrome it is postulated that a partial rupture of the neural tube (neuroschisis) occurs in the region of the the fourth ventricle. The overlying ectodermal bleb does not rupture resulting in the formation of adhesions with the inner layer of the dura. As a consequence there is incomplete development of the vermis.

5. Theory proposed by Barkovich(1989)

It is postulated that the patient suffers an insult (the timing and nature of which is as yet undetermined) to both the developing cerebellar hemispheres as well as the fourth ventricle. The resultant congenital anomaly varies according to the site and nature of the insult.

a. Insult is severe and diffuse

As a consequence the cerebellum is severely hypoplastic and the fourth ventricle is large.

This represents the classic picture of the Dandy-Walker syndrome and in the classification of Barkovich is called the Dandy-Walker type A.

b. Insult more localised with the developing cerebellum prominently involved

This form of insult results in the development of a hypoplastic cerebellum without marked expansion of the fourth ventricle.

This represents the Dandy-Walker variant or Dandy-Walker type B.

c. Insult more localised with the fourth ventricle more involved

In this form of insult the posterior fossa is expanded with a posterior fossa cyst which communicates with the fourth ventricle. The cerebellar hypoplasia is relatively minor.

This represents a mega cisterna magna or Dandy-Walker type B

The anomalies describes in b. and c. seem to be the result of a more localised insult and depending on the relative amount of cerebellum or fourth ventricular involvement, a spectrum of pathology occurs. A mega cisterna magna is part of the spectrum of pathology seen in the Dandy-Walker type B. This postulate is confirmed by the clinical and CT/MRI findings presented by the authors.

Summary

The Dandy-Walker syndrome is a developmental anomaly of the posterior fossa, the primary cause of which is unknown, and the embryogenesis, uncertain. The associated systemic anomalies help one in timing the origin of the insult. Certainly the lack of associated spinal dysraphism suggests a later time of origin than the Arnold-Chiari malformations making it difficult to postulate a single theory for both malformations, as proposed by Gardner and Padget. It is also difficult to separate which intracranial abnormalities are primary or secondary events.

It seems that the key to understanding the embryogenesis of the Dandy-Walker syndrome is an understanding of the normal embryological development of the posterior fossa particularly in the timing of the various events. Certainly the large number of associated CNS and systemic anomalies imply that the pathogesis is more complex than the initial theories described.

STUDY

AIM

The differentiation between the Dandy-Walker syndrome and other posterior fossa cysts is problematical. Many different terms are used to describe posterior fossa cysts resulting in an attempt by many authors to reclassify posterior fossa cysts. It is hoped that this reclassification will make the diagnosis clearer and facilitate the assessment and management of patients. Although it is of academic importance, particularly to the paediatric neurosurgeon, to make this differentiation it is unclear whether this influences the treatment of the patient.

Aims of the study:

*to determine whether the classification of Barkovich et al.[7] which is based on the CT characteristics of posterior fossa cysts had any revelance to the management and outcome of Dandy-Walker cysts and their variants.

*to review our experience in the management of the Dandy-Walker syndrome and to evaluate the results of treatment.

PATIENTS AND METHODS

The clinical records, investigations and management of children presenting to the Dept. of Neurosurgery, Red Cross War Memorial Childrens Hospital, Cape Town with a diagnosis of a midline posterior fossa cyst were retrospectively examined. The characteristics of the vermis, cerebellum, posterior fossa cyst and brainstem, as seen on axial CT scans, were analysed and the patient classified into the sub-groups of Barkovich et. al.

Definitions of terms used

Vermian hypoplasia: small or absent inferior vermis.

Vermian compression: frank deformity of vermis or diminished sulci between folia of the inferior vermis.

Cerebellar hypoplasia: diminished size of the cerebellar hemispheres without enlargement of the sulci or fissures between folia.

Cerebellar atrophy: all lobules present but the fissures between lobules and folia enlarged.

Classification of posterior fossa cysts

Dandy-Walker Syndrome

Type A

Type B

Prominent Cisterna Magna

Arachnoid Cyst

Diagnostic criteria

Dandy-Walker Type A (figure 7)

Midline posterior fossa cyst

Clear communication between cyst and V4

Absence of vermis on axial images

Hypoplasia of cerebellar hemispheres

No atrophy of the cerebellum and vermis

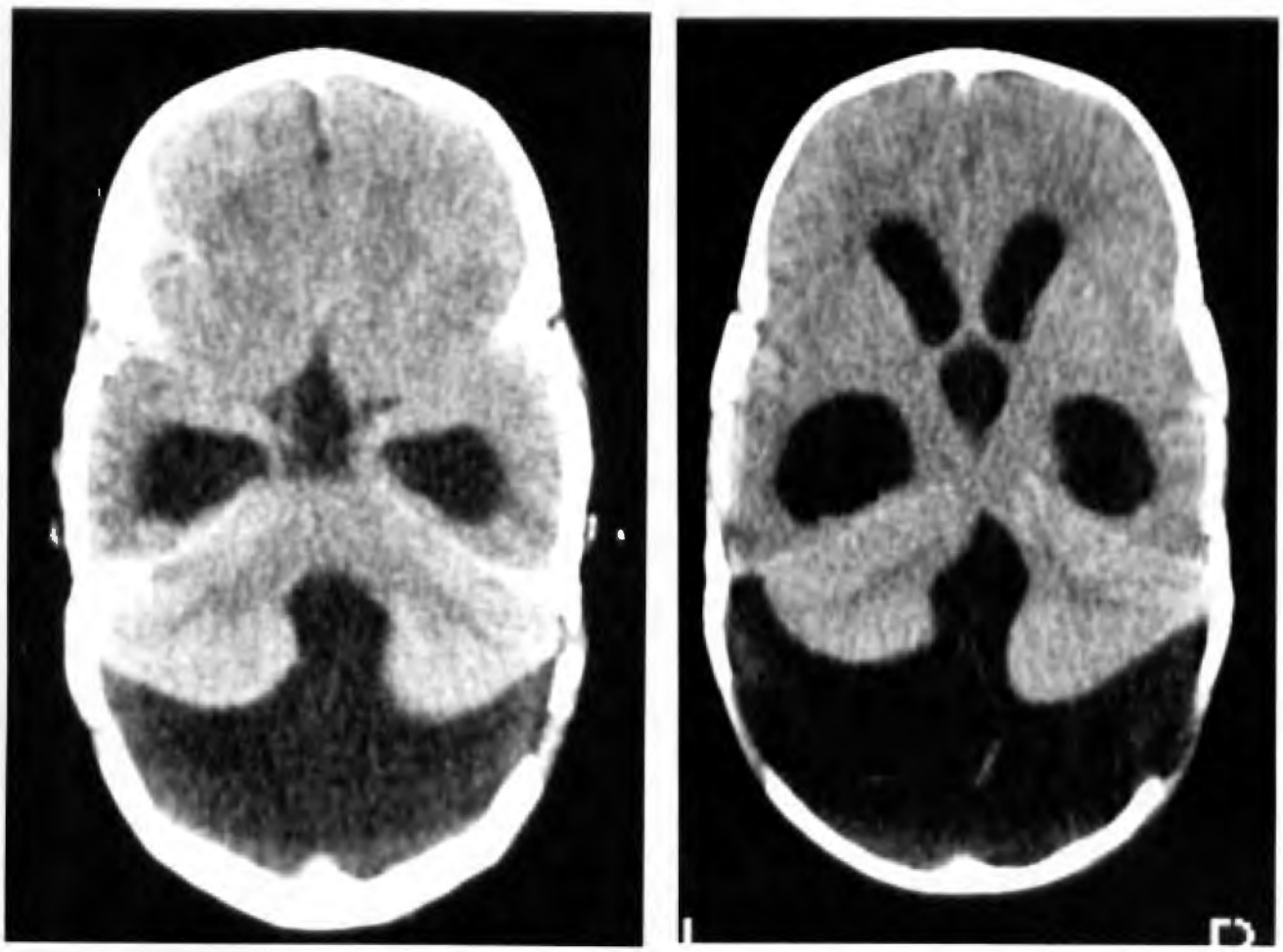


FIGURE 7: Dandy-Walker syndrome type A

Dandy-Walker syndrome type A showing a midline posterior fossa cyst which communicates with the fourth ventricle. There is no vermis visible on the axial images. Cerebellar hypoplasia is present.

Dandy-Walker Type B (figure 8)

