Jean Talairach: a cerebral cartographer

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Although French psychiatrist-turned-neurosurgeon Jean Talairach (1911–2007) is perhaps best known for the stereotaxic atlas he produced with Pierre Tournoux and Gábor Szikla, he has left his mark on most aspects of modern stereotactic and functional neurosurgery. In the field of psychosurgery, he expressed critique of the practice of prefrontal lobotomy and subsequently was the first to describe the more selective approach using stereotactic bilateral anterior capsulotomy. Turning his attention to stereotaxy, Talairach spearheaded the team at Hôpital Sainte-Anne in the construction of novel stereotaxic apparatus. Cadaveric investigation using these tools and methods resulted in the first human stereotaxic atlas where the use of the anterior and posterior commissures as intracranial reference points was established. This work revolutionized the approach to cerebral localization as well as leading to the development of numerous novel stereotactic interventions by the Sainte-Anne team, including tumor biopsy, interstitial irradiation, thermal ablation, and endonasal procedures. Together with epileptologist Jean Bancaud, Talairach invented the field of stereo-electroencephalography and developed a robust scientific methodology for the assessment and treatment of epilepsy. In this article the authors review Talairach's career trajectory in its historical context and in view of its impact on modern stereotactic and functional neurosurgery.

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KEYWORDS Jean Talairach; stereotaxy; cerebral localization; psychosurgery; epilepsy surgery; neurosurgical history

JEAN Talairach was born in 1911 in Perpignan, on the French-Spanish border (Fig. 1). As a youth, he was immersed in music and developed a passion for architecture, often exploring abandoned mines and drawing architectural building plans.^{20,22} Perhaps to follow in the footsteps of his cousin (psychiatrist Henri Ey), or perhaps due to the inspiring historic halls of the Faculty of Medicine at Montpellier, Talairach decided to pursue a career in medicine.³³ After finishing his undergraduate medical training in 1938, he moved to Paris for training in psychiatry at Hôpital Sainte-Anne under renowned psychiatrist Jean Delay.^{4,20}

Sainte-Anne was originally established as an asylum for the mentally ill in the 1600s and was converted to a psychiatric hospital in the following century.⁴³ It was right around the time Talairach arrived at the institution that the neurosurgery department was established by neurosurgeon Pierre Puech with the aim of exploring surgical treatments to psychiatric diseases.⁴³ Although Talairach was named clinical director of the psychiatric service, a

meeting in 1942 changed his career trajectory and resulted in reverberating effects on the field of neurosurgery. Neurologist Julian de Ajuriaguerra introduced Talairach to neurosurgeon Marcel David (who would later become the second chief of neurosurgery at Sainte-Anne). Talairach recounts: "I will never forget this first meeting on a Monday in April 1942 and that particular anguish, known to those who suddenly discover a world hoped for, and one that would make me irresistibly abandon my career in psychiatry that was already laid out before me."³² (Quotes in the text represent the first author's [M.H.] translation from the original French text.) He subsequently began his neurosurgical training at Hôpital Paul-Brousse under the tutelage of David.

Psychosurgery

While Talairach's name is most commonly associated with his significant contributions to the field of stereotaxy, he made his initial contributions at the intersection of his

ABBREVIATIONS AC = anterior commissure; AP = anteroposterior; ECoG = electrocorticography; MNI = Montreal Neurological Institute; OR = operating room; PC = posterior commissure; SEEG = stereo-electroencephalography.

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FIG. 1. Photograph of Dr. Jean Talairach. Reproduced from Bourdillon P, Apra C, Lévêque M, Vinckier F: Neuroplasticity and the brain connectome: what can Jean Talairach's reflections bring to modern psychosurgery? *Neurosurg Focus* 43(3):E11, 2017. Published with permission.

two paths in medicine—in the field of psychosurgery.⁴³ Talairach began his career at a time when neuroleptics were not yet available and Egas Moniz's prefrontal lobectomy, first performed in 1936, was being popularized.²¹ Partnering with his new mentor, David, the two went on to perform numerous prefrontal lobotomies at several Paris hospitals, reporting mixed results.⁴³

