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H. Krayenbühl, Zürich (Managing Editor)

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Preface

As an addition to the European postgraduate training system for young neurosurgeons we began to publish in 1974 this series devoted to Advances and Technical Standards in Neurosurgery which was later sponsored by the European Association of Neurosurgical Societies.

The fact that the English language is well on the way to becoming the international medium at European scientific conferences is a great asset in terms of mutual understanding. Therefore we have decided to publish all contributions in English, regardless of the native language of the authors.

All contributions are submitted to the entire editorial board before publication of any volume.

Our series is not intended to compete with the publications of original scientific papers in other neurosurgical journals. Our intention is, rather, to present fields of neurosurgery and related areas in which important recent advances have been made. The contributions are written by specialists in the given fields and constitute the first part of each volume.

In the second part of each volume, we publish detailed descriptions of standard operative procedures, furnished by experienced clinicians; in these articles the authors describe the techniques they employ and explain the advantages, difficulties and risks involved in the various procedures. This part is intended primarily to assist young neurosurgeons in their postgraduate training. However, we are convinced that it will also be useful to experienced, fully trained neurosurgeons.

The descriptions of standard operative procedures are a novel feature of our series, and in this it differs from the similarly entitled series "Progress in Neurological Surgery"; also, our series will be mainly, but not exclusively, a forum for European neurosurgeons. We intend as well to make available the findings of European neurosurgeons which are published in less familiar languages to neurosurgeons beyond the boundaries of the authors' countries and of Europe, and we aim to promote contacts among European neurosurgeons.

We hope that neurosurgeons not only in Europe, but throughout the world, will profit by this series of "Advances and Technical Standards in Neurosurgery".

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Contents

A. Advances

List of Contributors XI

Stereotactic Radiosurgery in Intracranial Tumours and Vascular Malformations. By E.-O. Backlund, Department of Neurosurgery, Karolinska Hospital, Stockholm, Sweden 3

Introduction 3
Technique 5
Acoustic Tumours 9
Case Report 10
Conclusions 13
Tumours in the Pineal Region 13
Case Report 15
Conclusion 15
Craniopharyngiomas 17
Case Report 17
Conclusions 18
Hypersecreting Pituitary Tumours 19
1. Pituitary Dependent Cushing's Disease and Nelson's Syndrome 19
a) Cushing's Disease 20
b) Nelson's Syndrome 20
Case Report 21
2. Acromegaly 23
Case Report I 23
Case Report II 24
Conclusions 25
Arteriovenous Malformations 27
Case Report I 30
Case Report II 32
Conclusion 34
General Conclusions 34
Acknowledgements 35
References 35

Infection in Neurosurgery. By J. Klastersky, Service de Médecine Interne, Institut Jules Bordet, Centre des Tumeurs de l'Université Libre de Bruxelles, Bruxelles, Belgium, L. Kahan-Coppens, Service de Médecine Interne et Laboratoire d'Investigation Clinique H. J. Tagnon (Section des Maladies Infectieuses), Institut Jules Bordet, Centre des Tumeurs de l'Université Libre de Bruxelles, Bruxelles, Belgium, and J. Brihaye, Clinique Neurochirurgicale, Université Libre de Bruxelles, Bruxelles, Belgium 39

Meningitis 40
Intrathecal Administration of Antibiotics 42
Brain Abscess 44
Osteomyelitis and Epidural Abscess 46
Disc Space Infection 47
Pulmonary Infections 47

Wound Infection 50
Bacteriuria After Indwelling Catheterization 51
Conclusions 51
References 53

Spasticity-Clinical Classification and Surgical Treatment. By C. Gros, Centre Hospitalier Universitaire, Montpellier, France 55

I. Introduction 56

II. Pathophysiology 57
1. The Segmentary Control of Alpha Motoneurons 58
2. The Intersegmentary Control 60
3. The Supra-Segmental Control 61
4. Laboratory Investigations 62

