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Review

The Montreal procedure: The legacy of the great Wilder Penfield

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ABSTRACT

Wilder Penfield pioneered the early practice of brain surgery. In binding together the disciplines of neurosurgery, neurology, neuropathology, psychology, and related basic sciences, Penfield transformed our understanding of the field of neuroscience. He brought to the operating room the meticulous techniques of Sherrington, combined with methods of stimulation described by Foerster, which he complemented with expert knowledge of the neurocytology of nervous tissue. While developing surgical treatments for epilepsy, Penfield began to map the brain. He established the "Montreal procedure" for the surgical treatment of epilepsy. His scientific contributions on neurostimulation were transformative in their time and continue to resonate today. This article reviews the life of Wilder Penfield and summarizes key scientific contributions. Specifically, we detail the Montreal procedure. We additionally present a painting by Canadian artist Iris Hauser, which purports to display the hidden treasures of the human mind.

1. Introduction

Dr. Wilder Penfield was a distinguished neurosurgeon of international reputation, and his work greatly advanced the knowledge in neurological sciences. He has been widely celebrated as a "brain explorer" and a cartographer distinguished by his "cortical travels". Penfield ushered in a new era of neuroscience understanding by demonstrating that stimulation of specific brain areas could evoke emotions and allow one to recall precise personal experiences that had long been forgotten, including sensations, sounds, and smells [1].

Penfield established what is now referred to as the "Montreal procedure". In the fully awake patient, he employed local anesthetic to remove the skull to expose the brain. When he stimulated certain areas of the brain, patients were able to provide feedback on what they were experiencing at that very moment, and through this, he could isolate and map the topography of brain function. Focal epilepsy, then considered an incurable disease, attracted his attention. The procedure also opened a window to the mind, providing a glimpse of how dreaming occurs, memory function, and where consciousness and speech comprehension reside [2].

In this article, we review selected historical manuscripts describing the "Montreal procedure"; the majority of these records were written by Wilder Penfield himself. This paper highlights photographs and original medical drawings of brain mapping and Penfield's contribution to epilepsy with an emphasis on medical history and biographical accounts of Wilder Penfield and his team at the Montreal Neurological Institute (MNI).

2. Methods

We performed a comprehensive search for articles published from 1870 to 2017 using Medline, Embase, Index medicus, Cochrane database and bibliographies of pertinent reviews, and original articles to identify the history of the Montreal procedure. We also searched Internet resources including newspapers and personal webpages. We used the following search terms: Penfield, Montreal procedure, direct cortical stimulation, epilepsy surgery history, Montreal Neurological Institute, and homunculus.

This paper aimed to summarize the published literature describing Dr. Penfield's life and specially added the historic evidence of the Montreal procedure since its creation in Germany to its improvement in Canada. Finally, this document celebrates the life of Dr. Penfield in his 127th birthday anniversary, presenting a contemporary painting depicting a portrait of Penfield by the Canadian artist Iris Hauser.

3. Results

3.1. The life of the man

3.1.1. A privileged medical career

Wilder Graves Penfield was born in Spokane, Washington on January 26, 1891. At an early age, it became apparent that Penfield

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excelled in both academic and athletic pursuits. He completed his premedical degree in literature at Princeton University where he was a top student and a talented football player and wrestler [3]. He earned a Rhode's scholarship, which enabled him to study at Merton College at Oxford in 1915, where he completed a bachelor's degree in sciences [4]. In 1915, he launched his medical career in England, where he benefitted from the company of medical luminaries such as Sir William Osler and Sir Charles Sherrington [5].

Sherrington, in particular, "opened up for him the gates into the unexplored regions of brain physiology and research" and helped nudge Penfield toward a career in neurosurgery. Penfield described himself as a "neurologist-in-action" [6] or as Cushing would say, "a neurologist who did his own operating" [7]. Penfield undertook research on the Golgi apparatus and the decerebrate preparation in Sherrington's laboratory. His thesis examined the Golgi apparatus in anterior horn cells using techniques described by Cajal. Penfield's studies on spinal reflexes in the decerebrate cat were published in the journal *Brain* [8]. Penfield assisted in teaching Sherrington's laboratory course on mammalian physiology, a highly organized series of 25 'exercises' of increasing complexity. The detailed instructions and drawings describe sophisticated surgical techniques, such as dissecting out the splanchnic and sympathetic nerves or performing a laminectomy to expose the spinal cord. In that course, Penfield learned how to handle living tissues gently and how to utilize fine surgical dissection instruments [9] (Fig. 1).

Sir William Osler, then Regius Professor of Medicine at Oxford, became an early mentor and offered Penfield invaluable help in gaining the maximum advantage from his first 2-year stay at the university [10]. Osler allowed Penfield to complete coursework during vacations, thereby expediting his return to Johns Hopkins. Penfield completed the anatomy dissection course during the late summer of 1915 in Edinburgh [11]. In his first winter vacation, he spent time at the French Red Cross hospital at Ris Orangis. Then as a second-year medical student, he was granted intern-level responsibilities and tasked with caring for an entire ward. It was a big job for a second-year medical student [12]. Upon completion of his duties, he attempted to cross the channel on the SS Sussex to return to France, but a German submarine torpedoed the ship. Penfield was fortunate to be rescued and transported to a military hospital in Dover. With a fractured leg, he was taken into the Osler family to recuperate where he was exposed to Osler's lively conversations [11]. Penfield's experience at Oxford after his injury was thus both recuperative and formative [13].

