sure response. A few widely separated muscle slips would require even less tension in each.

The evidence presented suggests that the evoked intraocular pressure response is produced by contraction of the orbital smooth muscle of Müller. This muscle contraction appears to be $\alpha$-adrenergically mediated through the sympathetic nervous system which, in turn, is activated during a general arousal response to a sensory stimulus.

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## Temporary Abolition of Pain in Man

Abstract. *In eight patients with intense chronic cutaneous pain, sensory nerves or roots supplying the painful area were stimulated. Square-wave 0.1-millisecond pulses at 100 cycles per second were applied, and the voltage was raised until the patient reported tingling in the area. During this stimulation, pressure on previously sensitive areas failed to evoke pain. Four patients, who had diseases of their peripheral nerves, experienced relief of their pain for more than half an hour after stimulation for 2 minutes.*

One of the predictions of the "gate control" theory of pain is that stimulation of large diameter cutaneous afferent nerve fibers might reduce pain (*1*). The prediction was based on the observation, made in cats, that volleys of impulses in afferents set off a depolarization of terminal arborizations of cutaneous fibers (*2*). This presynaptic depolarization is believed to be the result of activity in the small cells of substantia gelatinosa (*3*). Presynaptic depolarization reduces the excitatory effectiveness of afferent impulses on cells in the dorsal horn (*4*). Eight patients with severe cutaneous pain were stimulated and the results were divided into two groups. In one group (patients No. 1 through 4) the effects lasted more than 30 minutes after 2 minutes of stimulation. In group two (patients No. 5 through 8) the effects lasted from a few seconds to a few minutes after the stimulus ended. The type of stimulation used (0.1-msec square-waves at 100 cycle/sec) was tested on ourselves before it was used in the experiment. Needle electrodes insulated except for the tip were applied to our infraorbital nerves; a tingling or buzzing sensation was evoked near threshold in the sensory region of the nerve. It was not unpleasant and always tolerable for an indefinite period. During stimulation and for a few minutes thereafter, pin prick in the tingling area did not feel sharp to either of us. In all eight patients, the sensations produced by stimulation were not painful and were acceptable for an indefinitely long time.

Patient No. 1 was a 26-year-old female suffering from the consequences of a fractured elbow; she experienced a burning and stabbing pain and extreme tenderness in the skin area supplied by the ulnar and median nerves. The disease became progressively worse over a period of 2½ years and had been treated by transplantation of the ulnar nerve and by severance of the dorsal roots C7 through T2. The medial side of her arm and hand lost feeling, but she reported a steady burning pain in the anesthetic region of the hand and extreme tenderness of the middle finger and the mid-palm. Silastic split-ring platinum electrodes were implanted around the median nerve above the elbow with the leads being run through the skin of the antero-medial forearm. Threshold stimulation of the median nerve at 100 cycle/sec with 0.1-msec square-waves induced a sensation of tingling and buzzing in the lateral palm, thumb, and first and second fingers. During the stimulation, pressure on the tender areas failed to cause any discomfort to the patient. For a period of more than half an hour after the stimulation, the patient reported that the hand felt numb and free of pain, and it could be moved freely. Light pressure on the previously tender areas was reported by the patient as touch.

Patient No. 2 was a 40-year-old man who had been shot 2 months prior to the study. The .32-caliber bullet had entered behind the right shoulder and emerged above the medial end of the left clavicle. There were no immediate neurological signs but, after 3 days, severe burning pain developed in the third and fourth fingers of the right hand. The patient said that the pain felt as though a blowtorch was being passed over his fingers. Lancinating pains radiated proximally from the fingers. The brachial plexus was explored and the sympathetics were blocked without effect. A 20-gauge concentric bipolar stimulating hypodermic needle was placed close to the ulnar nerve in the wrist. Electrical stimulation of the type used in patient No. 1 produced tingling in the medial side of the hand and in the third and fourth fingers. The results during 2 minutes of stimulation and for more than half an hour after stimulation were the same as in patient No. 1.

Patient No. 3 was a 50-year-old man with severe burning and stabbing pain of unknown origin in the area supplied by the ulnar nerve. The pain had been treated unsuccessfully for 3 years by removal of the C6 disc, exploration of the ulnar nerve at the wrist and elbow, exploration of the brachial plexus, and partial section of the dorsal roots C7 through T2. Stimulation of the ulnar nerve at the wrist through electrodes on the skin surface produced a buzzing and tingling sensation in the medial side of the hand and in the third and fourth fingers; the general results were the same as in the previous patients.

