GASTRO-INTESTINAL, vasomotor, and other visceral disturbances secondary to focal brain lesions are phenomena of obvious importance not only to the neurosurgeon, neurologist and psychiatrist but also to the general surgeon, genito-urinary specialist, pediatrician and obstetrician.

Birth trauma, for example, may produce injuries of the hippocampal gyri\(^2\) leading subsequently to visceral disturbances associated with psychomotor attacks.\(^9,19,30,72\) Paroxysmal abdominal pain and intussusception may be manifestations of epilepsy in children\(^2\) and adults. Laparotomies have occasionally been done for gastro-intestinal symptoms, cystoscopic studies for difficulties in voiding, and electric shock treatments for viscero-emotional disturbances although the initial visceral symptoms in all these cases might have led to an earlier diagnosis of an organic cerebral lesion.

With regard to the frequent association of visceral and emotional disturbances, it is of interest to note that this important phenomenon has long been recognized, as indicated by the Lamentations of Jeremiah (Chapter I) in the old Testament: “... mine eye runneth down with water... I am in distress: my bowels are troubled... my sighs are many, and my heart is faint.”

The viscera, strictly speaking, include only the soft hollow organs of the body such as the heart, blood vessels, gut, urinary bladder and lacrimal sac. For the purposes of this discussion, however, mention will also be made of respiratory phenomena. Both visceral and respiratory disturbances will therefore be considered with regard to their representation in the cerebral cortex as indicated by focal brain lesions or electrical stimulation. Visceral phenomena secondary to massive intracranial lesions or generalized increased intracranial pressure will not be considered, having no localizing value.

While it has long been known that visceral symptoms such as pallor, salivation and epigastric distress may herald or accompany an epileptic seizure, these symptoms cannot be regarded as having any localizing value unless a focal brain lesion is proved to be their cause. With increasing frequency in recent years, however, it has been shown that specific visceral phenomena of this and other kinds are often caused by focal lesions involving certain parts of the frontal or temporal cortex or the insula (island of Reil). Reasonably accurate localization of cerebral pathology in such cases has

* Read at the annual meeting of the Harvey Cushing Society, Hollywood, Florida, April 23, 1938
been made by pneumoencephalography or ventriculography, surface and depth electroencephalography, angiography and intracranial surgery for verification by inspection, electrical studies and biopsy.

In the last analysis, however, methods of localizing function in the human brain are relatively crude, for the precise extent and effects of a brain tumor, scar or cortical ablation upon adjacent brain tissue are difficult to define. Likewise the exact extent of spontaneous or artificially induced abnormalities in electrical activity may be equally difficult to determine. Nonetheless, when brain lesions or electrical excitation of specific parts of the brain result consistently in similar effects, there is ground for accepting a localization of function. This is particularly true of brain tumors that give rise to specific visceral symptomatology long before any other symptoms occur, especially when these visceral disturbances disappear following removal of the lesion.

Electrical stimulation of the brain is unquestionably a more nearly accurate means of localizing function in the sense that it is usually possible to elicit constant and consistent effects from relatively discrete points, whereas no effect or a different effect may be produced by stimulation only 2 mm away. The fact that electrical stimulation may not yield an expected visceral response on excitation of a given cortical area may be caused by such influences as medication, anesthetic agents, metabolic or pathologic changes, existing background activity of the brain or viscera, or individual anatomical variations.

Despite these factors of inconstancy and uncertainty it is apparent that the effects of various lesions as well as electrical stimulation of the human brain indicate more or less discrete localization of visceral functions in the cerebral cortex.

Before assembling these data in diagrammatic form (Figs. 1–5) a few illustrative case summaries of brain lesions, including cortical ablations, will be presented with emphasis on visceral symptomatology. Observations on the effects of electrical stimulation and recording will then be described.

Additional data reported by others have been included in Figs. 1, 2, 3 and 5. Penfield, et al.,71,73,74 for example, have provided ample evidence that neoplastic or atrophic lesions of anteromedial temporal cortex and the insula may give rise to episodic vasomotor disturbances, such as pallor or tachycardia, and distressing epigastric sensations. Epigastric aura may also be secondary to “frontal intermediate” lesions.75 Others89,65 have confirmed the temporal and insular source of epigastric sensations.

Bucy,14 moreover, has described alteration of the peripheral circulation in the contralateral extremities following premotor cortical ablation, and also mentioned sudomotor changes secondary to lesions in this region. Scoville has reported transitory alterations in pulse rate on isolating the anterior cingulate gyri bilaterally,88,89 and vomiting in several cases after uncotony.89
THE VISCERAL BRAIN OF MAN

CASE SUMMARIES

I. BRAIN LESIONS


Case 1. Mc.C., 28-year-old machine inspector. His employment was threatened because of weekly attacks of sudden partial loss of contact with environment lasting a few seconds, always preceded by a sense of profound gastric distress and a feeling that someone was talking behind him.

