First clinical use of stereotaxy in humans: the key role of x-ray localization discovered by Gaston Contremoulins

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Although attempts to develop stereotactic approaches to intracranial surgery started in the late 19th century with Dittmar, Zernov, and more famously, Horsley and Clarke, widespread use of the technique for human brain surgery started in the second part of the 20th century. Remarkably, a significant similar surgical procedure had already been performed in the late 19th century by Gaston Contremoulins in France and has remained unknown. Contremoulins used the principles of modern stereotaxy in association with radiography for the first time, allowing the successful removal of intracranial bullets in 2 patients. This surgical premiere, greatly acknowledged in the popular French newspaper *L'Illustration* in 1897, received little scientific or governmental interest at the time, as it emanated from a young self-taught scientist without official medical education. This surgical innovation was only made possible financially by popular crowdfunding and, despite widespread military use during World War I, with 37,780 patients having benefited from this technique for intra- or extracranial foreign bodies, it never attracted academic or neurosurgical consideration. The authors of this paper describe the historical context of stereotactic developments and the personal history of Contremoulins, who worked in the department of experimental physiology of the French Academy of Sciences led by Étienne-Jules Marey in Paris, and later devoted himself to radiography and radioprotection. The authors also give precise information about his original stereotactic tool "the bullet finder" ("le chercheur de projectiles") and its key concepts.

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When modern neurosurgery slowly bloomed at the end of the 19th century, it came with an unavoidably high mortality rate, and physicians made every effort to limit postsurgical morbidity and mortality. As early as 1879, these physicians relied on newly developed anatomoclinical principles to locate intracranial tumors based on clinical signs, but open neurosurgery was associated with a high mortality rate. Several techniques were proposed to refine individual anatomical knowledge and precisely target the lesions, and stereotactic brain surgery was among these techniques. Whereas in the second half of the 19th century extensive studies were published about the use of external anatomical landmarks to locate deep anatomical structures (Fig. 1), Gaston Contremoulins (1869–1950) was the first to introduce radiography as an improvement to the concept of stereotaxy; this improvement allowed a spectacular surgical premiere, that is, successfully extracting intracranial foreign bodies from patients.

Birth of Modern Neurosurgery and Stereotaxy

Modern neurosurgery reputedly began at the end of the 19th century, after the revolution in thinking that had profoundly modernized medicine at that time.[9] In Great Britain, the anatomoclinical approach of John Hughlings Jackson helped to locate intracranial tumors and allowed William Macewen[13] to perform the first modern intracranial neurosurgery in 1879. Due to the high rate of mortality—Allen Starr in the US reported that only 54% of patients survived the surgery[24]—this new surgery remained anecdotal and in 1889 Ernst von Bergmann found only 7 intradural brain operations reported worldwide.[10] Even though Victor Horsley in Great Britain, Antony Chipault in France, and von Bergmann in Germany created the first dedicated departments of brain surgery, the specialty really bloomed with Harvey Cushing, who performed more than 2000 brain tumor removals between 1912 and 1931.[8] That is why stereotactic brain surgery was developed in the US

