# **Craniospinal Irradiation Principles of Planning & Clinical Applications**

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## **Craniospinal Irradiation (CSI)**

**\***Irradiation of entire neuraxis i.e. whole brain and spine

Useful in tumors prone to leptomeningeal spread like Medulloblastoma Germinoma Pineoblastoma Supratentorial PNETs Leukemia/Lymphoma (with CSF spread)

# Edith Paterson advocated irradiation of entire neuraxis

## CEREBELLAR MEDULLOBLASTOMA: TREATMENT BY IRRADIATION OF THE WHOLE CENTRAL NERVOUS SYSTEM

by

Edith Paterson and R. F. Farr

#### Introduction

The prognosis in cases of medulloblastoma of the cerebellum has for many years been regarded as fairly hopeless. This viewpoint is expressed by DARGEON (1948) where he states that "medulloblastomas ... have a consistently unfavourable prognosis". In their excellent book, "Intracranial tumours of infancy and childhood", BAILEY, BUCHANAN and BUCY come to the same conclusion. There are, however, a few authenticated cases reported with a long survival following treatment, cases which are almost historical in their rarity (PENFIELD and FEINDEL 1947; INGRAHAM, BAILEY and BARKER 1948).

For this reason it may be useful to describe the methods of treatment which have been used over the last ten years on proved cases of this disease, methods which have yielded over fifty per cent survival at three years following treatment. Over this period we have adopted, with these encouraging results, the principle of irradiation of the entire brain and cord as one undivided volume. This principle stems from the postmortem findings in untreated cases of this disease in which it is almost universal to find deposits in the brain and cord which have seeded from

## **CSI** Planning

## **Technically challenging:**

- Large target area to be covered
- Irregular shape of the target
- Multiple fields with junction overlap
- Normal tissue exposure and late toxicities



## **CSI Planning Steps**

- Positioning & Immobilization
- Target/OAR Delineation
- Field Arrangement
- Doses
- Treatment Verification

## **Patient Positioning**

## **PRONE:**

Direct visualization of the field junctions on the patient. Poor reproducibility Scope of patient movement and Discomfort Difficult anesthesia

## **SUPINE:**

Comfortable Relative ease in anesthesia

## Immobilization

## **Prone position:**

Neck neutral to hyperextended Arms by the side on a CSI board Base plate with prone head and chin rest Slots from A to E to allow various degrees of extension of neck Thermocol wedge for supporting chest





Prone Head Rest with Vacuum supports for trunk



## **RT Planning**

**2D Fluoroscopic Simulation** 

Conventional Definition of the second second

3D CT based Volume delineation & Conformal dose delivery

3D – Conformal





IMRT

## **2D Simulation and Field Placement**

## **CSI Fields:**

- Two lateral opposed cranial fields
- One or Two spinal fields

## **Issues in Planning:**

- Divergence of Cranial and Spinal fields
- Field matching at junctions

- Spinal field simulated first (get to know the divergence of the spinal field)
- SSD technique
- 2 spinal fields if the length is > 36 cm
- Upper border at low neck
- Lower border at termination of thecal sac or S2 /3 junction whichever is lower
- In case of 2 spinal fields , junction at L2/L3

## **Junction of Cranio-Spinal Field:**

Higher level - C1/C2 interspace, since overdose at cord is low as compared to low junction

Lower level - lowest level in the neck with exclusion of the shoulders in the lateral fields (from C5 to C7), lowers the exit dose to thyroid, mandible, larynx & pharynx

## **Termination of thecal sac**

- Traditional recommendation for lower border of spinal field is inferior edge of S2 (myelogram & autopsy studies).
- 8.7% patients have termination below S2-S3 interspace.
- MRI accurately determines the level of termination of the thecal sac

## **Fixed or Calculated gap spinal fields**

- Use of fixed gap ranging from < 5 mm to 10mm between fields OR
- Customized gap for each patient depending on the field length & depth of prescription
- Spinal fields are simulated after gap calculation
- Width include the transverse process, usually 5 to 7 cm

# **Gap calculation-formula**



**Gap calculation-formula** 



**Gap calculation-formula** 





# **Simulation-cranial field**

- Whole brain field is simulated & lower border is matched with the superior border of spinal field.
- AP width & superior border include the entire skull with 2 cm clearance.
- Techniques for matching craniospinal fields:
  - Collimator/couch rotation
  - Half beam block
  - Asymmetric jaws
  - Penumbra generators
  - Wedge
  - Tissue compensator