III. The Natural History of Spasticity 62
1. The Spastic Child 62
1.1. Investigations 63
1.1.1. The I.Q 63
1.1.2. The Evaluation of Functional Adaptation 63
1.1.3. Analytical Evaluation 63
1.2. Useful or Handicapping Spasticity 63
1.3. Codification of the Problems 64
2. The Adult Spastic 64
2.1. Period of Recovery 65
2.2. Spasticity in "Extension" 67
2.3. Spasticity in "Flexion" 68
3. Spasticity and Involuntary Movements 68

IV. Neurosurgery of Spasticity 69
1. Neurotomies 69
2. Radiculotomy 71
2.1. Direct Effect 72
2.2. "Distant" Effect 72
2.3. Failure or Deterioration 73
3. Posterior Radiculotomy: New Techniques 74
3.1. Posterior "Rhizidiotomy" of Sindou *et al.* 74
3.2. Partial Posterior Radiculotomy of Guidetti and Fraioli 74
3.3. Sectorial Posterior Radiculotomy (Gros and Privat) 75
3.3.1. Factorial Checking 75
3.3.2. Operative Technique 76
3.3.3. Results 77
4. Anterior Radiculotomy 78
5. Myelotomy 79
6. Central Operations 81
6.1. Dentatectomy-Dentatolysis 81
6.2. Pulvinarolysis 81

V. Utilization of Electrical Functional Stimulations (EFS) 82
1. Technical Conditions 82
1.1. Applications by Surface Bipolar Electrodes 83
1.2. EFS by Implanted Electrodes 83
1.3. EFS of the Spinal Cord 84
2. Clinical Effect of EFS 84
3. Pathophysiology of EFS 84

VI. Indications for Treatment 86
1. The Spastic Child 87
2. The Spastic Hemiplegia 88
3. The Spastic Hand of Hemiplegics 89

4. The Spastic Paraplegics ... 90
4.1. Spasticity in Extension ... 90
4.2. Spasticity in Flexion ... 90
5. Indications ... 91
5.1. Indications for Functional Improvement ... 91
5.2. Indications for Articular Protection ... 91
5.3. Indications for Comfort ... 91

VII. Concluding Remarks ... 91

References ... 92

B. Technical Standards

Surgical Approaches to the Sphenoidal and Clival Areas. By P. J. DEROME and G. GUIOT in co-operation with B. GEORGES, M. PORTA, A. VISOT, and S. BALAGURA, Service de Neurochirurgie, Hôpital Foch, Suresnes, France ... 101

Introduction ... 101

I. Intradural Approaches ... 102
a) Subtemporal Approach ... 102
b) Suboccipital Approach ... 102

II. Anterior Approaches ... 103
a) Transcervical Approach ... 103
b) Transoral (-buccal) Approach ... 106
c) Transsphenoidal (rhino-septal) Approach ... 109
d) Transbasal Approach ... 110

III. Choice of Surgical Approach ... 123
1. Biopsy ... 123
2. Tumor Relation to the Dura ... 123
3. Consistency of the Tumor ... 127
4. Histology ... 128
5. Localization and Extent of the Tumor ... 128
a) Intradural Approach ... 128
b) Extradural Approach ... 129
c) Combined Approaches in One Stage ... 134
d) Combined Approaches in Multiple Stages ... 134

IV. Conclusion ... 135

References ... 135

Cervical Spondylotic Myelopathy. By R. BRAAKMAN, Neurosurgical Department, Academic Hospital Dijkzigt, Erasmus University, Rotterdam, The Netherlands 137

Spondylotic Myelopathy ... 138
Definition ... 138
Spondylosis ... 138
Pathological Mechanism ... 140
Additional Investigations ... 145
Radiology ... 146
Contrastprocedures ... 147
Lumbar Puncture ... 148
Trauma ... 150
Therapy ... 152
Surgical Therapy ... 153
Results of Surgical Therapy ... 157
Author's Surgical Approach to SM ... 158
Laminectomy ... 159
Technique ... 159

Anterior Approach 162
Technique 162
Therapy in Case of Traumatic SM 164
Informing the Patient 165
Acknowledgement 165
References 166

Tumours of the Posterior Part of the Third Ventricle: Neurosurgical Criteria. By F. Isamat, Service of Neurosurgery, Ciudad Sanitaria "Principes de España", Hospitalet de Llobregat, Barcelona, Spain 171