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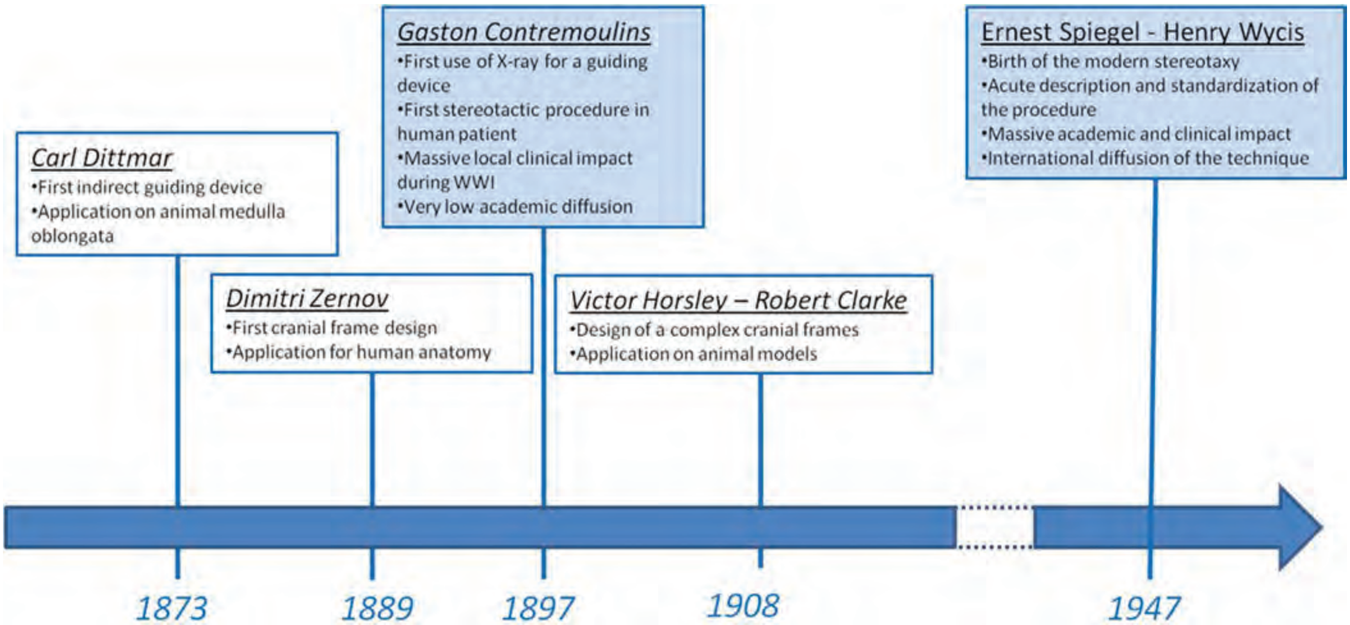

FIG. 1. Diagram of the stages of the main stereotactic developments before Spiegel. The *blue boxes* indicate clinical human applications, and the dotted lines indicate a time lapse. WWI = World War I. Figure is available in color online only.

in the second part of the 20th century[23] as an alternative to the "aggressive" conventional open neurosurgery. Nevertheless, the historical context of stereotactic principles is far deeper. Following the work of Eduard Hitzig and Gustav Fritsch on the functions of the CNS,[5] Carl Dittmar in 1873[7] and Konstantin Woroschiloff in 1874[26] proposed devices to target specific regions of the spinal cord in animals. Dimitri Zernov[27] in 1889 and his trainee Nikolay Altukhov in 1891[1] developed an encephalometer in Russia, and Allen Starr in 1893 proposed a frameless anatomical triangulation method in the US.[24] It is worth noting that, unlike Starr, Russian scientists took their inspiration from the phrenology misadventure.

The concept of stereotaxy is usually attributed to Victor Horsley and Robert Clarke[11] who created the word from "στερεός" meaning "solid" in Greek and "τάξις" meaning "position." Their Horsley-Clarke device was initially developed to establish a precise and reliable atlas of the cerebellum in animals. This approach—even if Robert Clarke[22] briefly suggested a human use of their device—was thus initially close to the technique previously described in Russia. This technique was then largely used to create lesions of the CNS in animals.

The clinical development of stereotaxy by both Ernest Spiegel and Henry Wycis in the US for a direct lesioning procedure,[23] Lars Leksell in Sweden for radiosurgery,[12] and Jean Talairach in France for electrophysiological recording,[25] occurred during the second part of the 20th century. These procedures shared a common purpose: reaching a precise intracranial target while reducing the adverse effects of extensive neurosurgical approaches. However, this concept had already been put into human clinical practice long before, although it has since been forgotten and unrecognized. The first documented stereotactic brain procedure was developed in France in 1897 by Gaston Contremoulins, a 26-year-old self-taught scientist, prior to any modern brain surgery in his country. It is the first reported human stereotactic surgery and the earliest adaptation of the geometrical concept using radiography.

