# *Stereotactic Techniques in Clinical Neurosurgery*

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# Preface

Various textbooks on stereotactic neurosurgery have been published during the last few years (Riechert 1980, Schaltenbrand and Walker 1982, Spiegel 1982), all of them dealing with functional stereotactics as the major subject in the field. Diagnostic and therapeutic stereotactic interventions are only briefly described, whereas localization techniques are not yet mentioned.

Since 1980, however, an increasing number of reports has been published on CT guided and computer monitored stereotactic performances which enable the surgeon to combine diagnostic and therapeutic efforts in one session.

With recent progress in scanning techniques, including high resolution CT, NMR, and PET imaging of the brain, it has become possible to study and localize any brain area of interest. With the concomitant advances in computer technology, 3-dimensional reconstruction of deep seated lesions in stereotactic space is possible and the way is open for combined surgery with stereotactic precision and computer guided open resection. This type of open surgery in stereotactic space is already being developed in some centers with the aid of microsurgical, fiberoptic, and laser beam instrumentation.

With these advances stereotactic techniques will rapidly become integrated into clinical neurosurgery. Stereotactics has become a methodology which enables the surgeon to attack deep seated and subcortical small tumors. Neurosurgeons may abandon therapeutic nihilism, still frequently seen in glioma treatment, in the near future when stereotactic resection will be feasible and remaining tumor cells may be killed by adjuvant treatment modalities still in development.

This comprehensive guide to stereotactic principles, methodology, and possibilities is presented for use by general neurosurgeons who feel that stereotactics and computer aided surgery deserve clinical attention. Schematic drawings illustrate the principles of target positioning and calculation.

Stereotactic instruments in current use, including CT and NMR guided instrumentation, are discussed. Many photographs show the Leksell system, as this is the instrument in use in the author's department. Photographs of other instrumentation have kindly been presented to the author by various colleagues with permission for publishing. References have been collected and updated to June 1, 1985.

Tilburg, November 1985 D. Andries Bosch

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## Contents

Chapter 1

# Introduction

Stereotactic neurosurgery was born in the mind of Robert Clarke, who in the early twentieth century (1906)—when he was convalescing from pneumonia in Egypt (Carpenter and Whittier 1952)—"used his genius to apply a simple principle out of its usual context", and gave the impetus to research into deep brain structures (Schurr and Merrington 1978). By that time clinical neurosurgery did not exist. Surgical neurology was performed by neurologists with some surgical training and consisted for a great deal of applied neurophysiology. It was, in fact, the ultimum refugium for neurologists to alleviate otherwise intractable disorders. Medical history describes three operations in which a burrhole was performed after localization of its site with the help of an "encephalometer". This instrument was constructed by Professor D. N. Zernov (Moscow 1892) and is the first apparatus based on mathematical principles that, after fixation on the skull, could be used for spatial orientation (Kandel and Schavinsky 1972). It was, however, employed mainly in surface topography for localization of the cranial sutures and cerebral sulci. Therefore it seems justified to state that the modern era of stereotaxy began in 1906 when Clarke and Horsley published work on a new method of brain research using a Cartesian tricoordinate system.

## I. Stereotaxy in Experimental Brain Research

### *A. Clarke's Instrument*

The original idea to apply geometry to the study of the brain came to Clarke when he collaborated with Victor Horsley in experimental work on the function of the cerebellum. Horsley tried to destroy deep tracts and nuclei to discover their function and felt an inability to be sure about the positioning of his electrodes with which he made electrolytic lesions. He recognized the problem and Clarke's idea brought the solution. Of course, the composition of the brain had occupied the minds of many people for centuries and its fine structure necessitated the development of very precise ways of investigation. But to make use of the cranium as a *platform* for localizing intracranial targets, to use it as a tool to a better understanding of