Introduction 171
Pathological Classification 172
Diagnosis 173
Clinical Symptomatology 173
Radiology 174
Management 178
CSF Diversionary Procedures and Radiotherapy 178
Neurosurgical Criteria 182
References 183

Author Index 185
Subject Index 189

A. Advances

Stereotactic Radiosurgery in Intracranial Tumours and Vascular Malformations

E.-O. Backlund

Department of Neurosurgery, Karolinska Hospital, Stockholm (Sweden)

With 19 Figures

Contents

Introduction 3
Technique 5
Acoustic Tumours 9
Case Report 10
Conclusions 13
Tumours in the Pineal Region 13
Case Report 15
Conclusion 15
Craniopharyngiomas 17
Case Report 17
Conclusions 18
Hypersecreting Pituitary Tumours 19
1. Pituitary Dependent Cushing's Disease and Nelson's Syndrome 19
a) Cushing's Disease 20
b) Nelson's Syndrome 20
Case Report 21
2. Acromegaly 23
Case Report I 23
Case Report II 24
Conclusions 25
Arteriovenous Malformations 27
Case Report I 30
Case Report II 32
Conclusion 34
General Conclusions 34
Acknowledgements 35
References 35

Introduction

In spite of the recent advances in brain surgery, the operative treatment of many intracranial conditions still offers great technical difficulties. The use of the operating microscope, especially in dextrous hands, considerably increases the possibility of achieving gratifying clinical results, but nevertheless the removal of some brain tumours, even benign, is still attended by considerable risks. Furthermore, arteriovenous malformations may if deep-seated be practically inaccessible to conventional techniques. These technical problems, inherent in traditional operations lend a sense of urgency to the development of new therapeutic methods.

In 1951, Leksell introduced the concept of "radiosurgery" and described a technique for stereotactically directing narrow beams of ionizing radiation to a limited target area within the brain without opening the skull (Leksell 1951). A new branch of the stereotactic surgery, "closed stereotactic operations", was thus established (Leksell 1971).

One of the principles of radiosurgery is that the radiation energy is delivered as a single dose to sharply circumscribed and precisely defined areas of tissue. This is possible if the radiophysical properties of the radiation sources are such that the dose gradient is very steep at the margins of the area chosen for irradiation. This, combined with precise anatomical definition of that area minimizes the side effects of the radiation. Thus, a dose can be given which is sufficient to cause necrosis of the area selected. Radiation can of course also be delivered to such an area by inserting radionuclides via a burrhole. However, when the concept "radiosurgery" was introduced, the "closed" technique was intended. In the present Chapter, the terms "radiosurgery" and "radiosurgical" will be used in this more limited sense.

The first clinical applications of radiosurgery were made with relatively low energy x-rays (Leksell *et al.* 1955) and later a well collimated proton beam (Larsson *et al.* 1958) was used for crossfire to deep structures of the brain, such as thalamic nuclei. It was suggested that this technique might also be used for the destruction of any area of tissue within the cranial compartment.

The aim of the present Chapter is to describe the radiosurgical techniques in use and the clinical experience hitherto gained during treatment of intracranial tumours and vascular malformations at the Radiosurgical Units of the Sophiahemmet Hospital and of the Stereotactic Service, Department of Neurosurgery, Karolinska Hospital, Stockholm, Sweden. Recently published case material is presented in a summarized form, but each group is illustrated with one or two representative cases from the author's personal experience, described in more detail.

At Harvard University, Boston, Massachusetts, stereotactic techniques are used for single dose treatment, predominantly for pituitary tumours and vascular malformations (Kjellberg and Kliman 1973). This group utilizes the so called "Bragg peak" of the proton beam to improve the radiophysical conditions.

Proton irradiation has also been used in the Soviet Union. An extensive study of the possibilities of achieving pituitary destruction in cases of advanced cancer has recently been published (Minakova 1977).

Lawrence and coworkers at the Donner Laboratories in Berkeley, California, have used a proton beam for irradiation of pituitary tumours since 1957; stereotactic measures are not used during these procedures, however.

Recently, 349 patients with pituitary tumours treated by this technique were reported (Lawrence *et al.* 1976).