Historical and Theoretical Context of Contremoulins' Work

Early Life and Work

Gaston André Gabriel Contremoulins (Fig. 2) was born in 1869 in Normandy, France. He graduated from art school before moving to Paris for his military service. He settled there in Montmartre's artistic bohemian quarter, where the development of photography fascinated him. He entered the scientific world by getting a position as a microphotography laboratory technician in the department of experimental physiology led by Étienne-Jules Marey, a French scientist and photographer from the French Academy of Sciences.[14,16] When Henri Poincaré presented the first radiograph in France, only 2 months after its first description by Wilhelm Röntgen in 1895,[15,17] Contremoulins immediately foresaw the numerous medical applications of this new technology. Within 2 months, he designed a device to significantly reduce the x-ray exposure time, initially 8 hours for the skull.[19,21] In 1897, he received an award from the French Academy of Sciences (the Montyon Prize) and in 1898 was appointed to design and create radiology departments for Paris' hospitals.[6] He pioneered the idea of x-ray toxicity, less than a year after the initial radiograph by Wilhelm Röntgen,[19] and all through his life developed the concept of radioprotection.

Epistemological Considerations and Scientific Contex

Contremoulins entered the medical world at a pivotal time: François Magendie began a revolution of thinking at

FIG. 2. Photograph of Gaston Contremoulins holding the compass. Courtesy of Dr. Patrick Mornet.[16]

the beginning of the 19th century when he rejected Latin as the only medical language and introduced the concept of causality to understand the functioning of the human body.[3,9] Magendie created "physiology" in massive opposition to the vitalism concept supported by the heirs of 18th century academic medicine, such as Xavier Bichat. Claude Bernard, Magendie's successor at the Collège de France, created modern experimental medicine based on a rigorous methodology.[4] This innovative approach spread quickly across Europe and resulted in many major steps forward in medicine in the second half of the 19th century. Étienne-Jules Marey was a direct heir of this school of thought; his rigorous methodology impressed Contremoulins and stimulated his creativity.

It is also worth noting that, at that time, more than today, scientists were commonly involved in several disciplines. Poincaré, reputedly one of the last mathematicians mastering all the fields of contemporary mathematics, was also close to other scientists such as Röntgen, which allowed the quick development of radiography. Contremoulins' work was thus the product of the meeting between a recent medical rigorous methodology, a cross-disciplinary access to scientific findings, and the enthusiasm of an intelligent self-taught young man.

A Crowdfunded Project

When Contremoulins, working with the French surgeon Charles Rémy, foresaw the many opportunities radiography could bring to medicine, they asked the University of Paris for financial support to create an experimental radiology department. The institution did not consider the technique promising enough and did not support the project.[2] Contremoulins and Rémy decided to buy their own Crookes x-ray sources to demonstrate the interest of radiography in intracranial projectile localization.[19] After the 2 first skull radiographs, Marey presented their work to the French Academy of Sciences and alerted public opinion to the lack of government consideration