Midline posterior fossa cyst

Clear communication between cyst and V4

Vermis present on some axial images

No atrophy of vermis and cerebellum

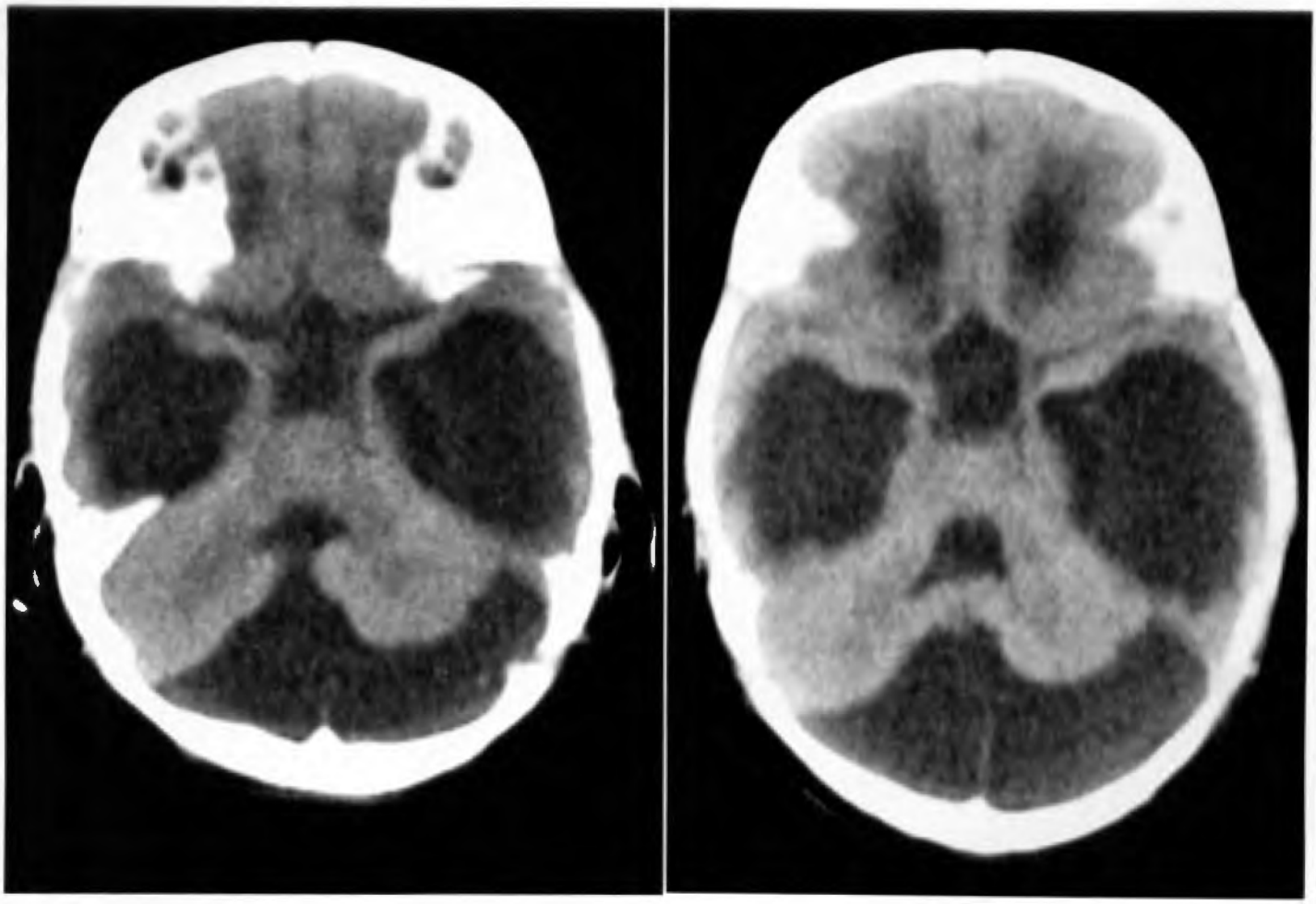


FIGURE 8: Dandy-Walker syndrome type B

Dandy-Walker syndrome type B showing a midline posterior fossa cyst which communicates with the fourth ventricle. The vermis visible on the axial images. Cerebellar hypoplasia is present.

Prominent Cisterna Magna

Midline posterior fossa cyst

Clear communication between cyst and V4

Atrophy of vermis and cerebellum

Arachnoid Cysts (figure 9,10)

Midline posterior fossa cyst

No communication between cyst and V4

No atrophy of vermis and cerebellum

Displacement of cerebellum and vermis

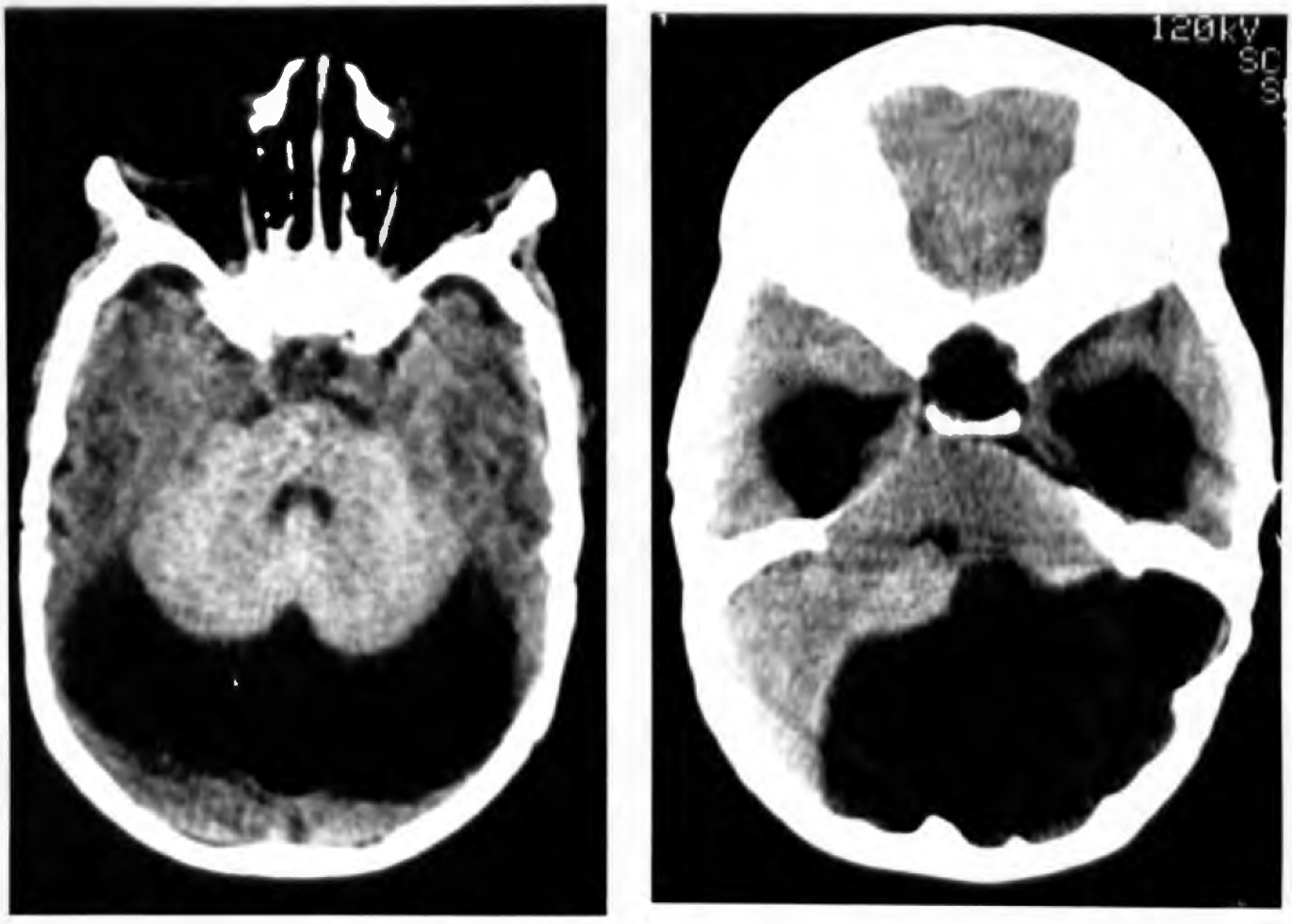


FIGURE 9,10: Arachnoid Cyst

CT scan showing the midline posterior fossa cyst which does not communicate with fourth ventricle. The vermis is present on all the axial images. The cerebellar hemispheres are normal but compressed. There is no atrophy or hypoplasia of the cerebellum and the vermis.

RESULTS

Patients (Table 1)

Fifty children with midline posterior fossa cysts were seen at the Red Cross War Memorial Children's Hospital, Cape Town, over a twelve year period from January 1980 to December 1991. There were thirty males and twenty females. The mean age of presentation was three and a half years with the group of patients with the Dandy-Walker type A cysts presenting at a much earlier age.

TABLE 1. Posterior fossa cysts. Clinical material

	Dandy-Walker Type A	Dandy-Walker Type B	Arachnoid Cyst
Number	22 **(44%)**	13 **(26%)**	15 **(30%)**
Sex: male	13	6	11
female	9	7	4
Race: White	4	3	4
Coloured	12	4	6
Indian	0	0	1
African	6	6	4
Mean age at presentation	0,4 yrs	4,2 yrs	6,4 yrs

Ante-natal course (Table 2)

TABLE 2. Pregnancy and Delivery

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Eventful Pregnancy	7 twins breech eclampsia eclampsia WR +ve APH APH	2 hypertension eclampsia	4 breech PROM renal dx eclampsia
Normal Vaginal Delivery	13	6	4
Birth Weight (g)	2993	3384	3220
Apgar 5 min (mean)	6,2	8,8	6,6
Abnormal siblings	1 hypospadias	0	0

PROM = Premature rupture of membranes
APH = Ante partum haemorrhage
+ve WR = positive serological test for syphilis
renal dx = renal disease

Clinical Presentation

Symptoms (Table 3): The majority of patients presented with symptoms of hydrocephalus. Respiratory difficulties were present in almost twenty-five percent of patients with the Dandy-Walker type A cyst. This is presumably a reflection of the congenital anomalies within the posterior fossa. Seizures were only present in two patients.

TABLE 3. Symptoms

	Dandy-Walker Type A n=22	Dandy-Walker Type B n=13	Arachnoid Cyst n=15
headache	0	0	5
vomiting	2	1	1
enlarging head	17	8	9
unsteady gait	2	1	4
depressed level of consciousness	1	0	0
seizures	1	1	0
feeding difficulty	2	1	1
floppy baby	2	1	1
respiratory problems	5	1	0
asymptomatic	2	1	0

Signs (Table 4): In all three groups of patients the commonest signs were those of hydrocephalus and raised intra-cranial pressure. Cerebellar signs were present in thirty-three percent of patients with arachnoid cysts of the posterior fossa.

TABLE 4. **Signs**

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
enlarged head circumference	18	10	9
full fontanelle	17	9	8
occipital mass	2	2	0
GCS 15/15	22	12	14
nystagmus	0	2	1
ataxia	1	1	4
cranial n. palsy	0	2	0
unilateral signs	0	2	2
visual signs	3	1	2
respiratory difficulties	2	0	1

Congenital Anomalies (Table 5)

The cardiac anomalies consisted of a transposition of the great arteries, ventricular septal defect and pulmonary stenosis. Two patients in the Dandy-Walker type A group had limb anomalies. One patient had contractures of the hand and the other a unilateral congenital dislocation of the hip. One patient had hypospadias. None of the patients with multiple congenital abnormalities fell into any of the described clinical syndromes.