Past History. Nine months gestation; 4 hours labor; instrument delivery without known abnormal effects. Head injury at 15 months with unconsciousness for 24 hours. At 4 years of age he began to suffer sudden attacks of ashy pallor, abdominal pain and nausea lasting a few seconds, and occasionally vomited. At 7 years: occasionally unconscious for 2 or 3 minutes and "stiff" in face and extremities after aura described above. He might then be drowsy for 1 or 2 hours. He also had unexplained "mucous colitis" for 3 months.

At age 29 (May 1952) the EEG showed a right anterior temporal focus on a sleep record. Previous waking EEG studies showed no focal signs but some abnormal bilateral medium voltage slow wave activity. A thorough 12-year trial of various anticonvulsant medications having failed to arrest attacks, surgery was elected.

Operation, May 1952. Right temporal craniotomy. Pentothal sodium anesthesia. The cerebral cortex appeared grossly normal but ECG indicated abnormal activity confined to the anterior thirds of the middle and inferior temporal gyri. This cortex was accordingly excised down to and including the uncus.

Pathology. Microscopic study revealed moderate gliosis, no tumor, and numerous monocytic phagocytes filled with yellow pigment clustered about the blood vessels, compatible with a long-standing, post-traumatic atrophic process.

Postoperative Course to April 1953. No further attacks, epigastric aura or "colitis." No personality changes. The patient is extremely pleased with operative results, and is fully employed at his former job.

2. Bilateral Subfrontal Tumor: Constipation 6 months.

Case 2. J.S., 49-year-old executive. Initial symptom was marked constipation for 4 months, for the first time in his adult life, without change in diet or fluid intake. This was followed by visual impairment for 2 months, and later by papilledema and headaches without focal signs. He had previously had unusually regular bowel habits. Constipation continued for the whole 6 months preceding surgery.

Operation. Ventriculogram and right frontal craniotomy revealed a low bilateral subfrontal invasive tumor. It was soft and necrotic and not accompanied by marked increase of intracranial pressure. A generous bilateral subtotal removal of tumor (angioneurotic glioblastoma) was done.

Postoperative Course. X-ray therapy was given. Vision improved and no further constipation occurred. A year after operation the patient was promoted to a more important executive post. No personality or mental changes have been observed by friends or family during the 3½ years since operation.

3. Superior Frontal Convexity Tumor: Urinary retention after progressive difficulty in voiding of 6 years' duration.

Case 3. J.W., a 50-year-old executive, had suffered progressive difficulty in void-
ing for 6 years. For more than a year prior to admission he had to sit on the toilet for 20 to 30 minutes in order to strain hard enough to empty his bladder. Repeated cystometric and cystoscopic studies by a number of G.U. specialists failed to disclose the cause of his difficulty. He finally became depressed, for which electroshock therapy was administered. Following this, signs of increased intracranial pressure developed without definite localizing signs.

Operation. Ventriculogram and right frontal craniotomy disclosed a convexity meningioma, 3.5 cm. in diameter, close to the falx cerebri. The posterior margin of the tumor lay beneath the coronal suture.

Course. Following total removal of the mass in 1948 there has been no further difficulty in voiding.

4. Frontoparietal Parasagittal Tumor: Urinary frequency and abdominal pressure sensations for 2 weeks.

Case 4. M.R., a 50-year-old right-handed male, was admitted on Oct. 10, 1949. Three months previously he had experienced fleeting weakness and a hot sensation in the left leg. During the following 2 weeks, when he had no further symptoms in the leg, he noted marked frequency of urination, nocturia, and a sense of pressure in the lower abdomen even though the bladder was empty. As these symptoms disappeared he began to suffer focal seizures starting in the left big toe, and later the left leg became weak.

Operation. On Oct. 28, 1949 a glioblastoma multiforme was found in the right sensorimotor cortex and paracentral lobule.

Course. There were no personality changes.

5. Deep Temporal Lobe Pathology (type unknown): Colon spasm with partial obstruction of colon; cecostomy and laparotomy.

Case 5. D.B., a 45-year-old male, was admitted to a general surgical service because of cramping abdominal pain, abdominal distension, vomiting and signs of partial intestinal obstruction. Barium enema revealed marked spasm and partial obstruction of the sigmoid colon, for which cecostomy was done. Three days later exploratory laparotomy disclosed no tumor or inflammatory process but did reveal marked spasm of the entire colon. Two days later a generalized convulsion occurred.

A neurological consultant was called who found a right homonymous hemianopsia, dysphasia, and right-sided hyperreflexia, but no papilledema. EEG showed a left temporal focus of abnormal activity. Angiography suggested the presence of a low parietal or temporal lobe mass.

Operation. Craniotomy failed to disclose any evidence of gross pathology or increased pressure.

Course. Despite supportive measures the patient became progressively drowsy and died 18 days later.

Autopsy disclosed no evidence of tumor, vascular pathology or inflammatory process in the brain, brain stem, gastro-intestinal tract or elsewhere. Cultures of the cerebrospinal fluid for torula and other organisms were negative.