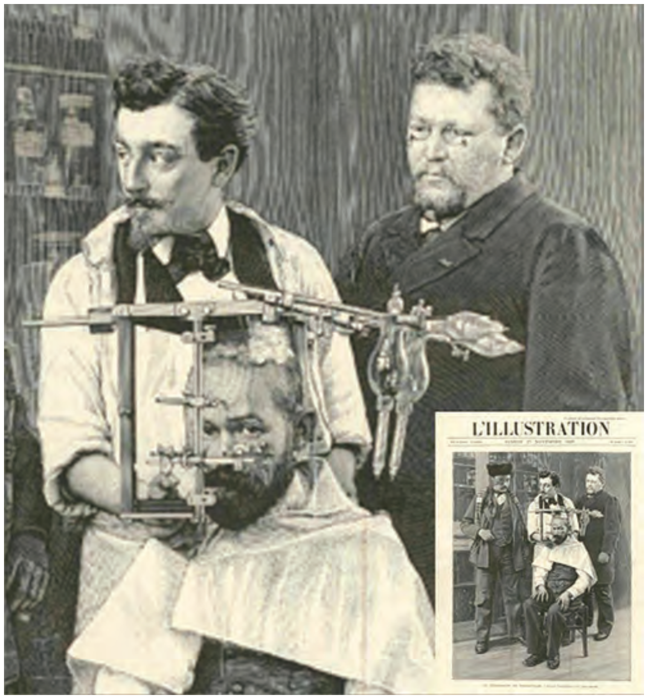

FIG. 3. The bullet finder (le chercheur de projectiles) presented in the popular French newspaper *L'Illustration* in 1897. From Dr. Bourdillon's personal collection. Figure is available in color online only.

for science. He published a call for capital in the popular French newspaper *Le Temps* and, as soon as the following day, the research team received more than was needed by crowdfunding (2500 francs, which corresponds to US $9000 in current value).

Contremoulins' Key Concepts of Stereotaxy

Many surgeons very quickly understood the opportunities offered by x-rays and used them to locate fractures and foreign bodies. However, locating an object from 2D radiographs led to inevitable adverse effects. More than any others, intracranial foreign bodies were considered as intractable due to the extremely high risk of surgical procedures. Contremoulins developed a strong and reliable technique to provide surgeons the exact trajectory to follow, focusing his work on the most challenging pathology. As early as 1897, he proposed an efficient intracranial bullet finder, i.e., "le chercheur de projectiles" (Fig. 3).

When Contremoulins reported his methodology for his bullet finder he formulated 4 major points. These are very important concepts for stereotactic procedures based on 2D radiography and remain used in many centers today. The third point is conceptually crucial and applies to the majority of stereotactic technologies today.

The first principle is to use multiple radiographs with different orientations to create spatial reconstructions of an object and compensate for the limitation of 2D images. In this way, Contremoulins resolves the difficulty of performing surgery based on 2D radiographs.

The second principle is to accurately know the position of the multiple sources of the x-ray, which therefore have