TABLE 5. Congenital Anomalies

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Total	5 **(22,7%)**	2 **(16,6%)**	2 **(13,3%)**
cardiovascular	1	1	1
capillary angiomas	0	0	0
hypertelorism	1	1	0
short nose	1	0	0
strabismus	1	1	0
limb anomalies	2	0	0
GIT anomalies	0	0	0
renal	1	0	0
facial	0	0	1
Clinical Syndrome	0	0	0

Investigations (Table 6)

In some patients the diagnosis of a posterior fossa cyst was suspected on skull x-ray and ultrasound examination of the brain. In all patients however the definitive diagnosis was made on CT scan. The findings on axial CT scan are listed in table 7.

TABLE 6. Investigations

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Skull X-Ray	13	5	12
Angiography	0	0	0
Ultrasound	7	6	5
Ventriculography	3	2	4
CT scan	22	13	15
MRI	0	0	0

TABLE 7. Axial CT Scan Findings

	Dandy-Walker Type A n=22	Dandy-Walker Type B n=13	Arachnoid Cyst n=15
Vermis:			
absent	22	0	0
hypoplastic	0	13	0
compressed	0	0	7
normal	0	0	6
Cerebellum:			
hypoplastic	22	12	0
compressed	0	0	15
normal	0	1	0
asymmetrical	5	4	7
Brain Stem:			
compressed	3	1	3
normal	19	12	12
Torcular:			
elevated	22	6	4
normal	0	7	11
mean height (mm)	46	40	25
hydrocephalus	20	11	12
Aqueduct Stenosis	0	0	0

Intra-cranial anomalies (Table 8)

Nine patients had associated cranial anomalies the commonest of which was agenesis of the corpus callosum. Three patients had an associated occipital meningocele.

TABLE 8. Intra-cranial congenital anomalies

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Total	6 **(27,2%)**	2 **(15,5%)**	1 **(6,6%)**
corpus callosum agenesis	3	0	1
occipital meningocele	1	2	0
septal cysts	2	0	0

Treatment (Table 9 to Table 15)

TABLE 9. **Initial treatment**

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Cyst exploration	0	0	3
Ventriculo-peritoneal shunt	10	7	5
Cyst-peritoneal shunt	8	4	4
Combined cyst ventriculo-peritoneal shunts	0	0	3
No treatment	4	4	0

TABLE 10. Further shunt treatment

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
VPS revised to CPS (patients)	5	1	2
CPS revised to VPS (patients)	1	0	0
VPS added to CPS (patients)	1	1	0
Total number of shunts performed:			
VPS	12	8	8
CPS	13	5	7

VPS = ventriculo - peritoneal shunt
CPS = cyst - peritoneal shunt

The results of treatment with ventriculo-peritoneal and cysto-peritoneal shunts are listed in tables 11 to 15.

TABLE 11. Results of Ventriculo-peritoneal shunts

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Total: patients	12	8	8
shunts	31	12	15
Hydrocephalus smaller	12	8	4
Cyst smaller	10	6	2

TABLE 12. Complications of Ventriculo-peritoneal shunts

	Dandy-Walker Type A n=22	Dandy-Walker Type B n=13	Arachnoid Cyst n=15
Total complications:			
patients	9	5	5
shunts	15 (55 %)	6 (50 %)	6 (40 %)
Complications:			
obstruction	12 (38,7%)	2 (16,6%)	4 (26,6%)
sepsis	2 (6,5%)	1 (8,3%)	0
slit ventricles	2 (6,5%)	1 (8,3%)	0
subdurals	0	1 (8,3%)	2 (13,3%)
poor position	1 (3,2%)	0	0
disconnection	0	1 (8,3%)	0

TABLE 13. Results of Cyst-peritoneal shunts

	Dandy-Walker Type A n=22	Dandy-Walker Type B n=13	Arachnoid Cyst n=15
Total: patients	13	5	7
shunts	17	8	9
Hydrocephalus smaller	13	4	6
Cyst smaller	13	5	7

TABLE 14. Complications of Cyst - peritoneal shunts

	Dandy-Walker Type A n=22	Dandy-Walker Type B n=13	Arachnoid Cyst n=15
Total complications:			
patients	9	5	2
shunts	10 (58,8%)	6 (75 %)	4 (44 %)
Complications:			
obstruction	1 (5,8%)	1 (12,5%)	1 (11 %)
sepsis	3 (17,6%)	0	1 (11 %)
slit ventricles	1 (5,8%)	0	0
subdurals	0	0	0
poor position	3 (17,6%)	3 (37,5%)	1 (11 %)
disconnection	0	1 (12,5%)	1 (11 %)
shunt migration	2 (11,7%)	1 (12,5%)	0

TABLE 15. Results of shunting. Ventriculo-peritoneal shunts versus cyst-peritoneal shunts.

	VPS	CPS
Total:		
patients	28	25
shunts	58	34
Total complications:		
patients	19	16
shunts	29 (50 %)	20 (59 %)
Complications:		
obstruction	18 (31 %)	3 (9 %)
sepsis	3 (5 %)	4 (12 %)
overshunting	6 (10 %)	2 (6 %)
slit ventricles	3 (5 %)	1 (3 %)
subdurals	3 (5 %)	1 (3 %)
poor position	1 (1,7%)	7 (21,5%)
disconnection	1 (1,7%)	1 (3 %)
shunt migration	0	3 (9 %)

VPS = ventriculo - peritoneal shunt
CPS = cyst - peritoneal shunt

Outcome

Two patients died. The first patient died at the age of 2,5 years as a result of multiple episodes of shunt sepsis. The second patient died at the age of 12 years following shunt obstruction and the development of acute hydrocephalus.

TABLE 16. Outcome of patients

	Dandy-Walker Type A n=22	**Dandy-Walker Type B** n=13	**Arachnoid Cyst** n=15
Poor psycho-logical outcome	8 **(36 %)**	5 **(38,5%)**	7 **(46,6%)**
Deaths	2	0	0

DISCUSSION

Clinical Features

Our fifty patients with midline posterior fossa cysts were classified according to the recently published criteria of Barkovich[7] which were established using axial magnetic resonance imaging. As in other series the presentation of patients with the Dandy-Walker syndrome was with symptoms and signs of hydrocephalus[15]. Patients with Dandy-Walker syndrome type A presented earlier (mean age of 0,4 yrs) and had a higher incidence of respiratory and feeding difficulties when compared to the Dandy-Walker syndrome type B. This presumably reflects a spectrum of pathology in the Dandy-Walker syndrome, the Dandy-Walker type A representing a more severe form of the anomaly.

Associated Anomalies

Systemic and facial anomalies associated with the Dandy-Walker syndrome have been well described[38,40,47]. Congenital anomalies were found in 22,7% of our patients with Dandy-Walker syndrome type A, 16,6% with Dandy-Walker syndrome type B and 13,3% with arachnoid cysts. The high incidence of hypertelorism noted in the series by Raimondi et al.[71] has not been found in our series. The Dandy-Walker

syndrome has been associated with facial angiomas[8,14,22,33,35,39,41,60,66,73,76,78,79,81] mainly of the capillary type, and rarely with intracranial vascular malformations [66,67,68]. No patient in this series had associated capillary angiomas of the face.

The Dandy-Walker syndrome may also form part of well defined clinical syndromes[56] . These include autosomal recessive syndromes of Warburg[57,64], Meckel-Grüber[57], Ellis-van Creveld[17], Joubert[11,23] and Coffin-Siris[50]. Sporadic diseases such as the Cornelia-de Lange syndrome[33] and the Goldenhar syndrome[1] may also be associated with the Dandy-Walker syndrome. In this series none of the patients with systemic congenital anomalies fitted into a described clinical entity. This association with well defined chromosomal abnormalities in a small percentage of patients would suggest that the aetiology is heterogeneous and is not only due to teratogenetic influences in the fourth to seventh embryonic weeks but that chromosomal aberrations or well defined single gene disorders may be involved.

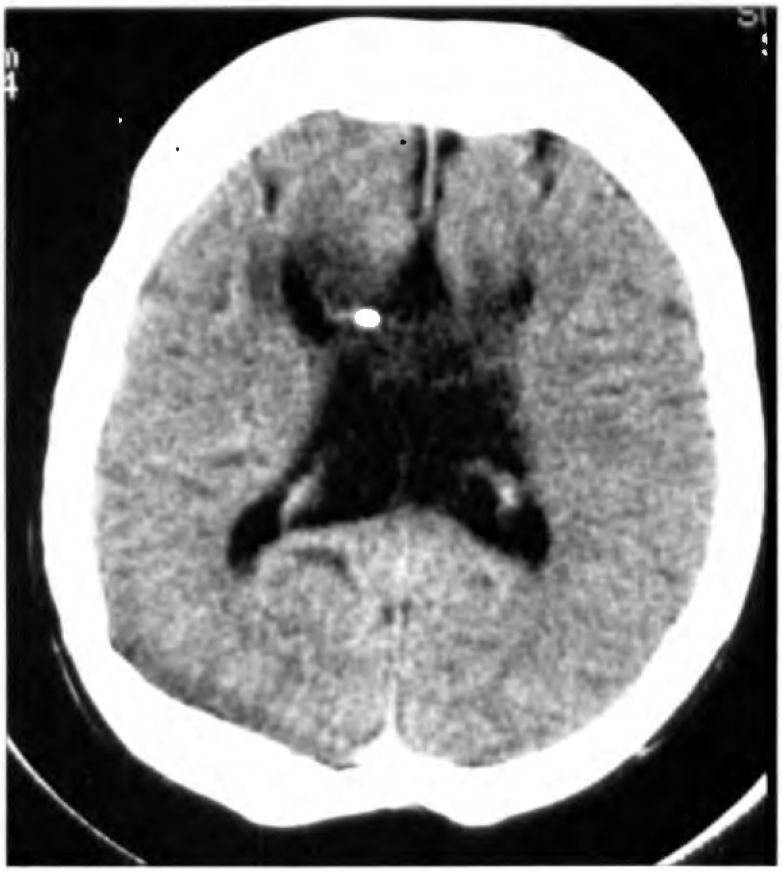
Various authors have questioned the value of CT in the diagnosis of the Dandy-Walker syndrome[5,54] but errors usually result from the criteria used to identify the malformation rather than from the quality of the images. In this series the diagnosis of all patients was based on the use of axial CT scans.