With his background in psychiatry, Talairach was critical of the technique and is in fact often quoted saying that “psychosurgery is too important to leave to the neurosurgeons.”^{9,43} Talairach was influenced by the work of his cousin, Sainte-Anne psychiatrist Henri Ey, on the organo-dynamic theory which adopts the Jacksonian framework of nervous system organization and applies it to psychology.⁵ In the context of the sensorimotor system, Jackson described the presence of a gradual hierarchy from sensory organs and motor neurons all the way to higher centers (i.e., premotor areas and sensory association cortices); at these higher levels, function is not represented in discrete areas, as is suggested by the localizationist theory, but rather by diffuse networks.¹⁶ Applying this theory to psychology, Ey maintained that mental illness, with complex pathologic manifestations such as hallucinations

and alterations in consciousness and behavior, is a result of disturbance in higher functional centers with diffuse representation.¹³ With this in mind, Talairach argued that gross resection/disconnection of large portions of the network involved in the pathology (i.e., frontal lobotomy/leucotomy) may not be necessary.⁴² Rather, a more selective approach, targeting a single network node or network fiber tracts may be sufficient. In this vein, in 1949, Talairach first described the use of bilateral anterior capsulotomy for psychiatric disease, turning a necessary new leaf for psychosurgery.³⁷ Ironically, that same year, Egas Moniz won the Nobel Prize in Medicine for the frontal lobotomy.

In 1952, Talairach's initial mentor, Sainte-Anne psychiatrist Jean Delay, and colleague Pierre Deniker discovered the first neuroleptic, chlorpromazine.¹⁰ The development of psychopharmacology and changes in public opinion, among other factors, led to a decline in psychosurgery, and Talairach turned his attention more fully to his work in stereotaxy and later, epilepsy surgery.⁴³

A New Stereotaxic Approach

In the early 1900s, Horsley and Clarke developed the first stereotactic frame based on a 3D Cartesian coordinate system for animal use.¹⁵ The first human stereotactic frame was built soon thereafter by Canadian neurologist Aubrey Mussen; his contribution went largely unnoticed at the time, likely because up until the 1940s the thought of using intracerebral electrodes in the human was faced with an ethical resistance to the violation of the human brain.^{17,26,33} In a book published shortly after his passing, Talairach recounts the moment that he moved from the theoretical to the practical stage of stereotaxy in the human brain.³³ David, Talairach, and neurologists Hécaen and De Ajuriaguerra attended a conference hosted by renowned neurologist Jean Lhermitte (of Lhermitte's sign, among others) at Hôpital Paul-Brousse. Lhermitte was presenting work on thalamic pain syndromes.³² “Driven by the feeling of false precision felt during interventions for abnormal movements or for mental disorders, and the discomfort felt in the trans-cerebral pursuit of some ever-elusive epileptogenic foci,”³² the attendants set the goal of building a device that would allow for the precise interrogation and, if necessary, ablation of deep structures in the human brain.^{27,33}

When it came to localizing thalamic nuclei, the question, then as it is now, was how do you find something you cannot see? At the time, neuroimaging was limited to monoplanar radiography, allowing for the identification of bony cranial landmarks. This could be supplemented with the use of intraventricular and intravascular contrast agents, allowing for a delineation of the ventricular system and cerebral arterial supply. These structures could therefore be localized in a *direct* fashion.⁴⁰ In contrast, localization of the deep gray nuclei and cerebral cortex could only be done in relation to these visible structures, in an *indirect* fashion. Interestingly, the term “direct localization” has taken on a somewhat different meaning in modern functional surgery; today, it most often refers to physiological localization by means of identifying stereotypical neuronal firing patterns obtained using microelectrode

FIG. 2. Talairach stereotaxic apparatus. 1 = frame; 2 = luminous sight target for x-ray beam centering; 3 = level; 4 = cranial fixation fastener; 5 = double grid. Reproduced from Talairach J: *Souvenirs des Études Stéréotaxiques du Cerveau Humain*. John Libbey Eurotext, 2007. Published with permission.

recording. Indirect targeting has become more granular thanks to the advances in modern neuroimaging which have made many more parenchymal structures visible.

Entrusted with developing a reliable, indirect method to localize deep gray nuclei, Talairach contracted Sainte-Anne's resident technician, M. Sabbaton, to help him build a suitable stereotactic frame to his specification.^{19,33} These efforts were mirrored by functional neurosurgeons all over the world, who began developing their own frames for human use by collaborating with local engineers; Talairach in France, Leksell in Sweden, Mundinger in Germany, Narabayashi in Japan, Bertrand in Canada, and Roberts in the United States all developed their own prototypes. While Spiegel and Wycis have long been credited with the first human stereotactic frame, much controversy exists over who actually "invented" the first human stereotactic frame, and Talairach and Wycis often debated this point heatedly, almost to the point of fisticuffs (G. Bertrand, personal communication). Nevertheless, Spiegel and Wycis were indeed the first to report the use of a stereotactic frame in the human in 1947, using it to perform a thermal medial thalamotomy.²⁹