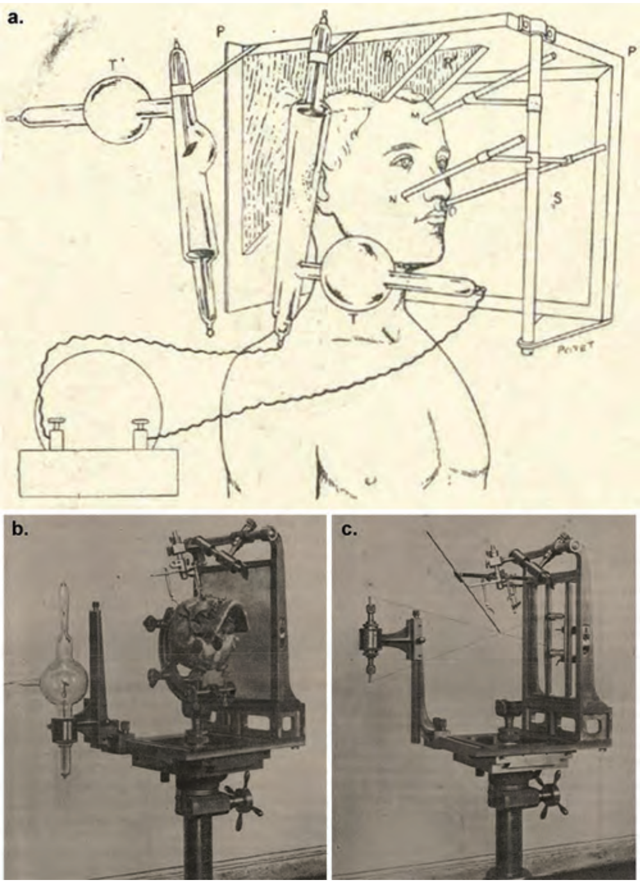

FIG. 4. a: Illustration of the metallic framework carrying the x-ray sources strongly fixed to the patient's head. Three landmarks are marked on the patient's head (from *L'Illustration*, 1897). **b:** Photograph of Contremoulins' frame with a skull (Gallica.BnF.fr; *Bulletin de l'Académie Nationale de Médecine*, 1916). **c:** Photograph of Contremoulins' frame without a skull. The position of the bullet is given by strings drawn between x-ray sources and the location of the bullet as visualized on the x-ray cassettes (Gallica.BnF.fr; *Bulletin de l'Académie Nationale de Médecine*, 1916). Courtesy of the Bibliothèque Nationale de France. Figure is available in color online only.

to be fixed in relation to the tracked object. This is the direct continuation of the previous principle and it allows the spatial reconstruction of an object.

The third principle is to define the position of the object in a frame of reference associated with an abstract coordinates system. And the fourth principle is to use the coordinates to guide a surgical procedure. For that purpose, a surgical device is fixed to the frame of reference to guide a surgical instrument.

Results of Their Work: The Bullet Finder

Contremoulins' Modus Operandi

Initially, the patient's head was put into the "research device" ("appareil de recherche"; Fig. 3), which was made of a metallic framework carrying x-ray sources (Crookes tubes). Because this framework—which corresponds to the present stereotactic frame—had to be perfectly fixed to the patient's head, 2 wood boards adapted to the head were sealed with plaster to the metallic framework (Fig. 4). The x-ray cassettes were strongly fixed on the metallic framework. Two radiographies were then performed with different orientations (each took 15 minutes to perform).

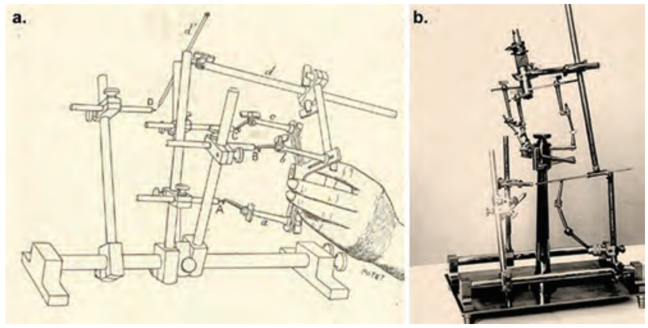

FIG. 5. Frame of reference reproduced on the "schema compass" on which is applied the "operative compass." From *L'Illustration*, 1897 (**a**), and Gallica.BnF.fr, *Bulletin de l'Académie Nationale de Médecine,* 1916 (**b**). Courtesy of the Bibliothèque Nationale de France. Figure is available in color online only.

Following these 2 radiographies, and before removing the framework from the patient's head, 3 landmarks were noted on it with a metallic adjustable device fixed on the framework. Those 3 landmarks were chosen on bony zones and were then tattooed on the patient's skin. After that, the framework was removed from the patient's head and strings were drawn between x-ray sources and the location of the bullet on the x-ray cassettes (Fig. 4). The intersection between the strings gave the position of the bullet and its coordinates in the frame of reference were consecutively obtained.

In the second part of the procedure, the position of the target (i.e., the bullet inside the patient's head) was reproduced in another frame of reference called the "schema compass" ("compas schéma"), similar to the previous one but without the Crookes x-ray sources and with the possibility to adapt, calibrate, and set a surgical device. This surgical tool, called the "operative compass" ("compas d'opération"), was then applied to this framework and set according to the coordinates of the bullet (Fig. 5). The operative compass thus reproduced the 3 landmarks previously defined on the patient and associated them with an operative guide.