Technique

The radiosurgical part of the Leksell system used in the present series is the "Gamma-Unit", shown in Fig. 1. The radiophysical measurements and calculations have been made by Sarby and Larsson (1965) and Dahlin *et al.* (1970).

The irradiation is performed by cross-fire to the target region with 179 narrow beams of Cobalt-60 gamma radiation distributed within a

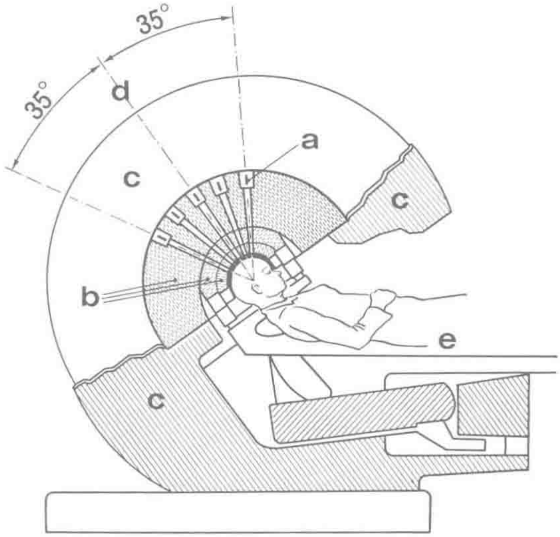

Fig. 1. Section through the Gamma Unit showing five of the beam channels. *a* ^{60}Co source, *b* collimator helmets, *c* shielding material, *d* central beam, *e* movable operating table

spherical sector. The beams are radially directed towards the centre of a collimator helmet, in which the predetermined tumour target point is positioned. At this point, the "effective radiation field" covers a very small area (Fig. 2).

As already mentioned, the technique was primarily developed for functional radiosurgery, such as thalamotomy. Because of this, the first Gamma Unit, called Unit I, was designed to give disc-shaped brain lesions with very steep dose gradients corresponding to the border zones of the lesions. For the treatment of pathological areas of tissue, however, such a dose distribution may be too small to be optimal. In order to adapt the irradiated volume to the shape of a tumour, for example, a number of target points in a predetermined spatial pattern can be utilized. To achieve even bigger fields of radiation and of spherical shape, another Gamma Unit with wider distribution of the radioactive sources and cylindrical apertures for each individual beam was designed (Unit II).

If the number and the spatial distribution of the cobalt sources are varied the "shape" of the summated dose distribution around the target point can be correspondingly altered. In Unit II it is possible to extinguish optionally any of the 179 sources by simply plugging the collimator channels, which allows the dose distribution, within certain limits, to be more or less "tailor-made" to the individual case. For this modification, a computer (PDP 11) is used. The calculation technique has been described by Arndt *et al.* (1975).

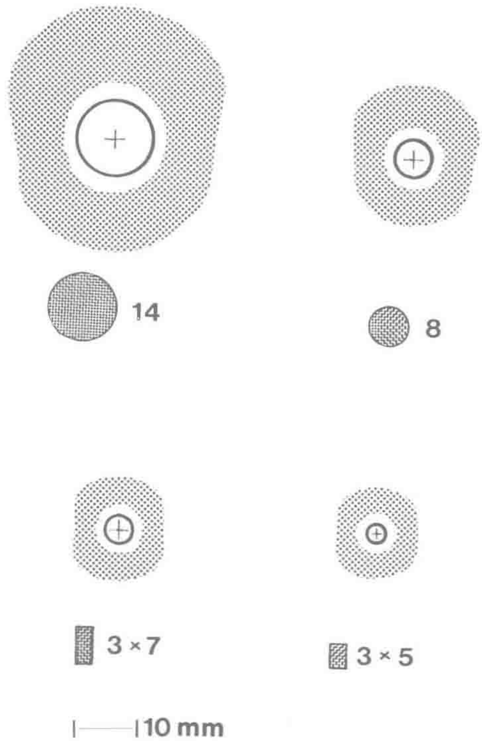

Fig. 2. Isodose diagrams in A-P plane at the centre of a human head: In Unit II the cross section of each individual beam is circular and can be varied to 14 and 8 mms in diameter, respectively. The dose distributions for these two collimator alternatives are shown in the upper row. In Unit I the cross section of each beam is 3 × 7 or 3 × 5 mm, respectively. These two alternatives are shown in the lower row. The black circular line of each dose diagram corresponds to the 90% isodose level and the dotted area to the 10 to 50% isodose level. The 100% level is at the centre (indicated by a cross)