# **Problem 1: Divergence of cranial field**



# **Solution A: Rotate the couch** S Spinal field



# **Problem 2 Divergence of spinal field**



# Solution A: Rotate the cranial field collimator



# **Solution B: Use asymmetric spinal block**



# **Simulation-cranial field**

- In practice 5 mm gap left in the cranial and spinal fields
- Cranial field Collimator angle = tan<sup>-1</sup> { <sup>1</sup>/<sub>2</sub> L<sub>1</sub>/SSD} L<sub>1</sub> is spinal field length
- Couch angle = tan<sup>-1</sup> { <sup>1</sup>/<sub>2</sub> L<sub>2</sub>/SAD}
  L<sub>2</sub> is cranial field length
- Use of asymmetric collimator jaws precludes the need of couch rotation.



# More important is what not to shield !

# DO NOT SHIELD

Frontal (cribriform plate)

Temporal region

# **SFOP Guidelines**

5mm margin below the orbital roof

1cm margin elsewhere below the skull base







# **Treatment & Verification**

- Port films after placing radio-opaque markers on the inferior border of cranial field can be used to verify craniospinal field matching.
- Electronic portal imaging has also played important role in verification & correction of set up errors.

# **Moving Junction in CSI**

Feathering after every 5 to 7 fraction smoothes out any overdose or underdose over a longer segment of cord







# Junction shift in CSI

# **Junction shift**

- Usually shifted by 1 to 2 cm at each shift
- Done every few fractions
- Either in cranially or caudal direction.
- Cranial inferior collimator is closed & spinal superior collimator is advanced by the same distance superiorly (if junction to be shifted cranially)
- Similarly, lower border of superior spinal field & superior border of inferior spinal field are also shifted superiorly, maintaining the calculated gap between them

## **CSI** for average-risk disease

(age >3 yrs, M0 status, and residual <1.5 cm2)

- Standard dose CSI: 35-36 Gy/21-20#/4 weeks @ 1.67-1.8 Gy/#
- Reduced dose CSI: 23.4 Gy/13#/2.5 weeks @1.8 Gy/# (+ adj CT)
- Very reduced dose CSI: 18 Gy/10#/2 weeks @ 1.8 Gy/# (+ adj CT)

## **CSI for high-risk disease**

(age <3 yrs, M+ status, and residual >1.5 cm2)

•Standard dose CSI: 35-36 Gy/21-20#/4 weeks @ 1.67-1.8 Gy/# •Higher dose spinal RT: 39.6 Gy/22#/4.5 weeks @1.8 Gy/#

# **Beam parameters**

Photons: 4 to 6mv produce good dose homogeneity

- Cranial field prescribed at midplane SSD
- Spinal field 5 to 6cm along central axis depending on depth of spinal cord at SSD (posterior vertebral body seen on Lateral X rays / CT scan / MRI).

Supine CSI planning CT based

## Imaging

1-2.5mm slice thickness from vertex to lower border of C3

2-5mm thickness from lower border of C3 to upper part of femur

CT to be co-registered with latest or Planning MRI, preferably FIESTA sequence

AjithKumar et al, Radiother Oncol 2018

# Individualized CT planning

- Method analogous to conventional simulation but with use of asymmetric collimator jaws for matching beam divergence
- Field junctions can be visually verified
- The distance between the two isocenters (three if two spine fields are required) can be calculated once the beams have been set
- This distance can then be used as the digital longitudinal table distance shift



# Sagittal MPR of patient in supine CSI





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## PEDIATRIC MEDULLOBLASTOMA: RADIATION TREATMENT TECHNIQUE AND PATTERNS OF FAILURE

RAYMOND MIRALBELL, M.D.,\* ARNOLD BLEHER, M.D.,<sup>†</sup> PIA HUGUENIN, M.D.,<sup>‡</sup> GERHARD RIES, M.D.,<sup>§</sup> ROGER KANN, M.D.,<sup>||</sup> RENÉ O. MIRIMANOFF, M.D.,<sup>§</sup> MARKUS NOTTER, M.D.,\* PHILIPPE NOUET, B.SC,\* SABINE BIERI, M.D.,\* PETER THUM, M.D.\*\* AND HECHMAT TOUSSI, M.D.<sup>††</sup>