Malformations of the brain are frequently found with up to 68% being reported in autopsy studies[14,33,46]. Twenty seven percent of the Dandy-Walker syndrome type A and 15,5% of the Dandy-Walker syndrome type B had associated intracranial congenital anomalies. Corpus callosum agenesis and occipital meningocoels were the commonest anomalies found. This is in keeping with most reported series[6,16,35,53,57,68,71,76,80]. Corpus callosum agenesis has been frequently associated with a low birth-weight and a poor prognosis. We did not find this in our series.

The incidence of corpus callosum agenesis in the Dandy-Walker syndrome is probably higher than is generally recognised (figure 11). The corpus callosum has a complicated origin and time course of development. It may occur in patients without the Dandy-Walker syndrome. Isolated agenesis of the corpus callosum (not associated with the Dandy-Walker syndrome) represents a failure of commisuration rather than an agenesis and thus its origin is probably in the foetal rather than embryonic period. Because of this it is of little help in determining the time of origin of the Dandy-Walker syndrome. The fact that such an association does exist indicates the possibility that whatever causes the Dandy-Walker syndrome may affect other structures in the median plane including the hippocampal and anterior commisures as well as the corpus callosum.

FIGURE 11: Corpus Callosum Agenesis

Agenesis of the corpus callosum in a child with Dandy-Walker syndrome type A.



The association between occipital meningoceles and Dandy-Walker syndrome has been well described[6,9,10,35,42,52,61,68,75] and was first noted by Sutton[78] in the first reported case of the Dandy-Walker syndrome. Ten percent of patients in this series had associated occipital meningocoels (figure 12,13). Although it has been suggested that an occipital meningocele in the presence of a Dandy-Walker syndrome implies poor intellectual development the results of most series would indicate that it is the presence of other associated central nervous system and systemic abnormalities which are more important in the determination of intellectual outcome.

In addition to corpus callosum agenesis and occipital meningoceles other anomalies of the brain including non-specific gyral disturbances, malformations of the olivary and dentate nucleus, cerebral and cerebellar hamartomas, pachygyria, microgyria, polymicrogyria and anomalies of the cerebellar folia have also been described[33,46]. These abnormalities were not seen in this series but this may reflect the resolution of the CT scan. Post mortem reports and MRI reports have a much higher incidence of these abnormalities.

FIGURE 12: Occipital Meningocele

Occipital meningocele in an infant with Dandy-Walker syndrome type B. The meningocele was surgically treated without any complications.

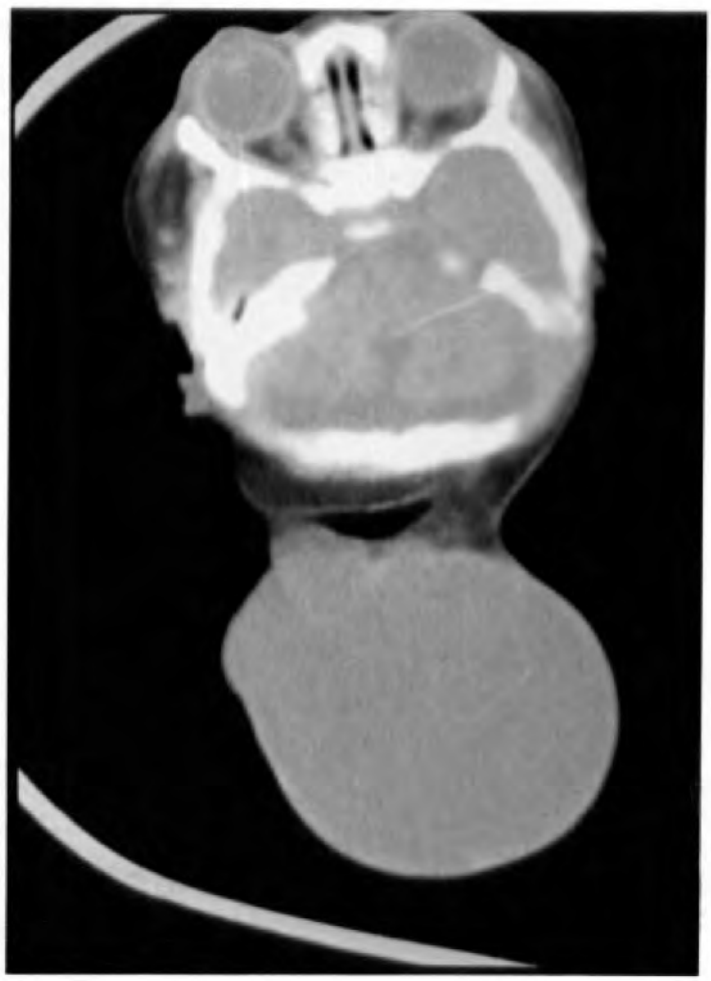
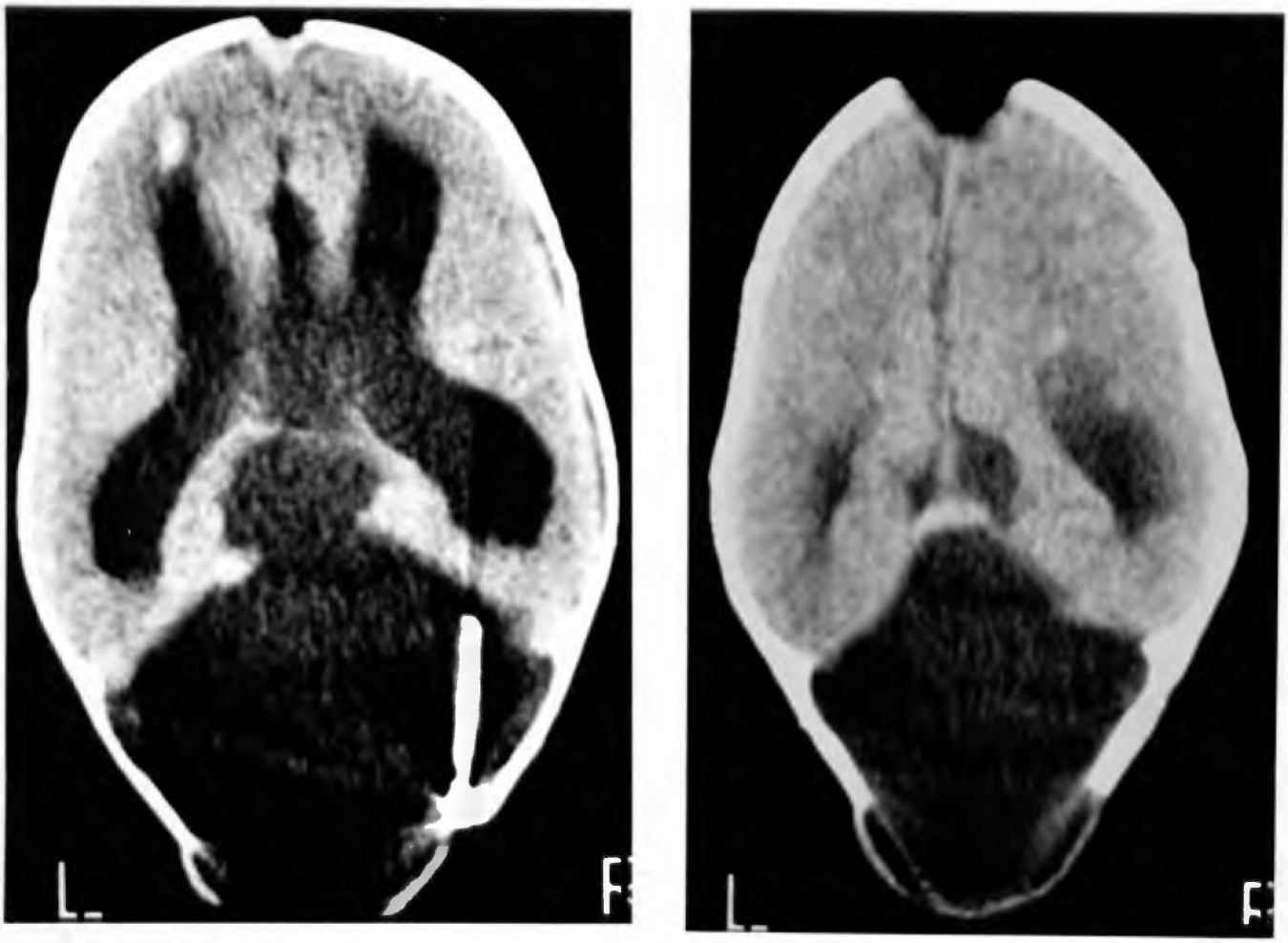


FIGURE 13: Occipital Meningocele

This chlid with a Dandy-Walker syndrome type A has both a occipital meningocele as well as agenesis of the corpus callosum.



Treatment

Treatment of the Dandy-Walker syndrome is directed toward controlling raised intracranial pressure. In the absence of hydrocephalus and compression from the posterior fossa cyst, which occurs in a small percentage of patients, no surgical treatment is indicated. In this series six patients did not require surgical treatment. Despite advances in diagnostic and therapeutic modalities the treatment of the Dandy-Walker syndrome remains controversial.

Membrane excision was initially proposed by Dandy for the treatment of the Dandy-Walker syndrome[21]. The results using this form of therapy have been poor with a high failure rate of up to 75% and a mortality of 10%. Earlier experience by Dandy, Taggart and Benda was associated with a much higher mortality[8,18,21,79,83]. This form of therapy was based on the assumption that the outlets of the fourth ventricle were blocked resulting in expansion of the fourth ventricle and supratentorial hydrocephalus. Membrane excision is still proposed for patients with arachnoid cysts although our experience would indicate that these patients do well with the insertion of a cyst-peritoneal shunt. In the Dandy-Walker syndrome there may also be a role for cyst fenestration in those patients who have undergone repeated shunt revisions and in whom further shunting procedures may carry a significant risk[2]. Our patients were treated with

either cyst-peritoneal, ventriculo-peritoneal or a combination of shunts.