The radiation doses mentioned in the following are, if not otherwise mentioned, expressed in terms of "target dose", *i.e.* the dose at the stereotactic target point, in the tumour cases as a rule identical with the centre of the tumour. The relative isodose levels are expressed in per cent of this target dose (dose maximum). A spatial agreement between the tumour surface and the 50% isodose level has been aimed at, in general.

The radiosurgical procedure including the determination of the stereotactic coordinates is intrinsically safe provided that the area chosen for destruction is either visible itself or can be spatially related to visible reference structures on the stereotactic films. As an example of the latter case, our experiences include attempts at indirect localization of pituitary microadenomas by studying discrete changes of the sella turcica. Examples of making target areas visible are those of stereotactic cisternography using positive contrast (acoustic tumours) and stereotactic angiography (arterio-venous malformations).

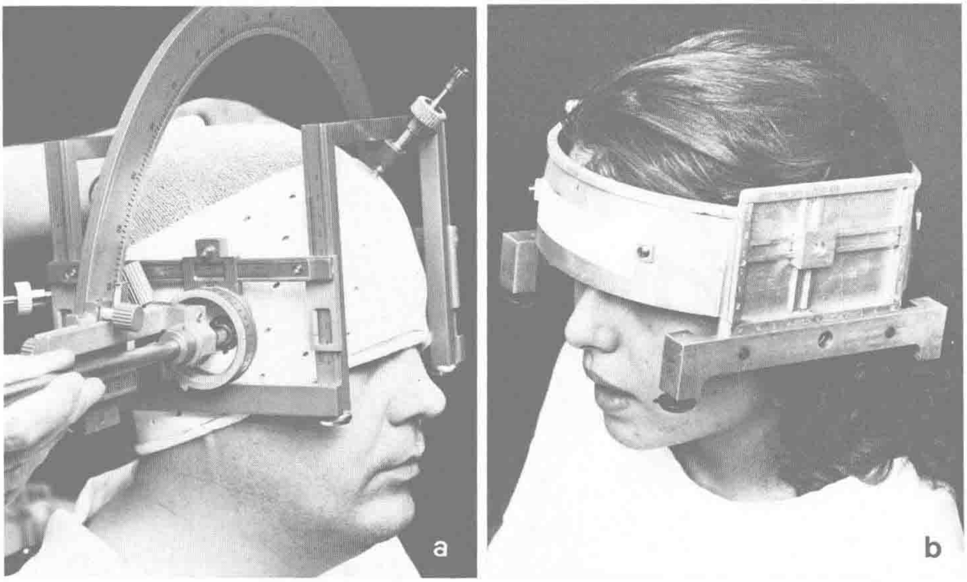

Fig. 3. The patient is fixed to the Gamma Unit by one of two methods: a) A thermoplast ("Orthoplast") is modelled around the patient's head. According to the stereotactic coordinates, metal bearings are attached, fitting to movable fixation axes of the collimator helmet. b) A circular metallic frame is secured to the skull by four screws and bearings on each side of the frame are adjusted according to the coordinates

Of equal importance is the technique for fastening the patient in the Gamma Unit's collimator helmet. At present, two alternative techniques are in use; either a well-fitting plastic cap is modelled around the patient's head, or a metallic fixture is applied to it by screws secured to the skull (Figs. 3 a and b).

The principles and the techniques of stereotaxy are related in a natural way to computed tomography (CT). This has been utilized in our practice.

The major practical and mechanical problems of aligning the scanner geometry to the stereotactic system have been solved (Greitz *et al.* 1975, Bergström and Greitz 1976). In a number of cases including pinealomas, acoustic tumours and retinoblastomas, stereotactic CT technique has been used. The target point of the area to be irradiated is selected on the CT-display, and its stereotactic coordinates are determined by the computer of the scanner (Fig. 4). This technique is now under further development.