77 children, 1972-91 **Retrospective review of simulation/port films of WBI** Median fu 8.5 yrs

16/72 pts fields judged acceptable Unacceptable anterior margin (too posteri Unacceptable inferior margin (

### Table 2. Medulloblastoma: first site of failure

Posterior fos	15 (31)	
Supratentoria	12 (24)	
Posterior fos	4 (8)	
Spine	3 (6)	
Posterior fos	3 (6)	
Supratent. +	spine	3 (6)
Posterior f	- supratent. + spine	2 (4)
-	's	7 (14)
C		

8.5 yrs	Posterior supratent. + spine	2 (4) 7 (14)
elds judged acceptable ole anterior margin (too posterial areas, over generi ole anterior margin (too posterial areas, over generi	al relapses ents and (%) rates. Table 3. Supratentorial only failures: s	ubsites of failure
Underdosage of Dass higher Super Underdosage of Dass to higher Super Underdosage of Dass to higher Super	Subfrontal Subtemporal Subtemporal	<mark>5 (42)*</mark> 1 (8) 2 (17)
use of eye sm	Intraventricular Hypothalamic Diffuse meningeal	2 (17) 2 (17) 1 (8) 1 (8)



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#### CLINICAL INVESTIGATION

Brain

#### IMPACT OF TARGETING DEVIATIONS ON OUTCOME IN MEDULLOBLASTOMA: STUDY OF THE FRENCH SOCIETY OF PEDIATRIC ONCOLOGY (SFOP)

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Prospective review of MB pts in French trials 169 pts, 1992-98 Median f/u 2.9 yrs

**RT Targeting Guidelines -**





Cont..

Table 1. Summary of site of targeting deviations*								
	A	B C	D	E	F	Н	Ι	
Minor deviation	40	<mark>53</mark> 9	19	11	34	19	16	
%	24%	31%5%	5 11%	7%	20%	11%	9.5%	
Major deviation	28	<mark>18</mark> 6	3	5	8	3	5	
%	17%	11% 4%	5 2%	3%	5%	2%	3%	
Total <i>n</i>	68	71 15	22	16	42	22	21	
%	40%	42% 9%	5 13%	10%	25%	13%	13%	

120 pts (71%) had at least one deviation 53 pts (31%) at least one major deviation

7/28 children with major deviation in 'A' relapsed5 of these relapsed in frontal region6/11 pts treated with electrons (<18MeV) relapsed in CSF or Spine</li>



Relapses strongly a/w insufficient coverage of cribriform plate or temporal regions & wrong choice of electron beam energy Fast imaging employing steady-state acquisition (FIESTA) MRI to investigate cerebrospinal fluid (CSF) within dural reflections of posterior fossa cranial nerves

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CSF & Cranial nerves evaginating into IAM, JF, HC

**BJR 2016** 

Cont..

Mean distance of CSF extension into – IAM: 12.2 mm, JF: 7.3 mm, HC: 9-10 mm

CSF flows beyond the inner table of skull base

**Clinical implications in tumor which spread via meningeal surfaces** 





TREATMENT TECHNIQUE & DOSE PARAMETERS

TOMOTHERAPY

Dmin

V95%

Dmin

PROTON

V95%

an

V95%

FIELD

Dmir

ACTA ONCOLOGICA 2019, VOL. 58, NO. 12, 1740–1744 https://doi.org/10.1080/0284186X.2019.1667023



Check for updates

ORIGINAL ARTICLE

MRI-guided definition of cerebrospinal fluid distribution around cranial and sacral nerves: implications for brain tumors and craniospinal irradiation

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10 healthy adult volunteers

MR from skull base & sacral plexus

Extension of CSF within dural sheath measured

**CSF** distribution observed in II, V, VII-XII nerves

No CSF spread outside the spinal canal at sacral level

Cont..

Table 1. CSF extension within the dural sheath of the cranial nerves, measured from the inner table of the skull.