Each feature of the Talairach frame was designed based on the understanding that the key to accurate indirect targeting was accurate and reliable imaging. A central feature of the frame was the double grid system (Fig. 2)—the grids were attached at opposite edges of the frame perpendicular to the path of the x-ray. If the image was acquired without distortion (displacement or magnification), the double grids would superimpose and appear as a single grid on the acquired image.^{19,20,31} The thick grids also allowed for the stable introduction of multiple probes.^{19,20} Another key difference between Spiegel and Wycis' frame and the one developed at Sainte-Anne was that the Talairach frame was fixed directly to the outer table of the skull, whereas the Spiegel and Wycis frame was fixed to the head by means of a plaster cap;^{29,40} the cranial fixation of the Talairach frame allowed for accurate repositioning between imaging and/or treatment sessions, which proved particularly useful in staged surgery. Talai-

rach also developed a system for collimated teleradiography to further reduce distortion and magnification, which was supplemented by the use of long-distance stereoradiology, made possible by the building of a large operating room to Talairach's specifications.^{4,19,20} The team first used their stereotactic apparatus in 1948 to perform a thalamotomy for the treatment of central pain syndrome.³¹ Over the years, the Sainte-Anne team used this apparatus for numerous stereotactic interventions, including tumor biopsy, interstitial irradiation, thermal lesioning, stereoelectroencephalography (SEEG), and endonasal procedures.^{19,32,33,35,37,39,41}

Talairach and colleagues used their stereotactic apparatus to study 100 cadaveric brains, which in 1957 resulted in the first stereotaxic atlas of the human deep gray nuclei.³⁶ Although the use of cranial bony landmarks was the standard in animal stereotaxic atlases, such as those used by Horsley and Clarke, bony landmarks were thought to be insufficiently reliable for human interventions—both due to the lower margin for error and due to the greater structural variability among humans than among laboratory animals.³¹ In lieu of bony landmarks, or the calcified pineal and foramen of Monro used by Spiegel and Wycis, Talairach introduced the anterior commissure (AC) and posterior commissure (PC) as the standard points of references, which were selected because they could be reliably identified on contrast ventriculography and were in close proximity to the deep gray nuclei.^{20,31} The newly established Talairach coordinate space was therefore defined by an origin at the AC, a y-axis along the AC-PC line, and a x-axis and a z-axis extending perpendicularly from AC along the horizontal and vertical planes, respectively (Fig. 3 upper). In 1958, Talairach became head of the newly founded stereotaxic and functional neurosurgical service at Sainte-Anne and continued his work, now with Hungarian-born neurosurgeon Gábor Szikla, to generate a second atlas focusing on the telencephalon.³⁸ In 1988, a third atlas was published, by Talairach and Tournoux, which covered the whole human brain. Recognizing the neuroanatomical variability between patients, they devel-

CATACOMB NETWORK UNDER PARIS

A hand-drawn map served the French Resistance against the city's Nazi occupation in 1943.

FIG. 4. Hand-drawn map of Paris catacombs produced by Talairach and Suttel. Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature. *Nature* 547:281. Second World War: Paris neurosurgeon's map outwitted Nazis; Bourdillon P, Lévêque M, Apra C: © 2017. <https://www.nature.com>.

using interictal ECoG alone, particularly in patients without a macroscopically visible epileptogenic lesion or with insular epilepsy.^{18,24,32} They emphasized the importance of understanding not only where epileptic seizure activity originated but also its pattern of propagation in surrounding tissue, as well as identifying when and where it eventually results in clinical symptoms.^{1,2,34,35} A characterization of the epileptic network enables cortical excision of epileptogenic tissue, when appropriate and safe, and/or disconnection of critical propagation pathways.³⁵ This dynamic physiological description of an epileptic seizure required ictal recordings in awake patients, with multiple accurately and safely placed multi-lead intracerebral electrodes—something that Talairach's stereotaxic method made possible.

