Postcentral Topectomy for Pain Relief: A Historical Review and Possible Improvements

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Postcentral topectomy is a neurosurgical procedure, practiced in the mid-20th century, in which surgical ablations of the primary somatosensory cortex were used as a therapeutic means of treating patients suffering from intractable chronic pain. While successful in curing some—but not all—patients, the procedure was poorly understood and eventually became displaced by methods that more consistently stopped patient complaints of pain, such as opiates and frontal lobotomies. However, a more recent discovery of a nociresponsive region in the transitional zone between the primary somatosensory cortex and the primary motor cortex (lying in Brodmann Area 3a anterior to its better known proprioceptive region) raises the possibility that the outcome of postcentral topectomy depended in each patient on whether the ablation extended deep enough into the central sulcus to remove this cortical region. Here we review every postcentral topectomy case we could find in the neurosurgical literature in order to evaluate its past effectiveness and to reassess its potential in light of modern knowledge of the cerebral cortex. We found 17 full-text reports from 16 different surgical teams describing outcomes of the procedure in 27 patients. Among those, in only 5 patients the procedure either failed to abolish the targeted chronic pain or the pain returned to its preoperational levels several weeks or months after the surgery. In the other 22 patients, their pain stayed abolished or at least significantly reduced as of the last evaluation by the treating physician (which was one year or more for 9 patients). We propose that the probability of a successful outcome might be brought to near 100% by selective targeting—guided by functional imaging—of the nociresponsive region in Area 3a.

Citation

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Introduction

Postcentral Topectomy is a neurosurgical procedure developed in 1940s which treated intractable chronic pain through selective ablations of the primary somatosensory cortex (SI). Most commonly used as a treatment for phantom limb pain, this procedure involved mapping the postcentral cortex to locate the region which received somatosensory input from the painful phantom, and then ablating this region. While apparently often successful, the mechanism for this procedure was not understood, and the surgery fell out of favor during the 1970s, when other means of dealing with patient complaints of pain came to the forefront.

While it has been long-suspected that the somatosensory cortex near the central sulcus is involved in pain sensation (e.g., Figure 1), what part of it is important for pain was not clear. In their studies of World War I and II soldiers, Kleist (1934), Russell (1945) and Marshall (1951) described soldiers who experienced a transient or permanent loss of pain sensibility following either shrapnel-caused bruising or bullet-caused injury of a restricted region confined to SI. Both Kleist and Russell noted a tendency for pain sensibility to be lost when the damage extended deep down the posterior bank of the central sulcus. Contrariwise, when damage was restricted to the crown of the postcentral gyrus, the patients exhibited hyperesthesia and allodynia. From this evidence, Kleist hypothesized that pain and temperature sensations were localized in small subregions of Brodmann Areas 3a and 3b.

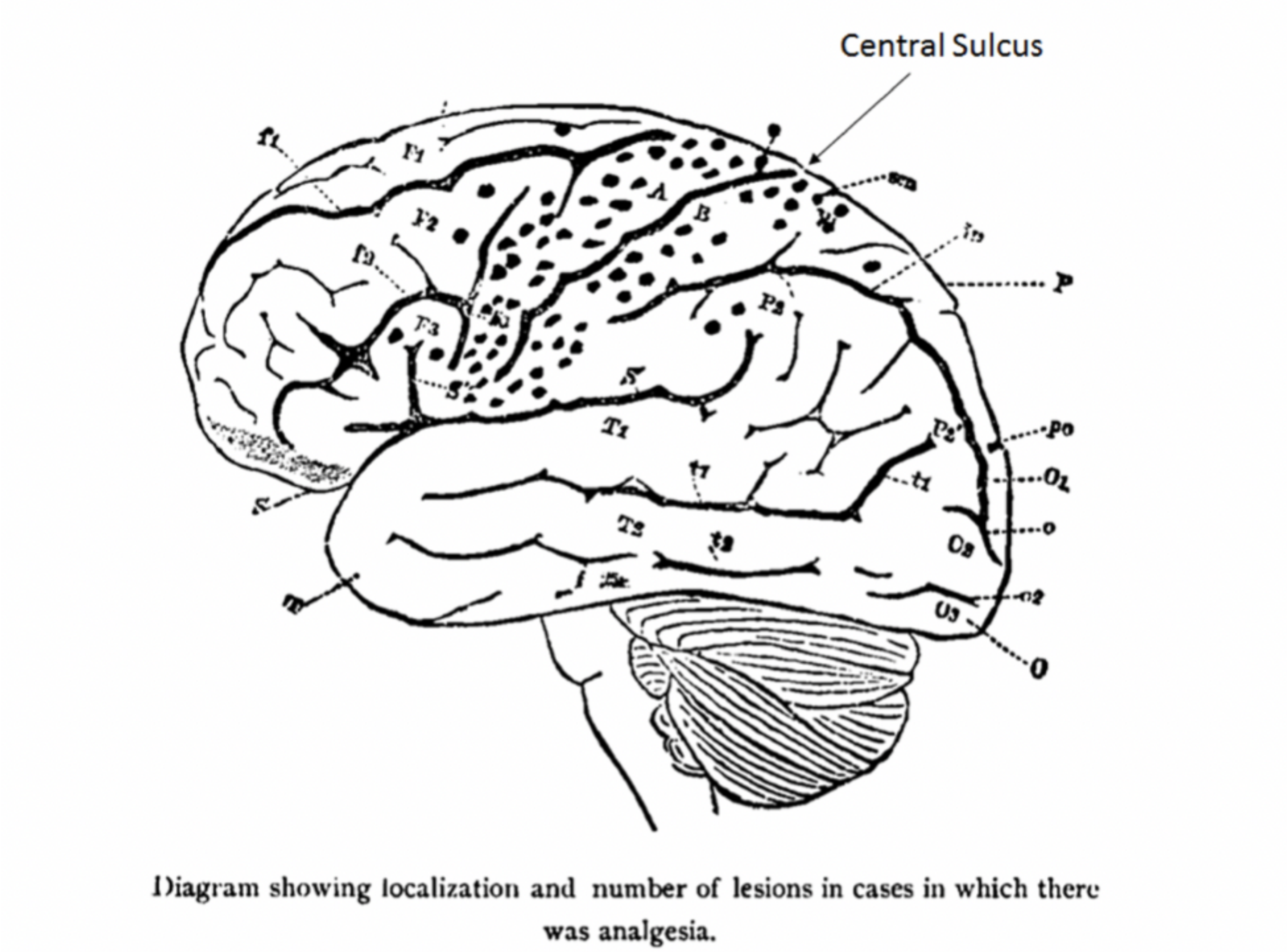

Figure 1. *Figure from Dana (1888). All lesions marked were from patients who experienced analgesia while alive, and had the exact lesion locations recorded in postmortem autopsies.*

This surmised existence of a “pain center” in the depth of the central sulcus, possibly associated with Brodmann Area 3a (Kleist, 1934; Perl, 1984), was eventually confirmed by using optical intrinsic signal imaging of stimulus-evoked activity in SI (Tommerdahl et al., 1996, 1998, Chen et al., 2009) and later using microelectrode recordings of neuronal spike firing (Whitsel et al., 2009), showing that thermonoxious skin stimuli selectively activate an anterior portion of Brodmann Area 3a (which in humans is buried in the depth of the central sulcus; see Figure 2), while suppressing activity in Areas 3b and 1.