Nerve	Mean (mm)	95% Cl (mm)	Maximum extension (mm)		
Olfactory nerve (I)	Not visible	Not visible	Not visible		
Optic nerve (II)	40	[38-42]	45		
Oculomotor nerve (III)	Not visible	Not visible	Not visible		
Trochlear nerve (IV)	Not visible	Not visible	Not visible		
Trigeminal nerve (V)	16	[15–19]	21		
Abducens nerve (VI)	Not visible	Not visible	Not visible		
Facial nerve (VII)	11	[11-12]	14		
Vestibulo-cochlear nerve (VIII)	11	[11-12]	14		
Glossopharyngeal nerve (IX)	7	[7-9]	10		
Vagus nerve (X)	7	[7-9]	10		
Accessory nerve (XI)	7	[7-9]	10		
Hypoglossal nerve (XII)	8	[7–9]	10		



**Optic N** 



**Trigeminal N** 

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Radiotherapy and Oncology



journal homepage: www.thegreenjournal.com

CNS radiotherapy

A comparison of optic nerve dosimetry in craniospinal radiotherapy planned and treated with conventional and intensity modulated techniques

Nicholas J. Rene<sup>a</sup>, Marylene Brodeur<sup>b</sup>, William Parker<sup>b</sup>, David Roberge<sup>a</sup>, Carolyn Freeman<sup>a,\*</sup>

5 pts treated with CSI 3DCRT vs Tomotherapy plans

## **3DCRT:**

2 lateral opposed cranial fields, one or two posterior spinal fields Optic nerves not included in the target volume

Tomotherapy: CNS with 3-5mm margin Optic nerves not included in the target volume

Optic nerves contoured separately with 3-5mm margin



Average mean dose, average minimum dose and average V95% to the optic nerves, anterior optic nerves, posterior optic nerves and optic nerve-PTV obtained with tomotherapy and 3D-CRT plans. Mean and minimum doses are expressed as percentage doses relative to the prescribed dose.

	ON		ANT-ON		POST-ON		ON-PTV					
	Min dose	Mean dose	V95%	Min dose	Mean dose	V95%	Min dose	Mean dose	V95%	Min dose	Mean dose	V95%
Tomotherapy	92%	98%	87%	92%	96%	79%	97%	100%	100%	84%	97%	81% (range 50–96%)
3D-CRT	99%	100%	100%	99%	100%	100%	99%	100%	100%	95%	100%	99% (range 95-100%)

V95% and Mean dose for Optic Nerve PTV lower in all Tomo plans, especially to anterior portion

Potential for underdosing the optic nerves, especially with lower dose CSI being used

Radiotherapy and Oncology 128 (2018) 192-197

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SIOPE Guideline

SIOPE – Brain tumor group consensus guideline on craniospinal target volume delineation for high-precision radiotherapy



Thankamma Ajithkumar<sup>a,\*</sup>, Gail Horan<sup>a</sup>, Laetitia Padovani<sup>b</sup>, Nicky Thorp<sup>c</sup>, Beate Timmermann<sup>d</sup>, Claire Alapetite<sup>e</sup>, Lorenza Gandola<sup>f</sup>, Monica Ramos<sup>g</sup>, Karen Van Beek<sup>h</sup>, Melissa Christiaens<sup>h</sup>, Yasmin Lassen-Ramshad<sup>i</sup>, Henriette Magelssen<sup>j</sup>, Kristina Nilsson<sup>k</sup>, Frank Saran<sup>1</sup>, Barbara Rombi<sup>m</sup>, Rolf Kortmann<sup>n</sup>, Geert O. Janssens<sup>o</sup>, on behalf of SIOPE BTG Radiotherapy Group



#### Target delineation

Since the entire CSF space is at risk of disease dissemination, the entire arachnoid space is defined as the CTV.

## CTV<sub>cranial</sub>

An accurate delineation of CTV<sub>cranial</sub> is established through the following three steps:

**Firstly**, the inner table of the skull is outlined using bony window settings (suggested CT Window/level: 1500–2000/300–350,).

**Secondly**, ensure that the cribriform plate (suggested CT window/level: 3000/400), the most inferior parts of the temporal lobes, and the whole pituitary fossa, which contains CSF are included in the CTV<sub>cranial</sub>.