Combined ventriculo-peritoneal and cyst-peritoneal shunting has been advocated[70,71,81]. The principle behind this technique has been to reduce the posterior fossa mass effect at the same time as decompressing the ventricles. This minimises the risk of upward herniation which can occur with the insertion of a ventriculo-peritoneal shunt alone[69]. This complication is, however, uncommon and double shunts have a higher complication rate[58]. Atlhough the use of double shunting is not advocated as a primary mode of therapy, it may be necessary later if secondary aqueduct stenosis or shunt failure developes.

The patency of the aqueduct has been used to determine the nature of the initial shunting procedure[52,53]. As CT scanning has largely replaced ventriculography in the diagnosis of the Dandy-Walker syndrome the patency of the aqueduct is difficult to assess. When one retrospectively analyses the effects of shunting the cyst alone on the ventricular size or the effect of ventricular shunting on cyst size only two patients with possible aqueduct stenosis were identified in this series. This is in keeping with the results of Sawaya and McLaurin[76] and Marinov et al.[53] where no patients with aqueduct stenosis were identified. Cyst-peritoneal shunting is said to encourage the normal flow of

CSF through the aqueduct and is consequently associated with a lower incidence of secondary aqueduct stenosis. Our results of cyst-peritoneal shunting would support this statement. This obviously needs further investigation.

When the results of shunting are analysed it is apparent that no significant difference exists in the outcome of the three groups of posterior fossa cysts examined. Significant differences did occur when one compared the results of cyst-peritoneal shunts and ventriculo-peritoneal shunts. Both groups of patients had a high incidence of shunt complications (50%-59%). Ventriculo-peritoneal shunts had a high incidence of shunt obstruction (31%) and overshunting (10%) (figure 14,15) when compared to cyst peritoneal shunts. Cyst-peritoneal shunts on the other hand are technically more difficult to position and secure and this is reflected by a 21,5% incidence of poorly positioned cyst-peritoneal shunts (figure 16,17) and a 9% (3 shunts) incidence of shunt migration (figure 18,19) with the entire shunt tubing lying within the posterior fossa cyst.

FIGURE 14: Overshunting - Subdural hygromas

This child had a ventriculo-peritoneal shunt inserted for a Dandy-Walker syndrome type A and hydrocephalus. Follow up CT scan shows bilateral subdural hygromas which were symptomatic and were treated with burrhole aspiration and removal of the ventriculo-peritoneal shunt.

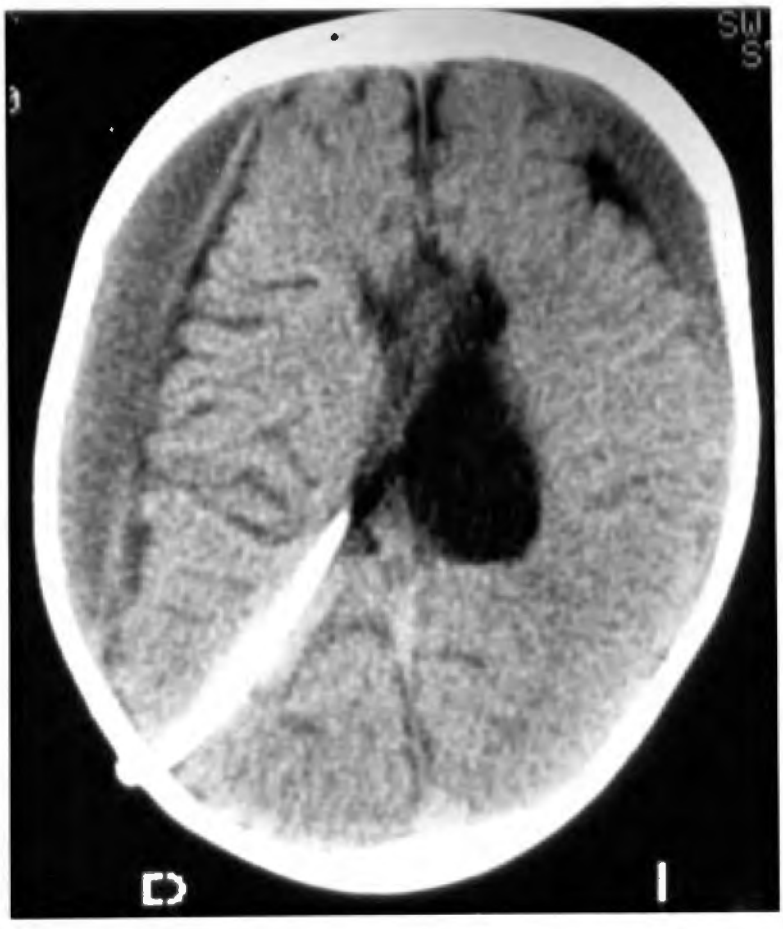


FIGURE 15: Overshunting - Slit ventricle syndrome

This child developed symptomatic slit ventricle syndrome following the insertion of a ventriculo-peritoneal shunt for Dandy-Walker syndrome type A. The ventriculo-peritoneal shunt was replaced with a cyst-peritoneal shunt with good results.

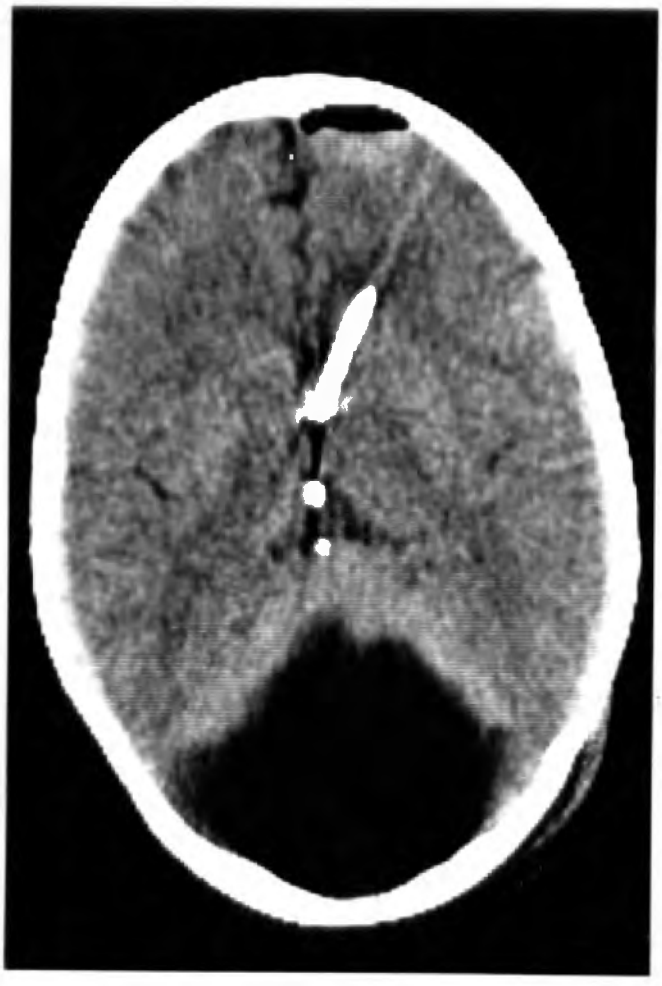


FIGURE 16: Poor shunt position

These CT scans show the tip of the shunt lying within the substance of the cerebellar hemispheres.

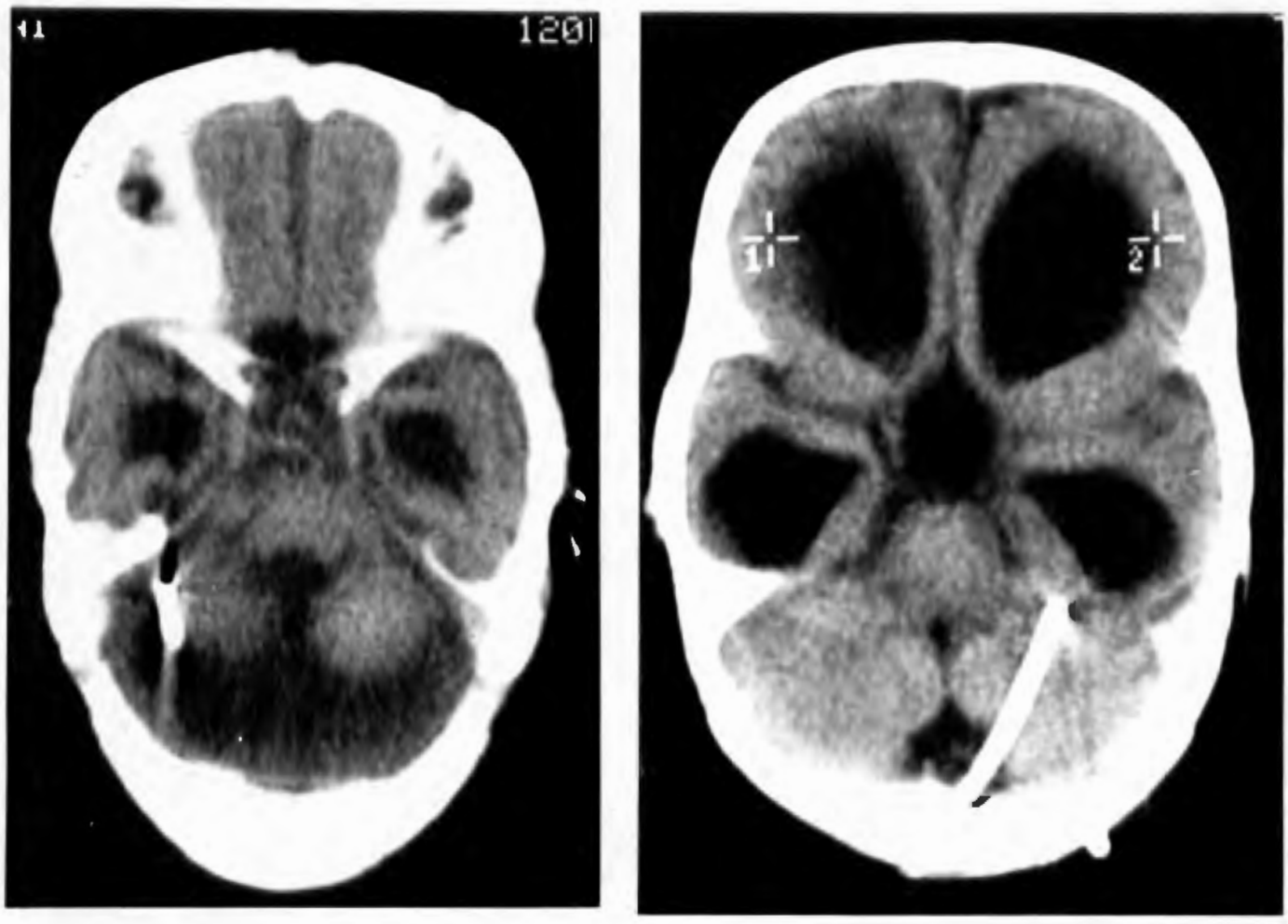


FIGURE 17: Poor shunt position

These CT scans show the tip of the shunt lying within the substance of the brain stem. The child had a sixth nerve palsy which resolved on removal of the shunt.