According to recent comprehensive reviews by Vierck et al. (2013) and Whitsel et al. (2019) of the published experimental evidence, this nociresponsive region might play a key role in perception of the 2^{nd}/slow pain as well as in chronic neuropathic pain. These recent developments reawaken interest in old postcentral topectomy attempts to treat chronic pain. The present review sets out to comprehensively summarize and assess all postcentral topectomy case reports in the literature, and evaluate the overall effectiveness and reliability of the surgery.

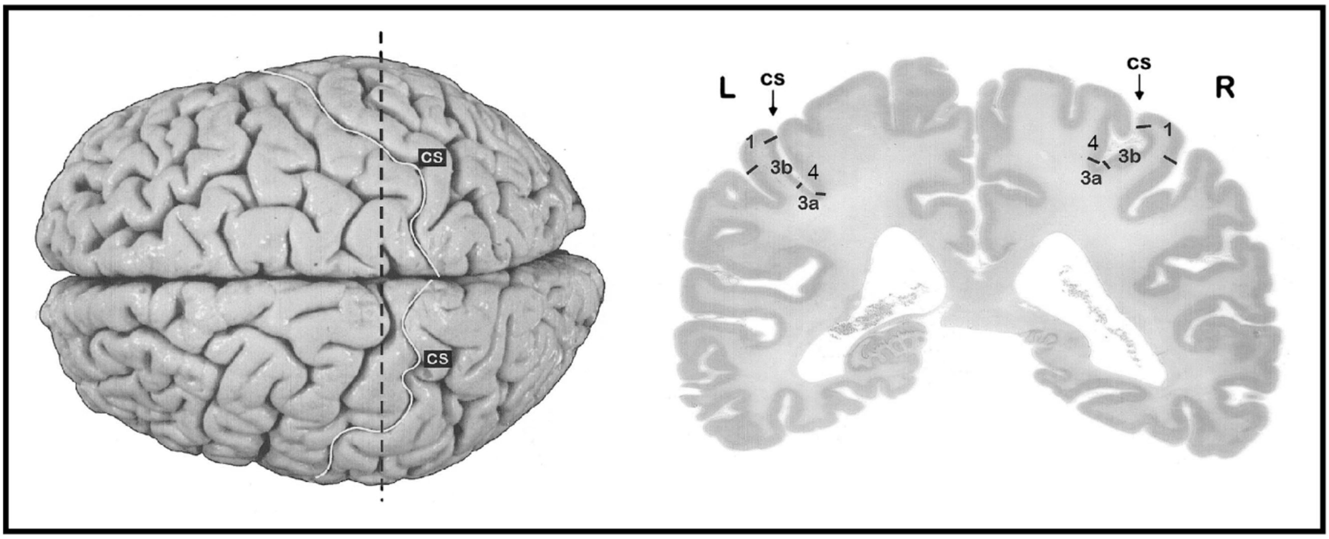

Figure 2. *Location of Brodmann Area 3a in human cerebral cortex. Shown are the top view of the cerebral cortex and a representative coronal section (its location is indicated on the top view by a dashed line). CS – central sulcus. (Adapted from Geyer et al., 2000.)*

Literature Reviewed

We identified 27 cases from 17 full-text reports in 5 languages (Gutierrez-Mahoney 1944; Lhermitte and Puech 1946; Horrax 1946; Odom and Lyman 1946; Echols and Colclough 1947; Gutierrez-Mahoney 1948; Wertheimer and Mansuy 1949; Stone 1950; Akhundov 1950; Sugar and Bucy 1951; Lewin and Phillips 1952; Pool and Bridges 1954; Török 1960; Carbonin 1961; Deák and Tóth 1966; Lende and Druckman 1971; Woolsey et al 1979).

PubMed, JSTOR and Google Scholar searches were conducted using the terms “postcentral topectomy”, “parietal topectomy”, “parietal cortex pain surgery”, “parietal phantom limb surgery”, and “phantom pain surgical treatment”. No date boundaries or language restrictions were set. The selection criteria were that: (1) the surgery was used to treat a chronic pain syndrome; (2) the author(s) provided a firsthand description of the ablated region; (3) the ablated region primarily engaged the postcentral gyrus; and (4) the outcome of the surgery was known. Case reports where the cortex was obviously damaged upon visual inspection of the surface were excluded.

In 22 of the 27 patients identified by this survey the surgery was successful. Success was defined as having the patient experience significant relief from the original pain at the end of the period recorded in the case report. Of these successes, 19 had a recording period that lasted at least six months after the surgery, and 13 were recorded for at least ten months. Of the failures, in 1 of the 27 cases, the surgery was entirely unsuccessful (with no pain relief whatsoever), and in 4 of 27 cases the original pain completely returned at some later point.

Case Reports

Chronological Case Reports

Postcentral topectomy case reports are scattered across the literature in five different languages, and even the most prolific authors only report on a few cases. In order to ensure a comprehensive review of the surgery, all case reports included in the statistical analysis have been individually summarized in this section.

Author	Date	Age	Sex	Ablated Region	Follow-up Period	Outcome
Gutierrez-Mahoney	1944	40	M	Postcentral Only	2 years	Lasting Success
Lhermitte and Peuch	1946	43	M	Left Parietal Lobe	0 days	Immediate Failure
Horrax	1946	55	M	Precentral and Postcentral	22 days	Recurrence
Horrax	1946	60	M	Postcentral Only	9 months	Lasting Success
Horrax	1946	42	M	Postcentral Only	10 months	Lasting Success
Odom and Lyman	1946	68	F	Precentral and Postcentral	1 month	Putative Success
Echols and Colclough	1947	53	M	Postcentral Only	11 months	Lasting Success
Gutierrez-Mahoney	1948	24	M	Postcentral Only	3 years	Lasting Success
Gutierrez-Mahoney	1948	56	M	Precentral and Postcentral	6 months	Recurrence
Gutierrez-Mahoney	1948	68	M	Postcentral Only	1 year	Lasting Success
Wertheimer and Mansuy	1949	58	M	Postcentral Only	6 months	Lasting Success
Stone	1950	27	M	Precentral and Postcentral	10 months	Lasting Success
Stone	1950	28	M	Postcentral Only	11 months	Lasting Success
Stone	1950	58	F	Postcentral Only	14 months	Lasting Success
Akhundov	1950	41	M	S1, and areas 5, 7, and 40	7 months	Lasting Success
Sugar and Bucy	1951	67	M	Postcentral Only	12 days	Recurrence
Lewin and Phillips	1952	66	M	Postcentral Only	6 months	Lasting Success
Lewin and Phillips	1952	58	M	Postcentral Only	5 weeks	Putative Success
Pool and Bridges	1954	66	F	Multiple Postcentral Areas	17 months	Lasting Success
Török	1960	59	M	Precentral and Postcentral	6 months	Lasting Success
Carbonin	1961	64	M	Postcentral Only	1 year	Lasting Success
Deák and Tóth	1966	49	F	Postcentral Only	5 years	Lasting Success
Deák and Tóth	1966	48	M	Postcentral Only	2 months	Recurrence
Lende et al.	1971	61	M	Precentral and Postcentral	20 months	Lasting Success
Lende et al.	1971	41	F	Precentral and Postcentral	2.5 years	Lasting Success
Woolsey et al.	1979	Unknown	F	Postcentral Only	6 months	Lasting Success
Woolsey et al.	1979	Unknown	M	Postcentral Only	<1 year	Putative Success