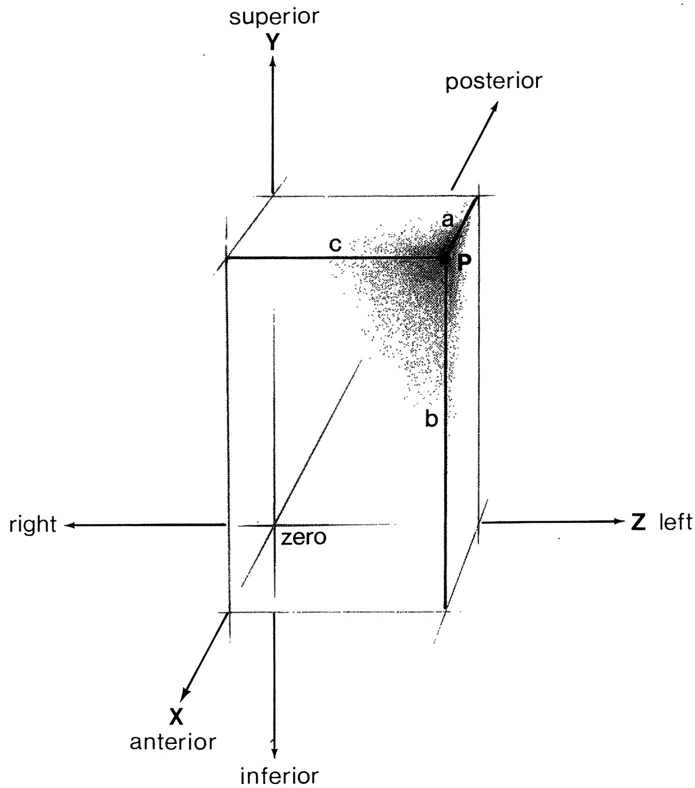



Fig. 1. Cartesian tricoordinate system for spatial orientation. P is given by: x = a mm anterior to zero, y = b mm superior to zero, z = c mm lateral to zero (to the left), XZ—plane is horizontal or axial plane, YZ—plane is frontal or coronal plane, XY—plane is sagittal plane

brain function, is to the merit of Clarke. He realized also that there is no constant relationship between the skull and the intracranial structures and that the only way to find out where to place a needle tip in a given internal part was to construct a map on which every target could be related to three "zero planes", perpendicular to each other. Herewith Clarke introduced a Cartesian coordinate system with which calculations could be made and any point could be described by its coordinates x, y and z (Fig. 1). Clarke's original apparatus was made in 1905 by Mr. J. Swift in London and consisted of a frame of brass which was applied to the head of the animal by means of rods attached to plugs inserted into the external auditory meati and adjustable bars which rest on the nose and orbital margins. It was fixed to the skull by pins which were screwed in laterally. The electrode was supported by another bar that could be moved in three planes at right angles to each other. With knowledge of the various types of stereotactic apparatus available today, it is remarkable to see how its simplicity in construction has been preserved and only refined in these up to date instruments. Based on his instrument Clarke (and Henderson 1911, 1914 and 1920) published stereotactic maps of sections of the brain of the cat and monkey. Once again, one is struck by the timeless value of a good idea!

### *B. Clarke's Idea*

Although the stereotactic techniques were only applied in experimental brain research during the following years (1907–1947), as stereotaxy was intended for standardizing lesions in various structures to study the topographical and nosological composition of the brain, Clarke already anticipated in 1920 the therapeutic possibilities of his invention in human neurosurgery. He thought his instrument would enable brain tumors to be treated by electrical means or by the implantation of radium, and that it might be possible to relieve pain by coagulating tracts within the brain through a 5 mm hole in the skull (Jefferson 1957). Inspired by Clarke's animal device, A. T. Mussen, who collaborated with Horsley and Clarke, designed the first stereotactic apparatus for use on humans. This instrument was built by an instrument maker in London in 1918 (Picard *et al.* 1983), but never used "because at that time no one was interested in it" (quote from a letter by Mussen to his son in 1971).