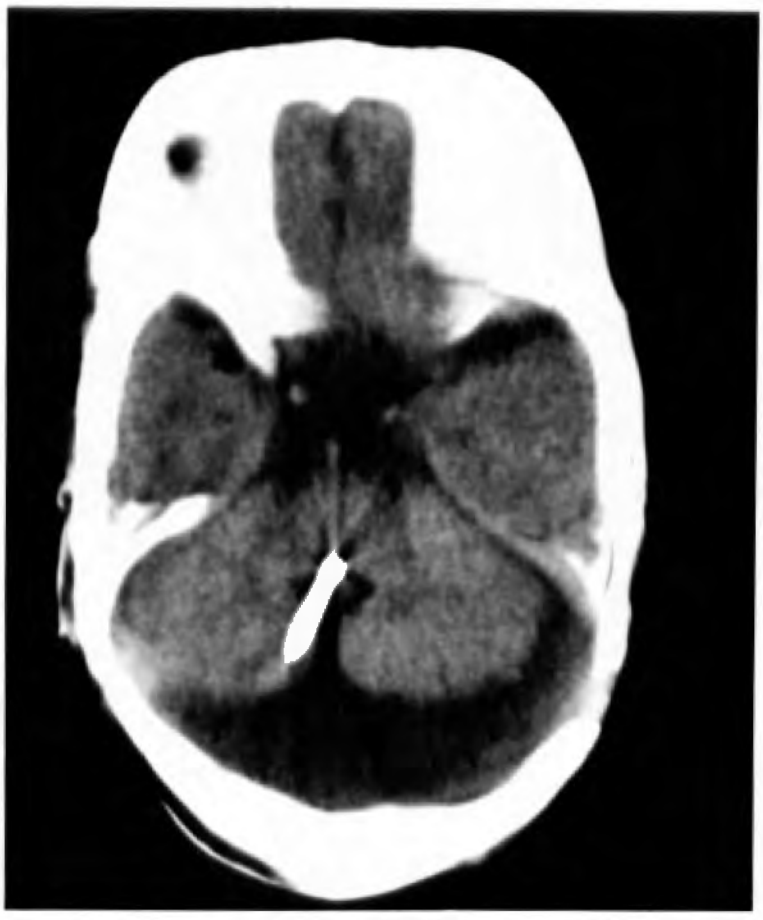
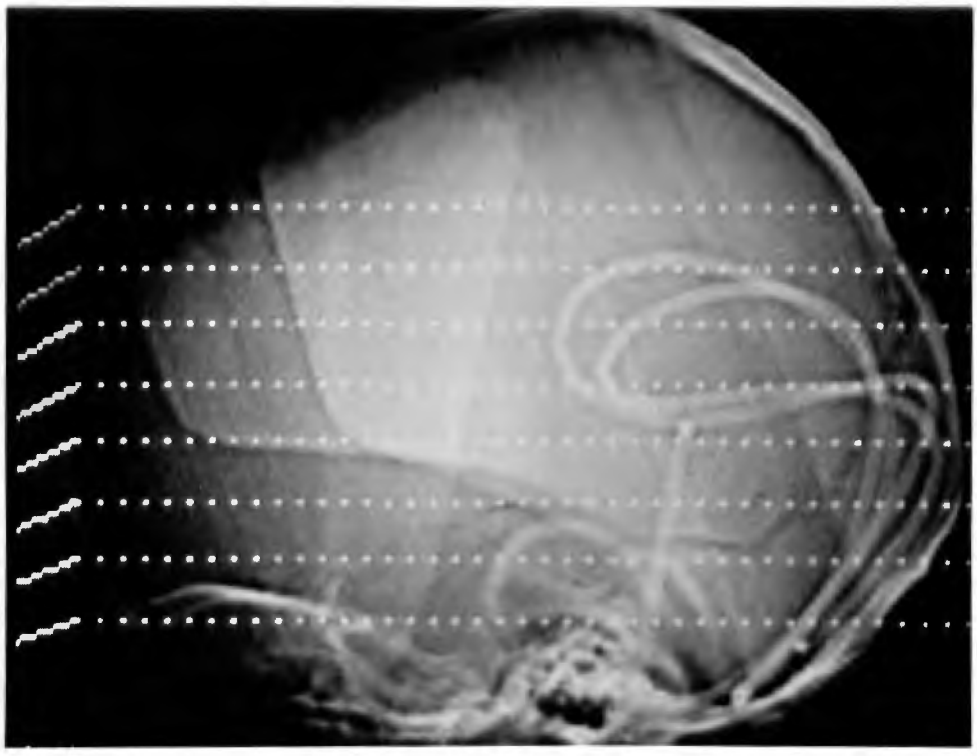


FIGURE 18: Shunt Migration

Plain lateral x-ray skull shows migration of the entire cyst-peritoneal shunt. On axial CT the entire shunt lies within the Dandy-Walker cyst. The child presented with symptoms and signs of shunt obstruction.



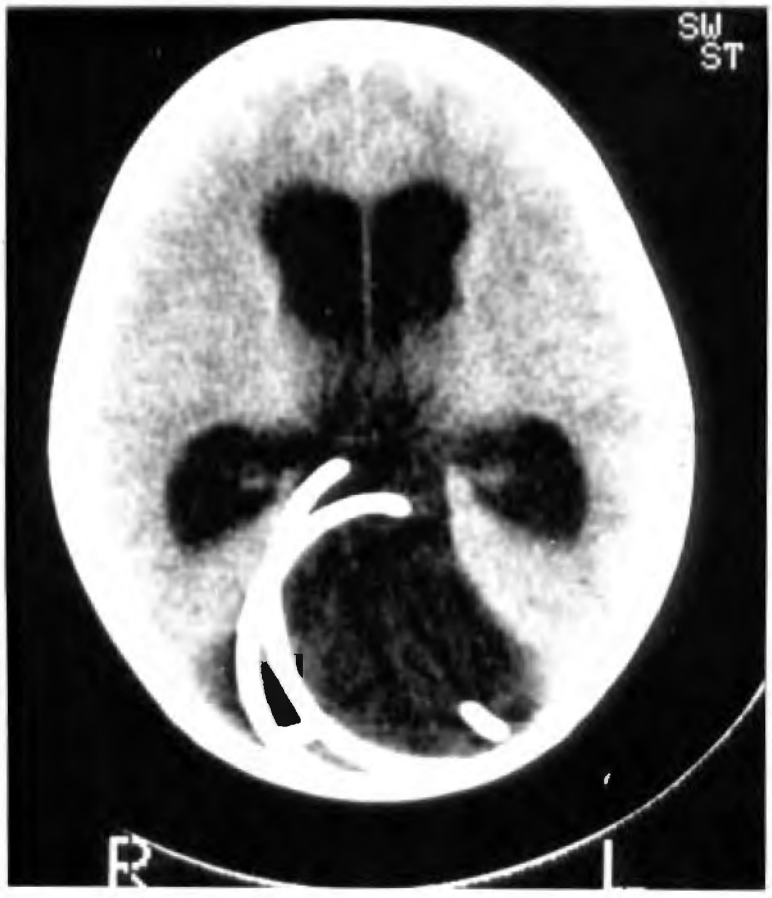
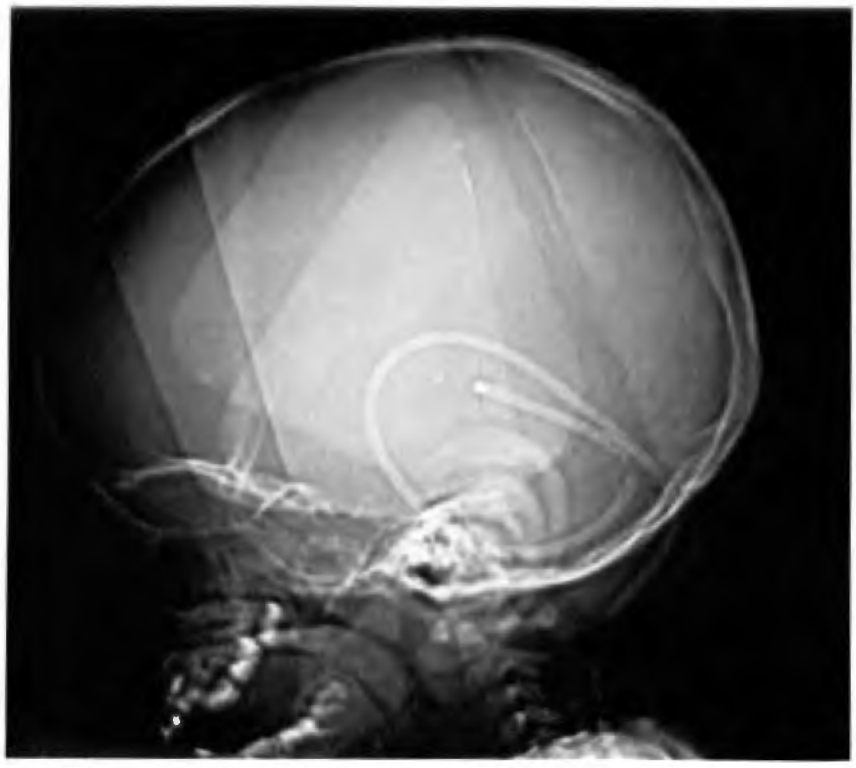
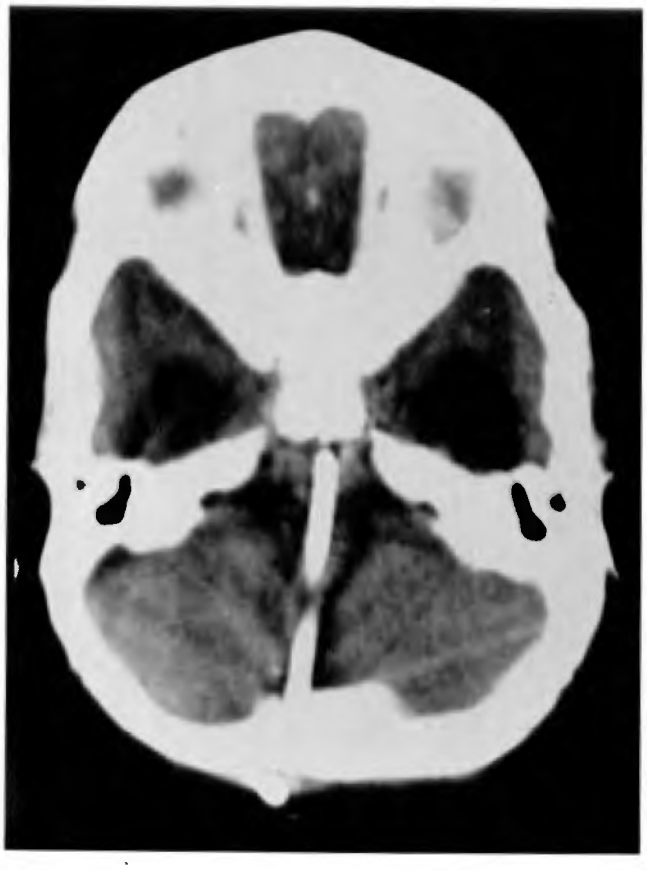