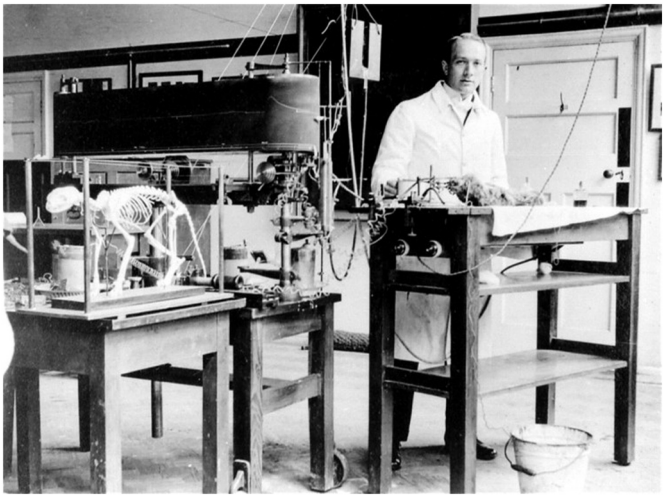

Fig. 1. Penfield's basic medical training. Wilder Penfield at the age of 25 years in the Sherrington's mammalian physiology laboratory at Merton College, Oxford University.

3.1.2. The pursuit of neurological sciences

In 1917, Penfield returned to the United States and completed his medical degree at Johns Hopkins University in 1918 [4]. He was a surgical intern at the Peter Bent Brigham Hospital in Boston, serving as assistant to Harvey Cushing [2]. He subsequently returned to the National Hospital at Queen Square in London where he developed a keen interest in epilepsy during his Beit fellowship in clinical neurology and neurosurgery [4]. There, he pursued further studies in neuroanatomy and neuropathology under the guidance of Sir Gordon Holmes, Godwin Greenfield [14], and Cuthbert Bazett, in which he carried out experimental research in a study of decerebrate rigidity [15].

In 1921, he completed his fellowship at London and began to work as an associate surgeon at Columbia University and Presbyterian Hospital and the New York Neurological Institute, where he augmented his surgical skills under Allen Whipple [1,8]. In 1922, Penfield made experimental brain wounds in animals in order to study the healing process of cerebral tissues. One year later, he was attempting to stain brain scars in the hope of identifying the cause of posttraumatic epilepsy, but he met a dead end in his work because of the inability to stain the nonneuronal cells of the brain. Penfield thought these cells were crucial in demonstrating the healing process of the brain and in helping to elucidate why a healing scar leads to epilepsy. He traveled to Madrid to learn advanced staining techniques from Cajal and Rio Hortega [16]. Whipple helped him to arrange and fund the 6-month long trip to Spain [17].

His research in 1924 with the neurohistologist Pio del Rio-Hortega, a pupil of Ramon y Cajal, provided Penfield with metallic staining techniques that allowed him to study glia [4], which provided insight on the embryology and evolution of glial tumors and the nature of brain scars [18,19]. Penfield met Cajal and studied his works stored in his laboratory, which had previously remained obscure as they were written in Spanish and thus inaccessible to much of the scientific community [20]. Penfield and his Spanish mentor completed the characterization of the "third element" of Cajal (non-astrocyte glial cells). The article "Oligodendroglia and Its Relation to Classical Neuroglia" was published in the journal *Brain* and helped establish the importance of glial cells [16] (see Table 1).

3.1.3. Scarred brain tissue: beginning to understand the origin of epilepsy

In 1927, just before moving to Montreal, Penfield spent 6 months in Breslau (at that time still a part of Germany) with German neurosurgeon Otfrid Foerster and learned his technique of electrical stimulation of the cortex in awake patients under local anesthesia (Fig. 2). This method became an invaluable tool in Penfield's hands [21]. He also learned the method of excising brain scars, which he used to treat focal epilepsy in 12 soldiers [4]. It soon dawned on Penfield that lesionectomy, performed after careful mapping of eloquent cortex, was a viable and safe approach to the treatment of focal epilepsies [19]. By 1928, Penfield and his surgical partner, William Cone, performed their first operation in New York, utilizing the Foerster method. The patient, a young man previously treated for a head injury, previously had as many as 20 seizures a day and vastly improved after three surgeries [22].

3.1.4. The birth of the Montreal Neurological Institute

At the end of 1928, Penfield accepted an invitation to relocate to Montreal and became a neurosurgeon at the Royal Victoria and Montreal General Hospitals. In 1934, he founded and became the first director of the MNI [2]. With funding from Rockefeller and the province of Quebec, the city of Montreal, and private donors, a stone building to house the MNI, a property of McGill University, was completed in the fall of 1934. The Institute gradually emerged as a world leader in neuroscience research, education, and patient care [6] (see Fig. 3).

In 1940, Penfield had the intuition that chemistry had to be integrated with neurophysiology and neurosurgery in order to advance the treatment of epilepsy. In his words, …"there is a decrease in the richness of