## II. Stereotaxy in Man

The stereotactic method developed by Horsley and Clarke received little attention until E. A. Spiegel, who had had contact with Clarke shortly before his death in 1926, to ask permission to construct another apparatus by Mr. Swift for use in Vienna, emigrated to the United States and joined H. T. Wycis. In 1947 Spiegel (*et al.*) reported the first human stereotactic operation. So after forty years the big step from animals to man was taken, and within some years a "hausse" could be noticed in the development of stereotactic devices for application in man (Spiegel and Wycis, Leksell, Riechert, Talairach). In the early years of stereotaxy in man, however, a stereotactic map of human brain anatomy was not available. The first atlas of the human brain for stereotactic surgery was edited by Spiegel and Wycis in 1952, in which the posterior commissure was used as a single intracerebral reference point in combination with several external cranial references. In the beginning of the era of stereotactic neurosurgery the main interests lay in functional surgery. Since brain surgery for tumors and other space occupying lesions had a high mortality rate in these years and was—if at all—performed with one goal in mind, to treat by extirpation or bulk resection, it is evident that the profit of stereotactic techniques was not realized by the surgeons. The link between experimental and human stereotactic surgery was laid by the neurologists, who studied the effects of different ablations and destructions of parts of the brain to alleviate otherwise intractable syndromes. So first of all attention was paid to stereotactic possibilities in the treatment of convulsive disorders, intractable pain, hyperkinesias and parkinsonism. Even psychosurgical interventions were extensively studied and tried out. The first attempts to treat peatients with stereotactic operations were made in cases of intractable pain. Instead of the formerly used leucotomy (Moniz 1936) or even cortical extirpations to manage pain, stereotactic destruction of targets deep inside the brain were performed with the help of guided instruments. This meant a great progress in surgical possibilities and a significant reduction in mortality, due to the precise localization of the targets with the help of a ventriculography that gave the reference points needed (posterior commissure and sagittal plane).

## *A. Functional Stereotactics*

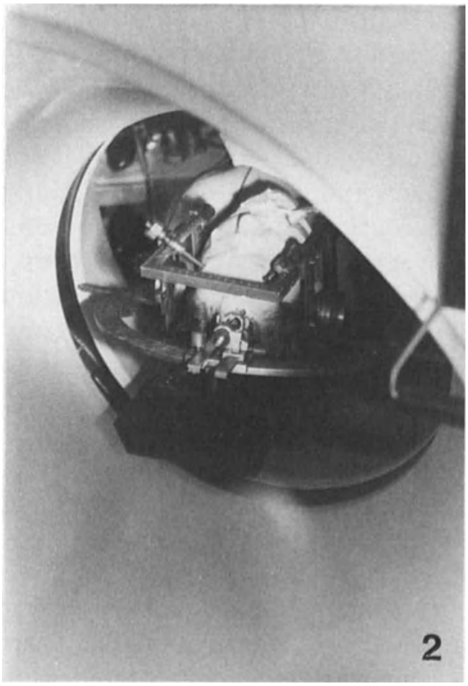
This development opened the way to treat by applying the same method other disorders, such as Parkinson's disease, the hyperkinesias and convulsive syndromes; these being illnesses in which open neurosurgical ablations were carried out formerly with considerable side-effects. During the two decennia after the introduction of stereotactic techniques in neurological surgery (1947–1967) clinical research flourished in this field and functional neurosurgery became closely related to stereotactic neurosurgery. After Hassler had published in 1955 (a–c) his results dealing with stimulation and coagulation in the human thalamus, this target became the lesion site of choice for the alleviation of various types of movement disorders. Spiegel and Wycis and also Cooper in America, Talairach and Guiot in France, Riechert and Mundinger in Germany and Leksell in Sweden brought their results with thalamic surgery over large groups of patients to the attention of everybody interested in neurological diseases and introduced improvements in stereotactic instrumentation and in the mapping of deep brain structures. Their results proved to be the most satisfactory in Parkinson's disease (tremor and rigidity) and in the various pain syndromes. New developments in neuropharmacology, which led to the introduction of dopamine drugs for the treatment of parkinsonism by Cotzias (*et al.* 1969) meant, however, a considerable drag on further progress of stereotactics in functional neurosurgery.