Table 1. *Selected Case Reports. Successes are cases with significant reduction of the original pain at the last recorded point, “Lasting” successes indicating a follow-up of at least six months, and “Putative” successes a follow-up period of less than six months. Recurrence indicates the complete return of the original pain.*

In 1941, Gutierrez-Mahoney was the first to perform a postcentral topectomy (Gutierrez-Mahoney, 1944). His patient suffered from painful phantom fingers after a hand injury. Based on a previous report from Holmes, where a cerebral lesion abolished a phantom limb, Gutierrez-Mahoney decided to operate, assuming that the pain originated somewhere in the somatosensory cortex. He explored the postcentral parietal cortex with electrostimulation to locate regions that evoked pain in the phantom limb. After those regions were identified and mapped, he excised them through subpial resection. The patient was cured, and remained so for at least two years after the operation.

Gutierrez-Mahoney went on to perform postcentral topectomies on three more patients (Gutierrez-Mahoney, 1948). The results were somewhat mixed. In the first of these cases, there was considerable pain relief, with a small amount of remaining pain that could be controlled with aspirin. In the second case of a patient with a mid-thigh amputation, the pain from the phantom limb was abolished, but the pain in his hip recurred within six months. In the final case, a variation upon the technique was performed: i.e., the precentral gyrus was removed along with the postcentral. This surgery ultimately proved less effective, as the patient's pain was abolished in the short term but recurred within six months.

Lhermitte and Puech (1945) were the second group to intentionally attempt a surgical intervention. It was, unfortunately, unsuccessful; their parietal resection caused only a temporary vanishing of the phantom limb, and also restored spontaneous movements of the stump, which had previously been abolished by a myelotomy. Lhermitte suspected that the operation failed due to an insufficiently large resection, but didn't provide exact details of the lesion's location and extent beyond saying he 'resected the left parietal lobe'.

The next year, Horrax (1946) reported on the four postcentral topectomies he performed, three of which were suitable to be included in the statistical analysis. In his first patient, he was unable to produce lasting pain relief, despite performing two separate surgeries and removing the pre- and post-central cortex both ipsilateral and contralateral to the phantom hand. The longest duration of pain relief lasted only twenty-two days. His later interventions, however, were more successful. The second patient experienced chronic pain in both arms after a spinal cord injury at the C6 vertebra, which had only been exacerbated by a cervical laminectomy. He received considerable relief from the pain in the arm contralateral to the topectomy (the more painful limb)[1]. The final patient had previously suffered from a fibrillary astrocytoma situated parasagitally in the arm and leg centers, which had been removed surgically. Two years after its removal, he suffered incapacitating pain in the right arm and hand, along with lesser pain in the right face and leg and hypoesthesia in all four locations. The surgeon conducted electrical stimulation of the postcentral cortex to evoke pain, followed by guided excisions. Relief of the patient's upper extremity pain was complete at ten months, when he died from a pontine hemorrhage. Notably, until death the patient experienced a total loss of pain sensation in his right hand.

Odom and Lyman had an unusual case report later in 1946. Their patient, a 68-year-old woman, experienced left trigeminal nerve pain for four years. A complete left trigeminal rhizotomy removed tic pains, but did not remove the burning pain on the left side of her face. A postcentral topectomy was performed in order to alleviate this pain. The motor and sensory areas for the face and left arm were mapped electrically, then removed. After the surgery, there was a loss of sensation on the left face and arm, except for the left eye, in which the patient complained of pain and photophobia. In addition, there was also a puzzling ataxic dysarthria observed; no other postcentral topectomy patients on record exhibited slurred speech as a symptom. It is possible that the extensive removal of motor cortex is responsible. It is also possible that brain damage occurred outside the region of incision, as after the surgery the patient spent five days with a fever, and during that time was "confused and incoherent". As she was only followed for a month post-surgery, it is impossible to know the long term results.

In 1946, Echols and Colclough (1947) performed a fully successful postcentral topectomy on a 53 year old male patient suffering from phantom limb pain in his leg, after an attempt at spinal anesthetic proved effective for only five minutes. Stimulation of the leg's motor cortex made the stump jerk, while stimulation of the corresponding sensory cortex made the phantom foot feel hot. Both the gray matter and some white matter of the leg and foot sensory cortex were removed, with the patient spontaneously announcing partway through the ablation that the phantom foot and pain had vanished. Although the patient experienced some Jacksonian seizures and aphasia due to an extradural blood clot, after it was removed in a second surgery he made a full recovery. Eleven months later he remained completely free of both the phantom and the pain.

Wertheimer and Mansuy (1949) operated on a 58-year old male patient whose leg was amputated in World War One. He had experienced phantom limb pain in his foot since 1916, and had undergone multiple surgical treatments in the intervening 31 years, all unsuccessful. During the surgery, the motor cortex was explored with electrical stimulation, and the corresponding region of the postcentral cortex was ablated, resecting two square centimeters with deep coagulation at the top and inside. The patient felt nonpainful jerks of the stump when stimulated, and the pain vanished at the end of the procedure. However, shortly after the surgery, the patient soon grew increasingly agitated, confused, and restless. The surgical staff discovered that he had—foiling all attempts at surveillance—secretly been treating his pain with daily doses of up to 240 mg of morphine, and was now suffering the withdrawal symptoms. He was released after ten days of detoxification, and six months later was in excellent condition.