The last part of the procedure involved applying the set operative compass to the patient by matching the 3 tattooed points on the patient's skin with the 3 points previously set on the operative compass (Fig. 6). A surgical tool, such as a needle, was carried by the operative compass. The entry point on the skull could be chosen by the surgeon without modifying the target thanks to an isocentric system. This allowed the surgeon to directly access the object without having to explore the intracranial space, thus minimizing the neurological risk for the patient.

First Clinical Use of the Bullet Finder

Shortly after the successful funding of his project, Contremoulins built the bullet finder and had the opportunity, along with the surgeon Charles Rémy, to perform the first 2 procedures. Two young men who shot themselves in the

FIG. 6. Gaston Contremoulins (*right*) and Charles Rémy (*left*) using the operative compass ("compas d'opération"; *L'Illustration*, 1897). From Dr. Bourdillon's personal collection. Figure is available in color online only.

head were admitted to Rémy's Department of Surgery. Because such injuries were considered intractable, an intervention using Contremoulins' bullet finder was proposed to the 2 young patients as a last resort. As far as we know from the popular reports, both of the operations were successful and the 2 patients were discharged from hospital a few days after having the bullets removed from their brains.[18,20]

Contremoulins' Legacy

Following the successful removal of the brain projectiles, Contremoulins and Rémy gained fame and their achievements were published in France's most widely read weekly newspaper *L'Illustration* (the November 27, 1897, issue, from which the engravings in Fig. 3 originate). A few months later, Contremoulins was appointed to design radiology departments for Paris' hospitals, and within a couple of years his techniques were commonly used by many physicists and physicians, while electric systems were not yet available throughout hospitals. Simultaneously, he managed to continually improve the procedure with radioprotection devices, extension of the bullet finder to extracranial foreign bodies, and so on. As a result, at the beginning of World War I, his guided surgical procedure to extract a foreign body took only 40 minutes, and he even managed to reduce this time to 5 minutes in some cases, which could be lifesaving in that time of war in which anesthesia was not always available and antibiotics did not exist. According to the report of Mornet, from 1914 to 1918 alone 37,780 x-ray–guided foreign body extraction procedures were performed.[16]

Surprisingly, although this technique was largely diffused and massively used during the war, it has not been reported in any scientific medium and all the data are only published in the annual activity report of Parisian hospitals ("Rapports d'exercice du laboratoire principal des hôpitaux de Necker"). This may be the consequence of a polemic in France that began in 1899 concerning the legitimacy of nonphysicians performing radiography.[14,16] In 1907, this prerogative became officially restricted to the physicians and a short list of physicists and gained the status of medical procedure in 1929. The only exception to that law was granted to Contremoulins, who, despite his lack of academic qualifi ations, had played a major role in the development of radiography in France. The difficulties he encountered being admitted to conventional academic institutions probably had a massive and underestimated impact on the diffusion of his work.

Conclusions

Stereotaxy is known to have developed step by step at the end of the 19th century, and Ernest Spiegel and Henry Wycis made the diffusion of this technique widespread in 1947. They described this approach in a scientific institutional environment as a response to the limits of a growing medical expertise in neurosurgery.[23] On the other hand, the initial description of an x-ray–guided stereotactic procedure by Contremoulins in 1897, which occurred before any local development of neurosurgery and far from medical institutional support, was not largely disseminated. Gaston Contremoulins' self-made education and scientific culture gave him a great freedom of thought and imagination, alongside the rigorous methods he learned from his contemporary colleagues. This report is not only an opportunity to give credit for the development of stereotaxy to those who earned it, it also highlights that cross-disciplinary research and a creative culture are keys for those trying to find innovative answers to medical issues.

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Disclosures

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Author Contributions

Conception and design: all authors. Acquisition of data: Bourdillon. Analysis and interpretation of data: Bourdillon. Drafting the article: Bourdillon. Critically revising the article: Apra, Lévêque. Reviewed submitted version of manuscript: Apra, Lévêque. Approved the final version of the manuscript on behalf of all authors: Bourdillon. Administrative/technical/material support: Bourdillon. Study supervision: Bourdillon.

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