The “Sainte-Anne method” developed by Talairach and Bancaud consisted of 2 stages—reconnaissance and SEEG exploration—with the purpose of generating an anatomico-electro-clinical correlation.^{1,34,33} In stage I, the patients would undergo a thorough clinical examination with a detailed assessment of seizure semiology as well as scalp EEG (Fig. 6). They would then be fitted with the stereotactic frame and undergo a series of anteroposterior (AP) and lateral imaging in the specialized stereotaxic operating room (OR), including fractionated encephalography, ventriculography, and arteriography. All images were developed on semitransparent paper which noted the frame's reference points, allowing for the transfer of information onto two, to-scale master tracings (AP and lateral).¹⁹ Applying the principles of direct and indirect lo-

calization and the proportional grid system, the patient's anatomy was mapped onto the tracings. This anatomy was then assessed by the multidisciplinary team in the context of the patient's seizure semiology and EEG recordings in order to design a patient-specific, hypothesis-driven SEEG lead placement plan that took safety into account (avoiding cerebral arteries shown on the arteriogram).³⁵

FIG. 5. Zones in epilepsy surgery: 1 = epileptogenic zone; 2 = irritative zone; 3 = paths of seizure spread. Reproduced from Talairach J: *Souvenirs des Études Stéréotaxiques du Cerveau Humain*. John Libbey Eurotext, 2007. Published with permission.

FIG. 6. Epilepsy surgery at Sainte-Anne. **Left:** Talairach in the operating room during an epilepsy case. **Right:** Operating room with overlooking room for SEEG, built after the MNI model. Reproduced from Talairach J: *Souvenirs des Études Stéréotaxiques du Cerveau Humain*. John Libbey Eurotext, 2007. Published with permission.

Stage II, which typically was done about 15 days after stage I, started with replacement of the stereotactic apparatus with verification of exact same location as prior.^{33,35} SEEG multilead depth electrodes were then placed according to the presurgical plan and their position was verified. Then came the time to wait for the occurrence of a seizure in the awake patient. Of this period, Talairach recounts: “This waiting requires a lot of patience, but remarkably, the patient, aware of the physicians’ effort to subdue a disease which is often frightening for the patient, remains not only patient but also contributes to the research. It is equally remarkable to see patients share in the physicians’ joy when they are able to elicit a seizure, indicating that they are reaching their goal and that a corticectomy may be done successfully, and that they may together overcome the disease.”³³ Although acute recordings were the rule at that time, chronic recordings (i.e., with the electrodes left in place) were also done occasionally.³⁵ The acute recordings were limited by their short EEG recording time span (6–12 hours) and often interictal activity alone or a single seizure. Once the electrodes were implanted, the surgical team would often retreat to the OR lounge to await a seizure over wine and cheese. The patient’s file, with all collected data, would be evaluated by the team to construct said anatomo-electro-clinical correlation, at which point a therapeutic intervention may be decided upon. In the first 42 patients assessed with this methodology, Talairach and Tournoux reported no surgical complications (which was a significant *a priori* concern, given this was the first such report on the use of numerous electrodes) and 79% recov-

ery/improvement rate in the 34 patients who were offered definitive surgical treatment based on the stereotactic interrogation.³⁵ The Sainte-Anne team went on to assess and treat hundreds of epilepsy patients utilizing this methodology in the decades that followed.³ Although advances in neuroimaging and digital surgical planning may have significantly changed how stage I is carried out, the principles that underlie Talairach and Bancaud’s methodology were carried on by their students and remain central to modern day epilepsy surgery.^{4,11,14,19} Mark Rayport—one of Penfield’s last residents—came to Sainte-Anne in the late 1960s as a visiting professor.²⁸ Rayport would later translate the 1988 atlas into English and was one of the early adopters of SEEG in North America; working with his wife, psychiatrist Shirley Ferguson, he combined the MNI and Sainte-Anne methods, adding an emphasis on the neuropsychiatric status of the patient.^{23,40}

Legacy

Talairach insisted on not patenting his stereotaxic apparatus, quoting the phrase “on ne s’enrichit avec la souffrance des autres” (“one must not get rich through the suffering of others”).³³ He embodied this phrase in every aspect of his clinical and academic career—through his generosity in time spent in the rigorous pursuit of better treatments for his patients and through his generosity in teaching the many students who came to learn the methods of the Sainte-Anne school.^{4,19,20} Jean Talairach retired from clinical practice in 1978. He would continue his dedi-

cated work in stereotaxy, publishing his third atlas in 1988 and then a fourth in 1993, until his death in 2007, leaving behind him tools, methods, and conceptual frameworks that are foundational to most aspects of modern stereotactic and functional neurosurgery.

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Disclosures

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Author Contributions

Conception and design: both authors. Acquisition of data: Harary. Analysis and interpretation of data: Harary. Drafting the article: Harary. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Harary. Administrative/technical/material support: Harary.

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