## *B. Mass Lesions Stereotactics*

The next leap forward—surprisingly enough originally thought of by Clarke in 1921—was made by the further progress in clinical neurosurgery. Mortality rate and complications after craniotomies decreased markedly by modern anesthesia, brain edema protection, and technical advances in instrumentation. Therefore neurosurgeons also became interested in deep seated brain lesions. Diagnostic possibilities increased surprisingly with the introduction of computerized tomography (Hounsfield *et al.* 1973) and even small lesions inside the brain could be detected. Neurosurgeons felt the need to discover and disclose the lesion's nature and had to decide again and again between exploration (including approaches with the microscope) and a biopsy through a burrhole. Stereotactic instruments could make a biopsy procedure a safe and reliable performance. Neuropathological investigation of the tissue specimen could give insight into the nature of the lesion and thus in the prognosis of the illness. In case of brain tumor the increasing number of treatment modalities made histological diagnosis imperative once and for all. Therefore, in otherwise inaccessible lesions of the brain stereotactically guided biopsy instruments came into use. Pioneers in stereotactic surgery (Leksell and Backlund in Stockholm; Riechert and Mundinger in Freiburg) utilized their talents to develop the necessary equipment and performed the first stereotactic biopsies. Herewith a technical solution was given to the problem of histological diagnosis in any case of neuroradiologically demonstrated brain lesion. In recent years histological diagnosis is becoming even more important, as radiation therapy and chemotherapy can offer substantial improvement in various types of brain malignancies. Today, stereotactic biopsy is more and more widely performed, and it is generally believed that, in the near future, this type of surgery can no longer be neglected in the treatment of tumor patients. Progress in neuro-oncology, which is a rapidly expanding field of interest and research, offers increasing possibilities for diagnostic and sometimes therapeutic stereotactic procedures. Possibilities, which are available to the neurosurgeon who has had a basic training in them. Moreover, in up to 10% of the cases suspected to have a tumor, stereotactic biopsy reveals the lesion to be no tumor at all, but a vascular or infectious disease, which should be treated in an appropriate way: especially the increasing group of immunocompromized patients shows a tendency to opportunistic infections (after cancer treatment or organ transplantation).

## *C. Stereotactic Localization*

The newest branch of stereotactic neurosurgery is formed by the localization stereotactics. The indication is given by small subcortical lesions, which could be treated perfectly by microsurgical means, but are not easily found. In the first place small arteriovenous malformations and hematomas, but also small tumors and abscesses, can be reached safely and without lesioning overlying brain tissue after stereotactic localization. Moreover, the shortest trajectory can be calculated and a minimal exposure of brain can be used. In this field of stereotactics the area of interest is



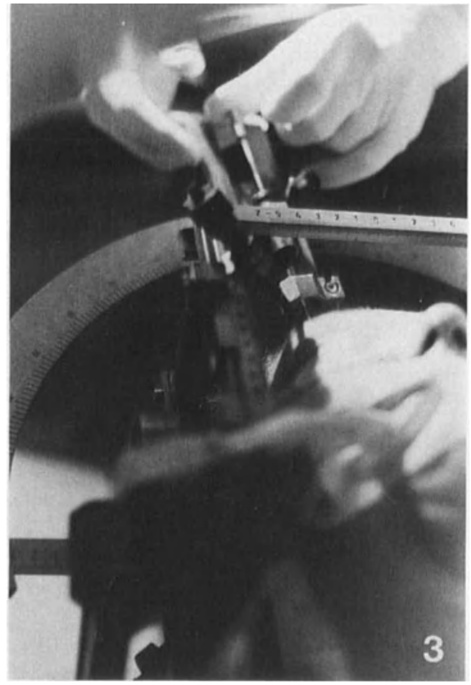




Fig. 2. Stereotactic surgery within the CT scanner (Leksell instrument)

Fig. 3. Stereotactic biopsy of a brainstem tumor with CT-guidance

marked (eventually with the help of intraoperative angiography) by the tip of a small silastic tube that is introduced along the preferential trajectory. With minimal damage to the brain and therefore even in as vital cortical areas as the parietal lobe, surgical intervention becomes acceptable. In case of deep seated small lesions stereotactic localization is the first step to adequate treatment, modalities for which are being developed nowadays with the use of isotope implantation, neurosurgical endoscopic designs with fiberoptically transmitted laser instrumentation and various types of external stereotactic irradiation (Apuzzo and Sabshin 1983, Edwards *et al.* 1983, Backlund 1979).