**Thirdly**, the CTV<sub>cranial</sub> is modified to include the extension of CSF within the dural sheath of cranial nerves as defined (Table 2) below:

*Olfactory nerve* fibres are encompassed in the CTV while covering the cribriform plate. While the majority of institutions include the whole length of the *optic nerves* in the CTV, a few institutions that routinely use PBT include only the posterior part of the optic nerves to avoid any potential risk of optic retinopathy and to spare the lens [22,23]. An MRI study (in 10 healthy volunteers) by Janssens et al. (*personal communication*) showed that CSF extends up to the posterior aspect of the eyeball in all scans (Fig. 1A). For this reason, the majority of expert paediatric radiation oncologists are in favour of including the whole optic nerves in the CTV. However, the consensus group acknowledges that the exact risk of isolated recurrence after partial irradiation of optic nerve is not known and would be difficult to study.

The oculomotor, abducens and trochlear nerves are thin nerves without a dural cuff. The trigeminal nerve consists of sensory and motor roots and exits from the ventral aspect of the pons. In the middle cranial fossa, the sensory root expands to form the trigeminal ganglion which is located in the trigeminal cave lateral to the cavernous sinus (Fig. 1B). The ophthalmic and maxillary divisions of the trigeminal nerve arise from the periphery of the trigeminal ganglion and exit through the superior orbital fissure and foramen rotundum. The motor root of trigeminal nerve runs along the floor of the trigeminal nerve and forms the mandibular division which exit via the foramen ovale. The CSF within Meckel's cave along the trigeminal nerve is enclosed by the medial part of the middle cranial fossa CTV.

## Skull Base Foramina A



Fig. 2. Illustrations of the skull base foramina relevant for CSA delineation.





## CTV<sub>spinal</sub>

The CTV<sub>spinal</sub> should include the entire subarachnoid space to encompass the extensions along the nerve roots laterally (Fig. 4A). The inferior limit of the CTVspinal is best determined by imaging the lower limit of the thecal sac on the latest spinal MRI. This usually comes down to the bottom of S1 vertebra as an obvious CSF space but there is often elongation which is less obvious extending down to the bottom of S2 or even further inferiorly (Fig. 4B-C). In case of doubt, it is best to seek expert neuroradiological advice about this landmark. In a study of 10 healthy volunteers, MRI did not show any CSF around the sacral nerve roots or in the sacral nerve root canals (Fig. 4D) (Janssens et al., personal *communication*) and these areas are therefore not included in the CTV<sub>spinal</sub>.

## Organs-at-risk (OAR)

The OARs to be delineated for the CTV<sub>cranial</sub> include the eye balls, lens, cochlea and the parotid and submandibular salivary glands. Adjacent to the CTV<sub>spinal</sub>, the OARs to delineate include the larynx, oesophagus, thyroid gland, breasts in females, lungs, heart, liver, stomach, intestine, pancreas, kidneys and the gonads. In growing children, partial vertebral irradiation leads to spinal deformities [24–26]. Therefore, it is important to ensure uniform radiotherapy dose to the vertebrae in the region of the CTV<sub>spinal</sub> in growing children to avoid non-uniform growth cessation. The parts of the vertebrae bearing growing plates (the body of the vertebra, the posterior element and facet joints; but not the lateral

elements and transverse processes) should be enclosed to a uniform minimum dose (18–20 Gy) [25,27]. The methods for irradiating the growing vertebrae to the lowest uniform growthrestraining dose vary between institutions (e.g. PTV covering uniform dose of 20 Gy, vertebra covering a fixed-isodose level etc.) and the SIOPE is currently developing a consensus guideline for optimal delineation and dose prescription for growing vertebrae.

## Planning target volume (PTV) and techniques

The PTV margin should be based on departmental data. Most institutions add a 3-5 mm margin to CTV<sub>cranial</sub> and a 5-8 mm margin to CTV<sub>spinal</sub>. A number of treatment techniques such as 3-D conformal, IMRT, VMAT, Tomotherapy and proton therapy are used for CSI. A recent comparison of different techniques of craniospinal radiotherapy across 15 European centres showed that highly conformal radiotherapy techniques have dosimetric advantages compared with 3D-conformal radiotherapy and proton therapy often leads to the lowest mean dose to OARs (Seravalli et al., Acta Oncology in press 2018). However, for most organs, ranges in mean doses were wide and overlapping between techniques making it difficult to recommend one radiotherapy technique over another.



- Proper immobilization
- Proper coverage and Dose homogeneity in the target volume
- Reducing the dose to OARs
- Evaluating the Integral Dose