Stone (1950) and John Martin operated on three phantom limb patients: two males, 27 and 28, and one female, 58. The first had his left forearm amputated after a shell fragment wound in 1944. After several failed procedures, including three neuroma operations, he was eventually taken in for a postcentral topectomy. When Martin attempted to identify the correct brain region through electrical stimulation, the patient had a generalized convulsion and lost consciousness. Nevertheless, Martin excised the region which seemed to include the hand representation, approximately 2×1 cm, to 1 cm of depth. The patient had no pain or awareness of his phantom limb post-surgery, and while the phantom itself reappeared four weeks after discharge, the pain was still absent ten months later. The second patient had his leg amputated at the thigh after a motorcycle accident. His phantom limb pain was concentrated in the heel, and any movement of the stump, including wearing his artificial leg, exacerbated it. A postcentral gyrectomy was decided upon. Electrical stimulation of the postcentral gyrus exactly at the midline produced “exquisite pain and tingling” in the phantom limb. When the excision was completed, the patient said he no longer felt the phantom. He remained free of the pain for at least eleven months post-surgery. The final patient, a 58 year old woman, suffered from both central pain and phantom pain, and because of this pain had attempted suicide on three occasions. The surgery excised the entire postcentral gyrus, from the posterior border to the next gyrus. Although the patient had a “truly stormy convalescence”, and temporarily suffered motor aphasia, her phantom limb pain was immediately cured, and remained so at the fourteen month mark.

Also in 1950, Akhundov treated a patient (male, 41) who was run over by a car and subsequently suffered from a form of supernumerary phantom limb pain (Akhundov, 1950). While his arm was physically intact, the nerves had been severed, and he felt a phantom with a harshly contracted elbow and hand, with both a continuous burning pain and intermittent increases in the ulnar or radial areas. Surgery was conducted four and a half months after the accident. Stimulation in the postcentral gyrus for the hand caused ‘pricking’ pains that immediately grew into the full phantom pain. They then electrocoagulated all the blood vessels in the region, and removed cortical matter 1 cm deep, 1 cm medial, and 2.5 cm posterior, all the way to the lower temporal lobe (removing not only S1, but also areas 5, 7, and 40). Recovery followed an unusual course. After one hour, the phantom was still present, with pain only present in digit 5, much diminished and periodic instead of continuous. At day four, the pain and sensation in the fingers was totally gone. However, on day 9 the phantom hand and pain abruptly reappeared, somewhat diminished, and then started vanishing again on day 12. As of the last recorded time—seven months after surgery—the phantom arm and pain were both completely abolished.

Sugar and Bucy (1951) attempted to treat postherpetic trigeminal neuralgia with a postcentral topectomy in 1946. The patient (male, 67) had a painful vesicular eruption on the left side of his face, with constant burning pain that persisted even after the rash vanished. Over the course of the next three years, several operations on the left trigeminal nerve proved ineffective, eventually leaving the area numb, but with continuing pain. Severing all the root fibers of the gasserian ganglion resulted in pain relief for only two days. All other courses having failed, they decided to perform a postcentral topectomy. Despite extensive attempts to stimulate both the precentral and postcentral gyri, they could not evoke the same kind of pain from the patient (one location caused a feeling of 'strangulation' accompanied by involuntary clearing of the throat). All of the postcentral gyrus was removed between the representation of the throat, and the representation of the thumb and index finger. Repeated stimulation still could not evoke pain, and the patient spontaneously said that the pain in the face had been completely relieved. However, on the fifth day a slight stinging pain recurred, spreading to including all the initial area on the twelfth day, and eventually returning to its original strength. Speculating that the failure might have been caused by the bilateral representation of the face, they attempted another topectomy five months later, on the ipsilateral side. However their region of excision was too posterior, and missed the postcentral gyrus entirely, resulting in an unsuccessful surgery.

Lewin and Phillips (1952) operated on two patients injured in World War I. The first patient (male, 66) had a left thigh amputation after a torpedo explosion. While his phantom limb was initially painless, by 1941 the phantom started hurting, and by the time of admission in 1951 he had undergone numerous local operations to treat the pain, all unsuccessful. Electrical stimulation of the postcentral gyrus immediately and repeatedly reproduced his pain. Excision of an area 1 cm in diameter had no effect on the pain, and stimulation deep in the anterior cut edge (on the posterior bank of the sulcus) still produced pain. The excision was increased in size until a 3×1×1 cm piece of cortex was removed. At this point the patient's pain had been considerably reduced (though not fully eliminated), and the operation was ended. This minor pain faded over the course of the next few weeks, but returned to a small extent six months later, controllable with aspirin. Their second patient (male, 58) had a mid-thigh amputation due to a gunshot wound. For 27 years he had no phantom limb sensation, however in 1946 the stump abruptly became extremely painful, and by the time of admission in 1951 he had numerous local operations, a cordotomy, and a spinal analgesic. Only the cordotomy offered any relief, which lasted for three weeks. Stimulation of the postcentral gyrus immediately and repeatedly reproduced the 'gripping' pain in his stump. Once again, the initial excision of 1 cm in diameter was insufficient to alter the pain. Unusually, using forceps to pinch a small blood vessel at the bottom of this excision reproduced the pain. As deeper gray matter was removed, the pain disappeared, leaving a final excision 2.0×1.5×1.5 cm deep. Following the operation the patient had some superficial tingling, with an attack of burning pain five days later, "quite different from any pain he had had previously", which vanished after 17 hours. Five weeks post-operation, he had been completely relieved of the pain existing before the operation, although he now had a few new and minor aches over a small area of the stump[2].

Pool and Bridges (1954) took a similar approach to Akhundov, removing both the postcentral gyrus and a large portion of the cortex posterior to it. The patient (female, 66) was admitted in 1952 for constant burning and cramping phantom arm pain. Pool first electrically stimulated the motor cortex to identify it, then drove a 'fence' of needles 2.5 cm down into the sensory cortex along the border with the motor cortex. Pool then started undercutting from a point 7.5 cm posterior to the central fissure, continuing the cut to the anterior until the pins blocked his blade. Recovery was difficult for the first six weeks, due to withdrawal symptoms from taking the patient off narcotics too quickly. By the sixth week, there were occasional twinges of phantom pain, but the original constant pain did not recur, and the occasional pains gradually decreased over the next four months. The patient continued to experience relief from her phantom limb syndrome at least seventeen months after surgery.

Török (1960) treated a patient (male, 59) who had suffered numerous accidents, leaving him blind and resulting in an arm amputation. Phantom pain appeared in the arm immediately after surgery, which could not be controlled by drugs and prevented him from sleeping. After eight days of conservative treatments proved unsuccessful, a postcentral gyrectomy was performed. Electrical stimulation outlined the area of interest, but did not provoke any pain. The topectomy was performed on both pre and post central gyri for both the hand and arm areas. Immediately after, the patient was a little stunned, and still complained about pain but without any emotion - by the next day, however, he was relieved that he had no more pain and his stump no longer convulsed. After a month, the patient started occasionally feeling a different kind of dull, drawn-out pain in his hand at irregularly spaced intervals. He reported going days without any need for analgesics, and during his weeklong follow-up clinic visit six months later, there were no complaints of pain. As the original phantom pain was gone, and the patient could now sleep at night, Török considered the surgery a success.