## III. Stereotactic Methodology

The advent of computed axial tomography has not only provided new insights into intracranial disease, but has also instigated a true revival of the neurosurgeon's interest in the utilization of stereotactics. CT guided stereotaxy with calculation of stereotactic coordinates from the computed tomographic scan (Gildenberg *et al.* 1982) has been available for some years and forms an integrated part of already existing stereotactic instruments (Leksell and Jernberg 1980, Mundinger *et al.* 1978 a, b), or has led to the construction of new stereotactic systems (Brown *et al.* 1981, Kelly *et al.* 1982 a, b). Devices for CT guidance may be divided into two groups: those with which the operation is performed within the scanner (Figs. 2 and 3) and

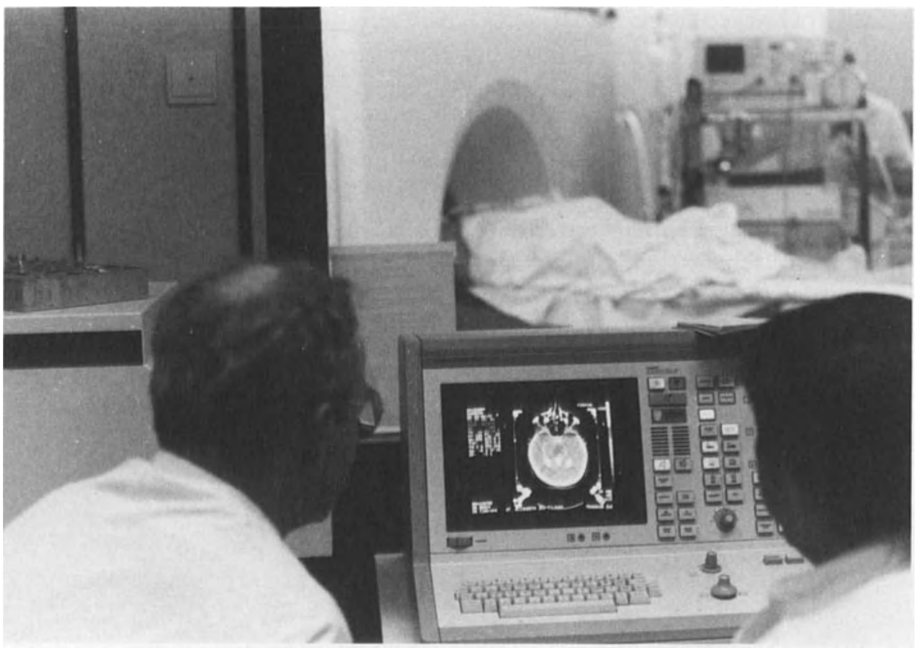


Fig. 4. CT scanning with stereotactic instrument fixed to the skull. Positive contrast is seen in the ventricles and around the brainstem for better visualization of the target

those that allow the translation of scanning data to the operating room (Fig. 4). With this instrumentation any intracranial point can now be reached with great accuracy (error is less than 1 mm). The stereotactic method therefore is a safe and rapid tool in the management and evaluation of mass lesions. By this method novel areas of interest can be explored, high risk craniotomies can be avoided and hospitalization periods can be reduced. Also by obtaining a tissue diagnosis the further strategy in the treatment of the individual patient can be planned better and subsequent craniotomy will be reserved for cases which benefit by open surgery. Stereotactic technique that originally has been presented as a method has matured to a methodology, a way of thinking and of treating the neurosurgical patient.