Patient No. 4 was a 55-year-old woman who had severe burning and stabbing pain in her right big toe and in the medial arch of her foot. The pain had lasted for 6 months and was accompanied by tenderness on the back of the leg and wasting of the calf. The diagnosis was diabetic neuropathy. Surface stimulation of the saphenous nerve with the standard intensities and frequencies produced a tingling sensation in the middle of the leg down to the ankle, but the stimulation had no effect on the pain. Surface stimulation of the superficial peroneal produced what the patient termed "an electric feeling" in the toes and in the top of the foot. After 2 minutes of stimula-

tion, she said that her toes felt heavy, numb, and free of pain, but that the burning pain persisted in the medial arch of the foot. Next we stimulated the medial plantar nerve with surface electrodes placed behind the medial malleolus in the order to produce a feeling of buzzing in the medial arch of the foot. The numbness, heaviness, and lack of pain in the whole foot persisted for more than half an hour.

Patient No. 5 was a 52-year-old woman who had metastatic pelvic carcinoma accompanied by burning and and knife-like pains in the sole of one foot and spreading up the back of the leg. An area on the Achilles tendon was particularly sensitive. A lumbar puncture needle was inserted into the spinal suborachnoid space between vertebrae L3 and 4 so that a phenol block could be produced later. A single insulated 22-gauge stainless-steel wire was pushed through the needle, and a stimulating current with the standard intensities and frequencies was passed from the tip of the wire to a large indifferent plate on the skin. The patient reported a dermatomal radiating band of paresthesia extending down the leg. If the area of the tingling sensation did not coincide with the painful region, then the stimulation had no effect on the spontaneous or evoked pain. If the patient was rotated about her longitudinal axis, the tingling regions shifted. When this region coincided with the painful region, the subjective pain disappeared, as did the sharp withdrawal evoked by gentle pressure on the Achilles tendon. The stimulus was removed after 10 minutes, and after 5 to 10 minutes the pain returned to its previous level. Similar results were obtained in patient No. 6, a 36-year-old woman, and patient No. 7, a 71-year-old man, both of whom had metastatic carcinoma producing pain in one leg.

Patient No. 7, a pharmacist, observed that "The buzzing is masking the pain." Patient No. 8, a 62-year-old man, had trigeminal neuralgia; the region of the hard palate behind the upper left incisors was particularly sensitive. Stimulation of the infraorbital nerve at the infraorbital foramen by a pair of wires in a 22-gauge hypodermic needle with the standard intensities and frequencies produced paresthesia in the left upper lip and gums. During the 5-minute stimulation and for 17 minutes thereafter, it was not possible to evoke the usual stabs of pain by lightly brushing the sensitive area of the hard palate. In three other patients, the test was inconclusive because we could not stimulate the relevant peripheral nerve or root so that regions of pain and induced paresthesia could be superimposed. Finally, in two patients who referred their pain to deep structures rather than to the skin, stimulation of the relevant peripheral nerves failed to alleviate their pain.

Certain patients report or exaggerate pains for psychiatric or social reasons. Patients No. 1, 3 and 4 were examined by psychiatrists who confirmed the organic nature of the disease. The pain of patients No. 5 through 8 was abolished by routine therapy after our tests; it is therefore unlikely that their pain was psychosomatic. Pain is notoriously subject to suggestion, but all patients except No. 7 and 8 had little or no knowledge of science. All patients had a chronic pain of predictable pattern, and all had received considerable attention, encouragement, and therapy, but without effect. We avoided any mention that the test would affect their pain. In patient No. 2, we intentionally suggested that his pain should not disappear, but he insisted that he was free of pain. These results should not be attributed to distraction since stimulation of neighboring nerves or roots did not have any effect.

Thus stimulation of fibers, causing a mild tingling sensation, interferes with the perception of pain accompanying certain diseases. The stimuli used produced impulses only in large diameter fibers since these have the lowest electrical threshold. Only the largest diameter fibers were stimulated in mixed nerves, as evidenced by the fact that the patient reported the sensation when the stimulus produced little or no motor movement. The gate control theory suggests a reason why these fibers should have the observed effect. There was a striking difference in the duration of the effect after stimulation was discontinued. Patients No. 1 through 4 can be presumed to have had diseases of the peripheral axons. It has been suggested (*1*) that pain in such cases is a consequence of the inability of the diminished number of large axons to close the gate. Once the gate is closed by an artificially generated heavy barrage of nerve impulses in the remaining large axons, the low level spontaneous activity in the smaller axons takes time to reopen the gate. This may explain the prolonged effect of the stimulus on the pain. By contrast, in cases 5 through 7, we can assume that the patients' peripheral axons were intact. The stimulus closed the gate by an unusually heavy barrage of nerve impulses in the large axons but, when the stimulus was removed, the peripheral disease was still producing an intense afferent barrage which rapidly reopened the gate. These results are of interest for a theory of pain, but the therapeutic implications are at present equivocal because two of the first group of patients, who were stimulated many times per day, reported a decreased effect on their pain after several months.

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