Carbonin (1961) treated a patient (male, 64) who had suffered an amputation of the lower two thirds of his arm in 1953. Three weeks after the amputation, the patient began experiencing a painful burning electric current sensation from the shoulder stump to the tip of his fingers. Novocainization of the stump, infiltration of the stellate ganglion, and resection of the median nerve all proved ineffective, granting only short-term temporary relief. Over the next few years the patient underwent ten different operations to treat his intolerable pain, all unsuccessful. In August 1959 a postcentral topectomy was performed. The somatosensory cortex corresponding to the arm was removed, with a total excision of 3 cm along the length of the convolution, 1 cm wide and 1 cm deep. Immediately upon waking, the patient was happy to find the pain had disappeared, except for a small point on his wrist and little finger. Two days later, he had a Bravais-Jacksonniene seizure. The surgeons reopened the site, removed coagulated blood from the cortical resection, and while they were there, removed a couple more millimeters of gray and white matter from the upper and lower limits of the incision. This succeeded at removing the wrist pain and all of the finger’s pain but a small dot under the fingernail. Notably, some time after the surgery the patient returned to the surgeons, claiming to be suffering from horrible pain. However, further investigation revealed the true source of this complaint lay in his severe opioid addiction, which had reached 219 codeine pills in 15 days. After a round of detox, the addiction and claims of pain were both gone, and as of a year later the patient remained cured of his pain.

Deák and Tóth (1966) attempted to treat two patients with postcentral topectomy (female, 49 and male, 48). The first had her arm amputated due to malignant tumor in the shoulder joint, which became painful over the course of the next four months. Injections of procaine locally and to the plexus brachialis were ineffective, giving only a few hours of relief. The surgeons performed a postcentral topectomy, stimulating the brain for mapping, excising the sensory representations of the face and arm, and getting no reaction from the resected areas. Recovery was uneventful, and as of five years later, the patient was entirely free of symptoms, aside from occasional headaches. The second patient had his foot amputated in World War II, phantom pain resulting in three additional reamputations and removal of a neurinoma, all unsuccessful. Removal of two additional neuromas halted the pain for two months, after which severe pain resurfaced and the patient attempted suicide. A right posterior radicotomy provided pain relief for a few more months, then failed. Severing and reconnecting the sciatic nerve also proved ineffective. As all peripheral options had failed, a postcentral topectomy was attempted. The somatosensory area corresponding to the foot was stimulated, paraesthesia was evoked, and the corresponding cortical areas was excised. While the pain stopped immediately, two months later osteomyelitis developed in the stump, and the pain returned. After this failure, he refused further operations.

Lende et al. (1971) decided to treat two patients with intractable facial pain (male, 61 and female, 41) by ablating both the postcentral and precentral cortex. The first patient had what was believed to be a pontine lesion, resulting in continuous burning left facial pain. Sectioning the trigeminal nerve had no effect. The mapping stimulation provoked a burning feeling in the hand, but not the face. The facial region’s representation in both the precentral and postcentral gyri was removed, extending from the border of hand representation inferiorly to the Sylvian fissure, and exposing the insular gyri. The patient’s pain was fully relieved after the operation, although he suffered from some slight weakness of the left hand. He remained free of pain until his death from a coronary thrombosis 20 months later. The second patient suffered from constant facial pain caused by trigeminal neuralgia. She underwent multiple alcohol injections, resections of the trigeminal sensory root, numerous medications, and a frontal lobotomy, all unsuccessful. A postcentral gyrectomy was performed, and as with the other patient, the excision extended from the area of arm representation to the Sylvian fissure, exposing the insular gyri. After the procedure, the patient was completely free of pain, suffered from some weakness of the left hand, and pain could no longer be elicited from the left side of the face. As of the report two and half years later, the patient remained completely free of facial pain.

Woolsey published the most recent report on postcentral gyrectomies in 1979 (Woolsey et al., 1979). Two patients (female and male, age unknown) were treated for intractable phantom pain. The first had her leg amputated 13 years earlier, and now suffered from pain in the phantom leg. Stimulation of the postcentral gyrus was capable of evoking the pain at multiple locations. The region of interest was then excised, which immediately caused the patient to lose awareness of the phantom limb entirely. Six month later, the phantom was still present, but greatly diminished in size, and while the phantom pain had not entirely disappeared, it was less intense. The second patient had his arm amputated after getting it stuck in a hay-baler. Since the accident, he had severe chronic pain in his hand, sometimes intensifying to the point where it caused nausea. Every point in the hand stimulated in the postcentral cortex gave rise to a burning sensation, which the patient described as like his normal pain. The whole postcentral arm area was removed surgically. While no recurrence was noted, long term follow-up was impossible, as the patient died within a year.

Additional Case Reports

In order to further ensure this literature review includes all published resources, all case reports excluded from the statistical analysis will be quickly gone over in this section, along with the justification for their omission.

Bornstein provides the most dramatic postcentral topectomy case report in the medical literature (Bornstein, 1949). Serving as a medic in World War II, he treated a Russian officer whose leg had been shot and amputated. This officer now suffered from crippling phantom limb pain which grew even more intense at night. One day, Bornstein walked in to find the officer collapsed on the floor, unconscious, in a pool of his own blood, a knife embedded in his skull. He had tried to take his own life. However, the suicide attempt was unsuccessful, and when the officer stabbed himself in the brain, he successfully wounded the contralateral parietal lobe, apparently precisely in the somatosensory cortex associated with the missing leg. When he regained consciousness a few days later, the phantom limb—and the pain—were both gone, and remained so for the rest of his life. As this occurred in 1942, by sheer luck this Russian officer was the second person to successfully perform a postcentral topectomy. Unfortunately, the exact details of this impromptu operation weren't particularly detailed, so this case is entirely omitted from the overall analysis of the surgery's success or failure.

Several other case reports were also omitted for being insufficiently detailed. Echols reports "5 consecutive successful cases", but only went into detail for one of them. John Martin reports three of his five patients had "immediate and lasting relief", but did not go into enough detail to clarify how this overlaps with the procedures he performed with Stone (Martin, 1952). Sorgo gives a one sentence summary detailing a relapse at three months (Sorgo, 1951). Penfield and Welch mention a relapse at 18 months, but were primarily concerned with the supplementary motor cortex (Penfield and Welch, 1951). H. C. Trumble produced temporary relief in a paraplegic patient suffering from chronic pain with some variety of cortical excision, but never published (Sunderland and Kelly, 1948). Sweet and White made several secondhand references to various cases from their personal communications as well (Sweet and White, 1969).