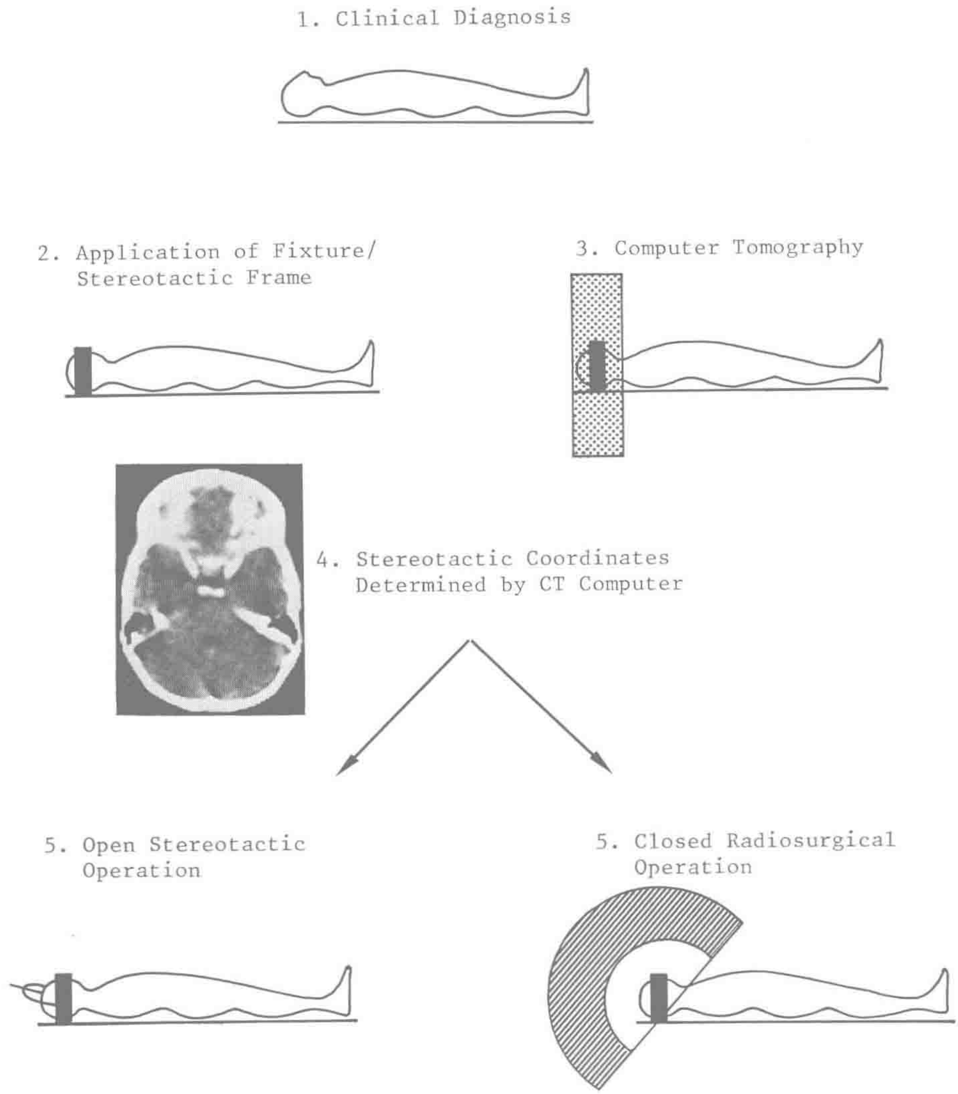

Fig. 4. Coordinate determination by computed tomography preceeding the stereotactic procedure: The patient's head fixture is secured in the CT-scanner whereby the stereotactic coordinates can be obtained by the computer of the scanner. The method is used optionally prior to either open stereotactic operations or closed radiosurgery

In concluding this section, the simplicity of the radiosurgical technique as compared with the painstaking and often tedious conventional operations should be emphasized. The patients reported in this presentation have as a rule been treated under slight pre-medication only, and in a number of cases, the radiosurgery was even performed entirely as an out-patient procedure.