FIGURE 19: Shunt Migration

Plain lateral x-ray skull shows migration of part of the cyst-peritoneal shunt. On axial CT a loop of the peritoneal portion of the shunt lies within the Dandy-Walker cyst. The child presented with symptoms and signs of shunt obstruction.





Outcome

The Dandy-Walker syndrome is said to be associated with a high mortality and a high incidence of mental retardation and motor dysfunction in the survivors[55] . An overall mortality of 40%-50% has been described in many series with infection, uncontrolled hydrocephalus and shunt obstruction having been identified as the major cause of death[14,24,35,39,68,70,76,80]. In our series, as with more recently published series in the post CT scan era, the mortality rates have been considerably lower in the region of 10%-20%[6,9,53]. Two patients died in this series, both related to shunt complications, with an overall mortality of 5%.

Poor developmental outcome and mental retardation remain a significant problem in survivors. In many series poor developmental outcome has been associated with seizures and central nervous system abnormalities excluding corpus callosum agenesis and occipital meningoceles, hydrocephalus and various other systemic anomalies. In this series 37% of patients had a poor developmental outcome as measured by a developmental scale which assessed gross and fine motor function, speech development and social integration. This compares favourably with many other centres although mental dysfunction in up to 88% of patients has been described in some publications.

The high mortality and high incidence of mental retardation have led some authors to suggest termination of a pregnancy when the diagnosis in made during the ante-natal period[32]. The ability of the ultrasonographer to make the diagnosis in the antenatal period has improved considerably particularly with the newer high resolution ultrasound equipment available[34,44,59,77]. As associated cranial and extracranial anomalies have been correlated with a poorer outcome in some series the diagnosis of these abnormalities antenatally would make a decision regarding termination easier. The difficulty at present is that the associated central nervous systen anomalies are difficult to diagnose on ultrasound. There has been one report of an antenatal diagnosis using MRI scanning[32]. This was performed at thirty four weeks gestation and demonstrated not only the Dandy-Walker malformation but also agenesis of the corpus callosum and a porencephalic cyst.

CONCLUSIONS

The study reported is clinically orientated. Although the number of patients analysed is small, and therefore cannot be subjected to statistical analysis, it is one of the largest series in the literature. From this experience and other published series, the following conclusions can be reached.

Based on the morphological characteristics of posterior fossa cysts as seen on axial CT scan, differentiation between Dandy-Walker cysts type A and B and arachnoid cysts, as proposed by Barkovich, is possible. This morphological classification does not appear to help decision making in the management or the assessment of outcome in patients with midline posterior fossa cysts.

Cyst-peritoneal shunts have a lower incidence of complications due to obstruction and overshunting compared to ventriculo-peritoneal shunts. In view of this cyst-peritoneal shunting is the preferred initial method of treatment in all developmental midline posterior fossa cysts.

As all reported series are small, a multi-centre study is advocated so that statistical analysis is possible.

REFERENCES

1. Aleksic S, Budzilovich G, Greco MA, Epstein F, Folgin I, Pearson I. Encephalocele (cerebellocele) in the Goldenhar-Gorlin syndrome. Eur J Pediatr 140:137-138,1983

2. Almeida GM, Matushita H, Mattosinho-Franca LC, Shibata MK. Dandy-Walker syndrome: posterior fossa craniectomy and cyst fenestration after several shunt revisions. Child's Nerv.Syst. 6:335-337,1990

3. Ameli NO. Arrest of development and Dandy-Walker malformation. Brain 89:548-554,1966

4. Arai H, Sato K. Posterior fossa cysts: clinical, neuroradiological and surgical features. Child's Nerv. Syst. 7:156-164,1991

5. Archer CR, Darwish H, Smith K. Enlarged cisternae magnae and posterior fossa cysts simulating Dandy-Walker syndrome on computed tomography. Radiology 127,681-686,1978

6. Asai A, Hoffman HJ, Hendrick EB, Humphreys RP. Dandy-Walker syndrome: Experience at the Hospital for Sick Children, Toronto. Pediatr. Neurosci. 15:66-73,1989

7. Barkovich AJ, Kjos BO, Norman D, Edwards MS. Revised classification of posterior fossa cysts and cystlike malformations based on tne results of multiplanar MR imaging. AJNR 10:977-988,1989

8. Benda CE. The Dandy-Walker syndrome or the so-called atresia of the Foramen Magendie. J Neuropathol Exp Neurol 13:14-29,1954

9. Bindal AK, Storrs BB, McLone DG. Management of the Dandy-Walker syndrome. Pediatr. Neurosurg. 16:163-169,1991

10. Bindal AK, Storrs BB, McLone DG. Occipital meningoceles in patients with the Dandy-Walker syndrome. Neurosurgery 28:844-847,1991

11. Boltshauser E, Isler W. Joubert syndrome episodic hyperpnea, abnormal eye movements, retardation and ataxia, associated with dysplasia of the cerebellar vermis. Neuropadiatrie 8:57-66,1977

12. Brocklehurst G. The development of the human cerebrospinal fluid pathway with particular reference to the roof of the fourth ventricle. J.Anat. 105:467-475,1969

13. Brodal A, Hauglie-Hanssen E. Congenital hydrocephalus with defective development of the cerebellar vermis (Dandy-Walker syndrome). Clinical and anatomical findings of two cases with particular reference to the so called atresia of the foramina of Magendie and Luschka. J Neurol Neurosurg Psychiatry 22:99-108,1959

14. Carmel PW, Antunez JL, Hilal SK, Gold AP. Dandy-Walker syndrome: clinicopathological features and reevaluation of modes of treatment. Surg Neurol 8:132-138,1977

15. Carteri A, Gerosa M, Gaini SM, Villani R. The dysraphic state of the posterior fossa: clinical review of the Dandy-Walker syndrome and the so-called arachnoid cysts. J.Neurosurg. Sci. 23:53-59,1979

16. Chan CC, Egbert PR, Herrick MK, Ulrich H. Occulocererbral malformations: a reappraisal of Walker's "lissencephaly". Arch Neurol 37:104-108,1980

17. Christian JC, Dexter RN, Palmer CG, Mullar J. A family with three recessive traits and homozygositiy for a long 9 qt+ chromosome segment. Am J Med Genet 6:301-308,1980

18. Coleman CC, Trol CE. Congenital atresia of the foramina of Luschka and Magendie: with a report of two cases of surgical cure. J Neurosurg 5:85-88,1948

19. Conway JJ, Yarzagaray L, Welch D. Radionuclide evaluation of the Dandy-Walker malformation and congenital arachnoid cyst of the posterior fossa. Am J Radiol 113:306-314,1971

20. D'Agostino AN, Kernohan JW, Brown JR. The Dandy-Walker syndrome. J Neuropathol Exp Neurol 22:450-470,1963

21. Dandy WE. The diagnosis and treatment of hydrocephalus due to occlusions of the foramina of Magendie and Luschka. Surg. Gynecol. Obstet. 32:112-124,1921

22. Dandy WE, Blackfan KD. Internal hydrocephalus. An experimental, clinical and pathological study. Am J Dis Child 8:406-482,1914

23. Egger J, Bellman MH, Ross EM, Baraister M. Joubert-Boltshauser syndrome with polydactyly in siblings. J Neurol Neurosurg Psychiatry 45:737-739,1982

24. Fischer EG. Dandy-Walker syndrome an evaluation of surgical treatment. J Neurosurg 39:615-621,1973

25. Gardner E, O'Rahilly R, Prolo D. The Dandy-Walker and Arnold-Chiari malformations. Arch Neurol 32:393-407,1975

26. Gardner WJ. Hydrodynamic factors in the Dandy-Walker and Arnold-Chiari malformations. Childs Brain 3:200-212,1977

27. Gardner WJ. The dysraphic states - from syringomyelia to anencephaly. Excerpta Medica. Amsterdam. 1973.

28. Gardner WJ, Smith JL, Padget DH. The relationship of Arnold-Chiari and Dandy-Walker malformation. J Neurosurg 36:481-486,1972