Surgeries where noticeably abnormal cortex was excised, or where seizures were the primary cause of pain, were also omitted. Lewin and Phillips included a third patient in their case reports, who suffered from painful seizures which were successfully treated by a postcentral gyrectomy. Hamby treated a patient who suffered from central pain after a car accident with a postcentral topectomy, resulting in a total release from pain which lasted at least ten years after surgery

(Hamby, 1961). However, the surface of the postcentral cortex removed appeared “leathery and atrophic”, so the reason for the treatment’s success cannot be unequivocally determined. *Hécaen* and Penfield (1956) also had a case that was successful at a four and half year follow-up, but the postcentral cortex they removed was heavily scarred.

In addition, a few frequently-cited case reports were of historical interest, but were not entirely comparable to a traditional postcentral topectomy. Leriche (1949) was the first to attempt a postcentral treatment for phantom pain, however he injected procaine instead of ablating the area, and the treatment only lasted for two months. Lenshoek (1959) treated three patients, one of which was still cured ten years post-surgery; however, he ablated multiple regions of the brain in addition to the postcentral cortex, and the secondary somatosensory area appears to have been more important for his cases. Similarly, Sano (1977) operated in the cm/pf complex, outside the region of interest.

Previous Postcentral Topectomy Reviews

There have previously been three major reviews conducted assessing the postcentral topectomy’s effectiveness. Gutierrez-Mahoney, as the first person to perform the surgery, stayed in contact with the surgeons who attempted to replicate his early successes. His initial review was delivered at a combined meeting of the New York Academy of Medicine and the New York Neurological Society in 1949. Of the 28 patients treated by resection of the somatosensory cortex, the results were ‘good’ in 19, ‘fair’ in 4, and ‘poor’ in 5 (Gutierrez-Mahoney, 1950). Unfortunately, despite continuing work on the review for over six years (Sweet and White, 1955), he never published his completed results. Attempts to locate it proved unsuccessful (including the archives of the New York Neurology Society, the New York Academy of Medicine, the former Harvey Cushing Society, the National Library of Medicine, and the Gutierrez-Mahoney papers at the Georg-August-Universität Göttingen).

Talairach (1959) reviewed the postcentral topectomy as part of a more comprehensive analysis of parietal involvement in pain sensation. He viewed the postcentral topectomy as a surgical technique based more upon experimental and empirical results than logical reasoning from a theory. This was partially because the literature had very few detailed surgical examples, and partially because patient outcomes were not often tracked for long periods, so evaluations of the long-term results of a surgery were recorded mostly by chance. He also noted that actually performing the surgery properly is quite difficult, as minimizing the damage to the pia mater limits how effectively the involved cortex can be excised. He was more complimentary when assessing the surgery’s results, judging based on 40 cases that the surgery fully succeeded in roughly half, with the caveat that many of the ‘failures’ in the other half still provided extended temporary relief, which should still be regarded as valuable to the patient.

The final review, Sweet and White’s 1969 section in *Pain and the Neurosurgeon*, diverged significantly from the others, and contributed significantly to the decline of the surgery’s use. Sweet and White assessed the procedure as having been successful in only 4 out of 23 cases of phantom pain, and deemed its side effects too risky, due to the chance of seizures produced by scarring of the excision site, and a single patient of the 38 they investigated dying four days after surgery. They recommended treating phantom pain patients by performing a tractotomy, and cutting into the medulla instead. For thalamic pain and postcordotomy dysesthesia, on the other hand, Sweet and White recommended a conservative frontal lobotomy instead, claiming the procedure didn’t risk “significant mental deterioration”.

While influential, this review had several problematic elements. The methodology used to get the statistic of ‘4 successes out of 23 cases’ for a phantom limb treatment was extremely misleading. They only counted successes from case reports that had a follow-up at least one year later, but they included all case reports in the denominator. If, for example, every case was last followed up on exactly 11 months later, and the patient was entirely free of pain at that time, this methodology would yield a rate of 0 successes out of 23 cases. Sweet and White also seem to have applied a binary success/failure criterion, where recurrence of any amount of pain was considered a failure; this included patients of Gutierrez-Mahoney and Lewin and Phillips who had mild pain which could be controlled with aspirin. In addition, they classified surgeries performed in a number of different locations in the cortex outside of the postcentral gyrus as ‘postcentral topectomies’.

Lenshoek is one of the authors included in Sweet and White (1969) phantom pain assessment. In an earlier 1955 paper, Sweet and White requested that pain surgeries be followed up on for longer durations. In response, Lenshoek published a ten-year follow-up to one of his pain surgeries in 1959, specifically mentioning Sweet and White’s request in his introduction. Ironically enough, Sweet and White appear to have missed this paper, as their 1969 review listed Lenshoek as having made ‘no late observations’, despite one of his patients remaining pain-free ten years after the surgery. Lenshoek is therefore inaccurately listed as having performed three surgeries with zero long-term successes. This number is especially misleading because, of the three, only the successful surgery had any excisions in the postcentral cortex, and even in that case Lenshoek ascribes the pain relief to one of the excisions he made in the secondary somatosensory cortex.

Another particularly odd element is the Robert S. case report. Robert S. was a patient suffering from intractable phantom pain in the thumb, index, and middle fingers of his right hand. He was treated by Sweet and Carmody on January 9th, 1946, through a postcentral topectomy. The success of this procedure was reported inconsistently. In Sweet’s 1947 article *Relief of Pain by Operations on Nervous System*, he described the outcome of the surgery, reporting that it lasted more than a year, a very promising result: “The patient has remained practically free of his pain for the fourteen months which have elapsed since operation”. In the 1955 *Pain: Its Mechanisms and Surgical Control*, Sweet stated “the disagreeable phantom disappeared, but only for a period of several months” (Sweet, 1955). Finally, in 1969, *Pain and The Neurosurgeon* listed Robert S. in Table CIII as having “recurred after 2 months” (Sweet and White 1969). This is a patient personally treated by Sweet, and should ideally be the most accurate data point he included.

There are a few other differences between the published papers and what Sweet and White report. Some of these are intentional; Sweet and White reference personal communications with other scientists as follow-ups, although they do not include any direct quotations and did not create a consolidated list of what additional information came from these secondhand sources. Their apparent criteria that any degree of pain returning in the postoperative period rendered the surgery a failure explains some of the other differences. However, even taking those into account, the reason why a few cases diverge is still unclear. One of Lewin and Phillip’s patients being listed as having recurred despite only needing aspirin to control his pain has been previously discussed; the other one, however, was reported by Lewin and Phillips as “completely relieved of his pre-operative pain”, but is listed as having recurred. One of Erickson’s patients is listed as being free of pain for three months, instead of until the time of death at five months; they also omit the ‘until time of death’ for one of Erickson’s other patients, despite recording that elsewhere in their chart. One of Horrax’s patients had both his arm and leg pain cured; the arm pain recurred at five months, but as of the last record he was free of leg pain at 14 months; Sweet and White record this as a recurrence at 14 months (this case was excluded from our analysis due to widespread preexisting brain damage).