29. Geilfuss CJ, Puckett SE. Radiographic diagnosis of the Dandy-Walker syndrome with the emphasis on angiography. Radiology 92:255-258,1969

30. Gibson JB. Congenital hydrocephalus due to the atresia of the foramen of Magendie. J. Neuropathol. Exp. Neurol. 14:244-262,1955

31. Haller JS, Wolpert SM, Rabe EF et.al. Cystic lesions of the posterior fossa in infants: a comparison of the clinical, radiological and pathological findings in Dandy-Walker syndrome and extra-axial cysts. Neurol.(Minneap.) 21:494-506,1971

32. Hanigan WC, Wright R, Wright S. Magnetic resonance imaging of the Dandy-Walker Malformation. Pediatr. Neurosci. 12:151-156,1986

33. Hart MN, Malamud N, Ellis WG The Dandy-Walker syndrome: a clinicopathological study based on 28 cases. Neurology 22:771-780,1972

34. Hatjis CG, Horbar JD, Anderson GG. The in-utero diagnosis of a posterior fossa intracranial cyst (Dandy-Walker cyst). Am J Obstet Gynecol 140:473-475,1981

35. Hirsch JF, Pierre-Kahn Am Renier D, Sainte-Rose C, Hoppe-Hirsch E. The Dandy-Walker malformation. A review of 40 cases. J. Neurosurg 61:515-522,1984

36. Hoffman HJ, Epstein F. Disorders of the developing nervous system: Diagnosis and treatment. Blackwell Scientific publications. 1986

37. Holmes RL, Sharp JA, Brown MD. The human nervous system: A developmental approach. J & A Churchill Ltd. London 1969

38. Huong TT, Goldblatt E, Simpson DA. Dandy-Walker associated with congenital heart defects: report of three cases. Dev Med Child Neurol 17:35-41,1975

39. James HE, Kaiser GL, Schut L, Bruce DA. Problems of diagnosis and treatment in the Dandy-Walker syndrome. Child's Brain 5:24-30,1979

40. Jenkyn LR, Roberts DW, Merlis AL, Rozycky AA, Nordgren RE. Dandy-Walker malformation in identical twins. Neurology 31:337-341,1981

41. Kaiser GL, Schut L, James HE, Bruce DA. Problems of diagnosis and treatment in the Dandy-Walker syndrome. Neurology 27:771-780,1977

42. Kajina T, Waga S, Shimizer T, Sakakura T. Dandy-Walker cyst associated with occipital meningocele. Surg Neurol 17:52-56,1982

43. Keet PC, Berman MC. The Dandy-Walker syndrome. A report of three cases. SAMJ 35:6-11,1961

44. Kirkinen P, Jouppila P, Valkegkari T, Saukkonen AL. Ultrasonic evaluation of the Dandy-Walker syndrome. Obstet Gynecol 59 (Suppl):185-215,1982

45. La Torre E, Fortuna A, Occhipinti E. Angiographic differentiation between Dandy-Walker cyst and arachnoid cyst of the posterior fossa in newborn infants and children. J Neurosurg 38:298-308,1973

46. Lagger RL. Failure of pyramidal tract decussation in the Dandy-Walker syndrome. Report of two cases. J Neurosurg 50:382-387,1979

47. Lehman RM. Dandy-Walker syndrome in consecutive siblings : familial hindbrain malformation. Neurosurgery 8:717-719,1981

48. Lemire RJ, Loeser JD, Leech RW, Alvord EC. Normal and abnormal development of the human nervous system. Harper and Row, Publishers Inc. 1975

49. Lipton HL, Preziosi TJ, Moses H. Adult onset of Dandy-Walker syndrome. Arch Neurol 35:672-674,1978

50. Lukaya J, Garcia-Conesa JA, Bosch-Banyeras JM, Pons-Peadejordi G. The Coffin Siris syndrome. A report of four cases and review of the literature. Pediatr Radiol 11:35-38,1981

51. Maloney AFJ. Two cases of congenital atresia of the foramina of Magendie and Luschka. J Neurol Neurosurg Psychiatry 17:134-138,1984

52. Maria BL, Zinreich SJ, Carson BC, Rosenbaum AE, Freeman JM. Dandy-Walker syndrome revisited. Pediatr. Neurosci. 13:45-51,1987

53. Marinov M, Gabrovsky S, Undjian S. The Dandy-Walker syndrome: diagnostic and surgical considerations. British Journal of Neurosurgery. 5:475-484,1991

54. Masdeu JC, Doblen GD, Azar-Kia B. Dandy-Walker syndrome studies by computed tomography and pneumoencephalography. Radiology 147:109-114,1983

55. McLone DG, Naidich TP, Cunningham. Posterior fossa cysts: management and outcome. Conceps pediat. Neurosurg. 7:134-137,1987

56. Molland EA, Purcell M. Biliary atresia and Dandy-Walker anomaly in a neonate with 45, X Turner's syndrome. J Pathol 115:227-230,1975

57. Murray JC, Johnson JA, Bird TD. Dandy-Walker malformations: etiologic heterogeneity and empiric recurrence risks. Clin Genet 28:272-283,1985

58. Naidich TP, Radkowski MA, McLone DG, Leestma J. Chronic cerebral herniation in shunting Dandy-Walker malformation. Radiology 158:431-434,1985

59. Newman GC, Buschi AI, Sugg NK, Kelly TE, Miller JQ. Dandy-Walker syndrome diagnosed in utero by ultrasonography. Neurology 32:180-184,1982

60. Nova HR. Familial communicating hydrocephalus, posterior cerebellar agenesis, mega cisterna magna and portwine nevi. J Neurosurg 52:862-865,1979

61. Olson GS, Halpe DCE, Kaplan AM, Spataro J. Dandy-Walker malformations and associated cardiac anomalies. Child's Brain 8:173-180,1981

62. Opitz JM., Gilbert EF. CNS anomalies and the midline as a "Developmental field". Am J Med Genet 12:443-455,1982

63. Padget DH. Development of so-called dysraphism; with embryonic evidence of clinical Arnold-Chiari and Dandy-Walker malformations. Johns Hopkins Med.J. 130:127-165,1972

64. Pagon RA, Claren Sk, Milam DF, Hendrickson AE. Autosomal recessive eye and brain anomalies. Warburg syndrome. J Pediatr 102:542-546,1983

65. Palma A, Castro M, Olea E, Guzman G. Dandy-Walker Malformation and the contribution of radio-isotopic studies of cerebrospinal fluid dynamics to its diagnosis. Acta Neurochir (Wein) 61:319-324,1982

66. Pascual-Castroviejo I. Vascular and nonvascular intracranial malformation associated with external capillary hemangiomas. Neuroradiology 16:82-84,1978

67. Pascual-Castroviejo I. The association of extracranial and intracranial vascular malformations in children. Can J Neurol Sci 12:139-148,1985

68. Pascual-Castroviejo I, Velez A, Pascual-Pascual SI, Roche MC, Villarelo F. Dandy-Walker malformation: analysis of 38 cases. Child's Nerv. Syst. 7:88-97,1991

69. Pillay P, Barnett GH, Lanzeiri C, Cruse R. Dandy-Walker cyst upward herniation: the role of magnetic resonance imaging and double shunts. Pediatr. Neurosci. 15:74-79,1989

70. Raimondi AJ, Samuelson G, Yarzagaray L, Norton T. Atresia of the foramina of Luschka and Magendie: the Dandy-Walker cyst. J Neurosurg 31:202-216,1969

71. Raimondi AJ, Sato K, Shimoji T. Dandy-Walker syndrome. Karger, Basel (1984) pp1-82

72. Sahs AL. Congenital anomaly of the cerebellar vermis. Arch Pathol 32:52-63,1941

73. Saitoh K, Kawamoto T, Ebina T, Tanaka T. Sib cases of Dandy-Walker syndrome. Brain Nerve 30:875-879,1978

74. Sarnat HB, Netsky MG. Evolution of the nervous system. Oxford University Press, Inc. New York. 1974.

75. Sautreaux JL, Giroud M, Dauvergne M, Nivelon JL, Thierry A. Dandy-Walker malformation associated with occipital meningocele and cardiac anomalies: a rare complex embryologic defect. J Child Neurol 1:64-66,1986

76. Sawaya R, McLaurin RL. Dandy-Walker syndrome. Clinical analysis of 23 cases. 55:89-98,1981

77. Strassburg HM, Weber A, Sauer M. Diagnosing hydrocephalus in infants by ultrasound sector scanning through the open fontanelles. A study comparing ultrasound-sonography and CAT scan. Neuropediatrics 12:254-266,1981

78. Sutton JB. The lateral recesses of the fourth ventricle, their relation to certain cysts and tumours of the cerebellum, and to occipital meningocele. Brain 9:352-361,1887

79. Taggart JK Jr, Walker AE. Congenital atresia of the foramens of Luschka and Magendie. Arch Neurol 48:583-612,1942

80. Tal Y, Freigang B, Dunn HG, Durity FA, Moyes PD. Dandy-Walker syndrome: analysis of 21 cases. Dev Med Child Neurol 22:189-201,1980

81. Udvarhelyi GB, Epstein MH. The so-called Dandy-Walker syndrome: analysis of 12 operated cases. Child's Brain 1:158-182,1975

82. Van Dellen JR, Ford MAW. Dandy-Walker syndrome SAMJ 53:1034-1036,1978

83. Walker AE. A case of congenital atresia of the foramina of Luschka and Magendie: surgical cure. J Neuropathol Exp Neurol 3:368-373,1944

84. Whitten CA Jr, Moyar JB, Wise BL. Hydrocephalus syndrome: obstructions of the foramina of the fourth ventricle. Am J Dis Child 103:55-60,1962

85. Wolpert SM, Haller JS, Robe EF. The value of angiography in the Dandy-Walker syndrome and posterior fossa extra-axial cysts. Am J Radiol 109:261-272,1970