One of the cases that made Sweet and White worry about the procedure’s safety, an attempt by Dimitri and Balado to treat chronic pain, which led to the death of the patient four days later, is also odd. This surgery actually ablated the inferior parietal lobule; despite the operation taking place outside the postcentral gyrus this case is still included in the analysis (David et al., 1947).

As Sweet and White’s review makes it difficult to assess the outcomes of the surgeries it references, the conclusions it draws are hard to justify. In several cases it appears to not just misrepresent the results of surgical procedures, but also what procedures were being performed. In light of this, Sweet and White’s pessimistic assessment of the Postcentral Topectomy does not appear to be justified.

Discussion

Effectiveness of Postcentral Topectomy

Our estimation of the postcentral topectomy's effectiveness is in line with Gutierrez-Mahoney's original review of the procedure (Gutierrez-Mahoney, 1950). Out of Mahoney's 28 patients, he declared 'good' results in 19, 'fair' in 4, and 'poor' in 5. In our analysis of 27 patients, we found success in 19, putative success (less than six months of tracking) in 3, and total failure or relapse in 5. While Gutierrez-Mahoney's exact category definitions are unknown, these numbers are very close, which is particularly significant since 16 of our 27 cases were published after his 1950 review[3]. Talairach's (1959) estimate, that the procedure was a complete success around 50% of the time, is lower than our 70% estimate, but is still quite attractive. Our analysis is the least consistent with Sweet and White's (1969) review. The discrepancy between these reviews appears to arise from differences in methodology; Sweet and White had a very strong bias towards discounting successful outcomes, and their process for gathering reports proved rather mistake-prone.

It is quite possible that the true success rate of the postcentral topectomy—as it was practiced in 1940s-1970s—was lower than what we found in the published reports. Although it appears likely the unpublished reports in the Gutierrez-Mahoney review had slightly better outcomes than the published ones, we cannot discount a possibility that failed attempts were underreported in the literature. Nevertheless, the reported successful outcomes are sufficiently numerous and reproducible to draw a conclusion that primary somatosensory cortex has a certain mechanism that can be successfully exploited in treating patients suffering from at least some forms of severe chronic pain. In view of a recent discovery of a nociresponsive region in Area 3a, this region becomes the prime suspect.

Nociresponsive Region in Area 3a

The nociresponsive region of Area 3a lies in a cytoarchitectonically distinct territory between Brodmann Area 4 of the primary motor cortex and Area 3a of the primary somatosensory cortex. This cortical region combines cytoarchitectonic features of both Area 4 and Area 3a and its connectional and functional properties differ significantly from both adjacent areas (Whitsel et al., 2019). It probably should be recognized as a separate cortical area; to emphasize its distinctiveness, we will refer to it here as Area 3c. Unlike Area 3a proper (Krubitzer et al., 2004), this region is not activated by proprioceptive inputs, but it responds very well to noxious stimulation, such as noxious skin heating or intradermal algogen injection. The response properties of its neurons correspond closely to the slow, 2nd/burning pain sensation mediated by unmyelinated C-nociceptor afferents. This nociceptive input to Area 3c comes from lamina I of the spinal cord dorsal horn (Craig, 1995, 2014; Dum et al., 2009), which in turn receives its main peripheral input from small-diameter afferents associated with the sensations of cooling, warmth, itch, affective touch, muscle ache, fatigue, skin and internal organ pain (Craig, 2003, 2015; Craig et al., 2001; Craig and Andrew, 2002; Craig and Blomqvist, 2002). As Favorov et al. (2019) suggest, Area 3c might be primarily engaged in autonomic aspects of nociception.

Whitsel and colleagues (Whitsel et al., 2009, 2019) have described an Area 3c-based mechanism that might underlie the reported cases of successful postcentral topectomy. The sensorimotor cortex exerts prominent descending control over the spinal cord, with somatosensory cortex, in particular, targeting sensory functions performed by the dorsal horn of the spinal cord. The available experimental evidence (see summarized in Whitsel et al., 2019) suggests that Area 3c might be special in this regard, exerting positive rather than negative modulatory influences over nociceptive neurons in the superficial dorsal horn; i.e., the same neurons that provide the afferent input to Area 3c. Such an arrangement would create a positive-feedback closed-loop circuit between nociresponsive neurons in Area 3c and those in Lamina I of the spinal cord (Figure 3).

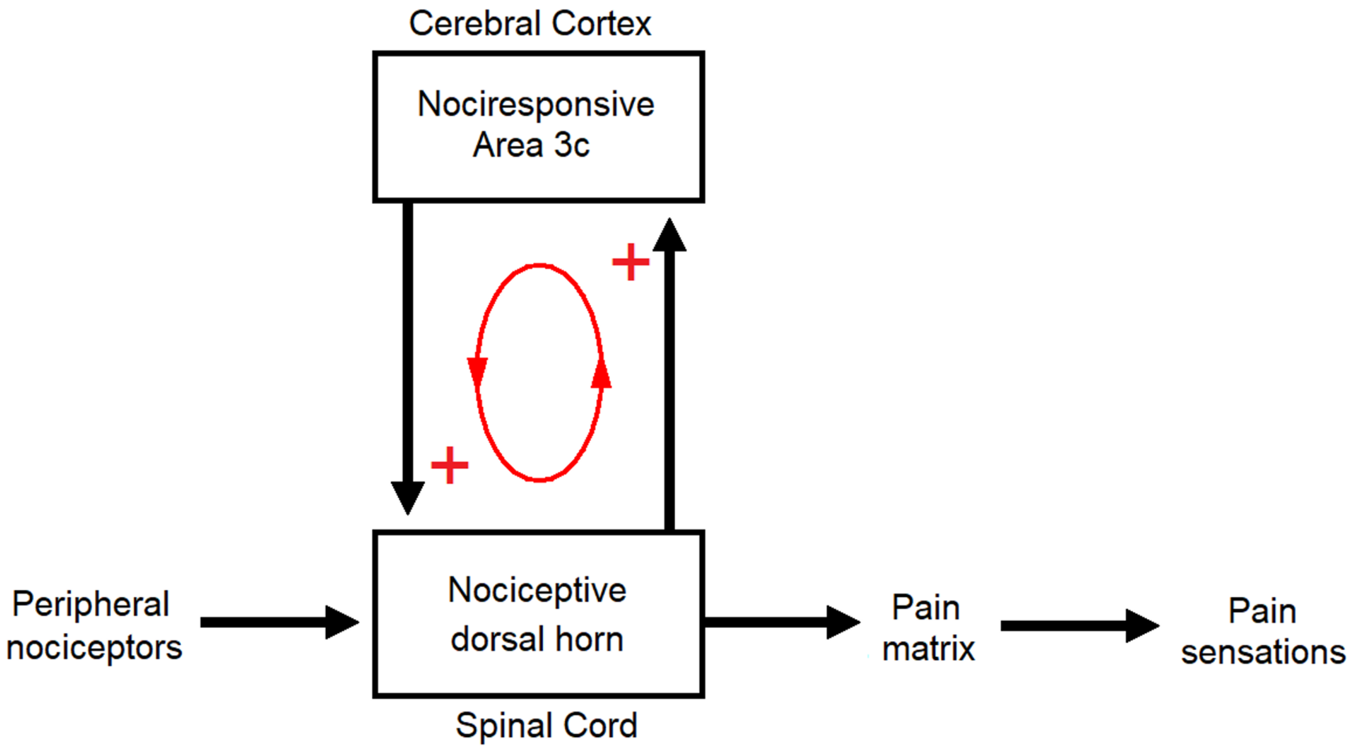

Figure 3. *Hypothesized positive-feedback closed-loop circuit linking spinothalamic nociceptive neurons residing in Lamina I of the dorsal horn with nociresponsive neurons residing in cortical Area 3c. By cycling spike discharge activity repeatedly between these two sets of neurons, this circuit may serve to amplify nociceptive inputs reaching the dorsal horn from nociceptor afferents in the body, scaling them adaptively to fit ongoing behavioral needs of the individual. Thus amplified nociceptor-evoked activity is propagated from the dorsal horn to all the other cortical and subcortical regions of the pain matrix that together generate slow/burning pain experiences.*

Such a circuit can be expected to cycle spikes repeatedly up and down between nociresponsive neurons in the dorsal horn and Area 3c, gradually building up activity in the entire circuit through such reverberations. Whitsel et al. (2009, 2019) propose that the function of this positive-feedback closed-loop circuit centered on Area 3c is to act as a cortical “pain booster” —to amplify noxious inputs reaching the dorsal horn from C-nociceptor afferents in the body. According to this proposal, in order for C-nociceptor afferents to effectively engage cortical areas involved in pain perception—such as insula, anterior cingulate, and frontal cortex—their raw activity has to be boosted in the dorsal horn by reverberating it through Area 3c. Through such long-distance boosting of noxious inputs to the dorsal horn, Area 3c can exercise flexible cerebral control over nociceptive information transmission in the dorsal horn, tailoring C-nocisensitivity to the ongoing situation so as to optimally balance the behavioral priorities of the individual and the vegetative needs of the body. On the other hand, such a control might become maladaptive under some extreme or pathological conditions, contributing importantly to various pain pathologies (Vierck et al., 2013; Whitsel et al., 2019).

Maximizing Effectiveness of Postcentral Topectomy

The varied reported outcomes of the postcentral topectomy are consistent with the hypothesis that its effect depends on how it impacts Area 3c. According to this interpretation, when ablations extended deep into the central sulcus and removed Area 3c, the targeted chronic pain was permanently abolished, whereas when ablations were shallow and removed only cortical tissues at the crown of the postcentral gyrus, sparing Area 3c, the loss of pain was at most transient, until Area 3c recovered from indirectly induced trauma (Vierck et al., 2013; Whitsel et al., 2019).

Based on these considerations and modern advances in medical technology, postcentral topectomy procedure can be greatly improved and made highly attractive for treating at least some forms of pathological pain. Specifically, location of Area 3c in the depth of the central sulcus of each patient can be precisely determined using functional magnetic resonance imaging, thus making it possible to target and ablate—or otherwise inactivate—the right Area 3c region engaged in boosting the patient's pathological pain. Ablations themselves can be more confined and less invasive. Currently, radiosurgery (as with a Gamma Knife) is the most precise method of noninvasively ablating arbitrary regions in the brain. While radiosurgery does not offer the same flexibility in effect types as other noninvasive methods, it is a mature and reliable technology with clinical accuracy averaging as small as 0.15 millimeters (Wright, 2017). Stereotactic radiosurgery is currently used as a noninvasive procedure to treat trigeminal nerve pain, selectively ablating in the trigeminal root entry zone (Régis, 2015). The largest drawback of radiosurgery is that the patient cannot actively give feedback about the subjective effects of stimulation or inactivation of the targeted brain region, and the effects of the gamma knife only appear gradually over the course of weeks or months, and may not be immediately noticeable post-surgery.

The most promising emerging noninvasive neurosurgical tool is transcranial MR-guided focused ultrasound (MRgFUS). MRgFUS can be tuned to have different effects on the targeted region; the ultrasound waves are capable of not only causing permanent ablations, but also temporarily exciting or inhibiting a region without inflicting damage (Legon et al., 2014; Lee et al., 2015; Dallapiazza, 2018). As ultrasound can be delivered using nonmagnetic methods, MR guidance and thermometry can be used continuously throughout the procedure. While the technology is still being developed, and the area of effect is generally a thin cylinder perpendicular to the brain's surface, current models have already obtained submillimeter precision in thalamic lesions (Moser et al., 2013). It has already been used in the thalamus to treat patients with neuropathic pain (Jeanmonod, 2012), essential tremor, and Parkinson's (Iacopino et al., 2018). Using MRgFUS as a method of transiently or permanently inactivating Area 3c is a very appealing prospect, as it could significantly reduce the risks inherent in lesioning, and incorporate ongoing patient feedback about perceptual changes and pain suppression, in order to precisely locate the target cortical region.

The technological advancements that enable this precise targeting of Area 3c are particularly timely. The opioid crisis has resulted in a massive increase in deaths from painkiller overdoses, and non-opioid alternatives for intractable chronic pain are urgently needed.

Footnotes

[1]Horrax's third patient has been excluded from the main statistical analysis due to widespread brain damage. This patient previously suffered from a glial tumor in the temporal lobe that damaged the basal ganglia and internal capsule. After its removal, he began experiencing pain in his right hand, arm, foot, and leg. Horrax mapped the motor cortex for the arm and leg and removed a large section of the postcentral cortex posterior to it. At five months, pain returned to the arm and hand, however as of fourteen months, there had been no chronic pain in the leg and foot, and the hand and arm were entirely anesthetic to external pain.

[2]The same paper includes a third successful (4 years) case report not included in the overall analysis. The surgery removed abnormal postcentral cortex to prevent painful epileptic fits - the epilepsy is a complication which makes this case insufficiently unambiguous to include as an example.

[3]Notably, of the 11 cases which occurred before 1950 and could overlap between our review and Gutierrez-Mahoney's, there were 3 failures and 1 putative success in our sample (with a lasting

success rate of 64%). If Gutierrez-Mahoney included all published results in his review, and used similar criteria, this breakdown implies that the 17 unpublished results he had access to included only 2 failures and 3 ‘fair’ results (with a lasting success rate of 71%). This provides some evidence that there was not a strong publication bias for success or failure.

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