Comment. While the cause of death in Case 5 thus far remains obscure (additional sections of the brain are in preparation), the visual field defect, other neurological findings and EEG indicated a deep temporal lobe dis-
turbance on the left. Careful consideration of this case strongly suggests a central origin for the spasm of the colon, although proof as yet is lacking.

6. Tumor of Insula and Adjacent Temporofrontal Cortex: Alternating diarrhea and constipation 3 months.

Case 6. K.W., a 47-year-old male, suffered alternating diarrhea and constipation for 3 months prior to the onset of headaches, nausea and vomiting. The latter symptoms, which began 3 weeks before admission, were associated with personality changes in the direction of uncooperative behavior. Clinical studies led to a diagnosis of right temporal lobe tumor.

Operation confirmed the presence of tumor. An internal decompression was done.

Course. There was only temporary relief of pressure symptoms and the patient expired 10 days after operation.

Autopsy showed that a glioblastoma multiforme had invaded the insula and adjacent temporal and subfrontal cortex.

II. CORTICAL ABLATIONS

1. Frontal Lobe: Fecal incontinence upon unilateral ablation of Area 6 (local anesthesia).

Case 7. D.S., a 32-year-old right-handed woman was operated upon under local novocain anesthesia at a city hospital in 1941, at a time when excision of Area 6 of Brodmann was often done for the relief of Parkinsonian rigidity and tremor. She suffered from marked rigidity and tremor, mostly of the left extremities, as the result of encephalitis.

Operation. Right frontal craniotomy revealed a somewhat atrophic-looking brain. The motor cortex for arm, hand and leg was outlined by electrical stimulation, and it should be emphasized that at no time during the entire operative procedure did the patient lose consciousness or contact with the environment. Indeed, she was unusually alert and cooperative throughout the operation.

The central and precentral fissures having been identified, a block of cortex approximately 2.5 cm. in the anteroposterior plane, 3.0 cm. in the dorsoventral plane, and 2.0 cm. in depth was outlined for resection. Silver clips rather than the electrocautery were used for hemostasis. The proposed margins of the excision began 3 mm. anterior to the precentral fissure, and extended almost to the falx. With a No. 11 scalpel the anterior margin of the cortical excision was first incised, and then the ventral margin. As the posterior margin was completed the patient suddenly exclaimed: "Oh, doctor, my bowels are moving, my bowels are moving and I'm trying to stop them but I can't. I'm terribly sorry—I apologize, but I just can't help it." A large stool was evacuated at this juncture.

Course. Following operation she was never incontinent of either urine or feces. The left extremities were temporarily weak, though never paralyzed. Improvement in rigidity was only transitory.

2. Bilateral Anteromedial Temporal Lobectomy: Abnormal oral or "feeding" behavior.

Case 8. A middle-aged chronically psychotic female was admitted to a psychi-
J. LAWRENCE POOL

atrie hospital for alleviation of extremely assaultive, unpredictable behavior that made her a taxing problem in ward management. She was childishly simple in general attitude and responses. Psychotherapy and electric shock treatment had been tried without success. The diagnosis was hebephrenic schizophrenia.

Psychosurgery was advocated by the psychiatric staff as a last resort. It was felt that even a radical prefrontal lobotomy would not alleviate her assaultive behavior except at the cost of creating an incontinent and thus equally unmanageable patient. Bilateral anteromedial temporal lobectomy was therefore suggested on the basis of laboratory data showing that such an operation in primates converted ferocious animals into tame and tractable beasts, provided the uncus was bilaterally removed.

The operation might also distort feeding habits to the extent that almost any available object might be seized, placed in the mouth, and chewed or swallowed, regard-

less of whether or not it was edible. With regard to the psychotic case under discussion, it was felt that if such a lack of discrimination and forced oral examination occurred, these disturbances would probably be transitory.

Operation was carried out in two stages, the 1st stage, on the right, in December 1952, and the second 8 weeks later. On each side the anterior portions of the 2nd and 3rd temporal gyri were removed as far posteriorly as the vein of Labbé. Each resection included the anterior temporal pole, the uncus and the adjacent part of the hippocampal gyri.

Course. Following the 1st operation there was no apparent change in the patient’s behavior, habits, speech, or attitude. After the 2nd procedure she was at first extremely negativistic, refusing food, fluids and attention, and not speaking save for an occasional solitary word like “cigarette.” In about 2 weeks she began to walk about and eat and talk, but seemed confused. When handed a cigarette during the ensuing month she sometimes lit and smoked it, but on occasions put it in her mouth and chewed it up.
She has gradually become less confused and less subject to abnormal oral intake, and has thus far remained docile instead of assaultive. She has never been incontinent of urine or feces, nor subject to vomiting.

Comment. The temporary postoperative oral reactions, and the lack of incontinence seem strikingly different from the usual effects of bifrontal lobotomy.

3. Bilateral Fractional Ablations of Frontal Cortex. In 1947 an extensive study was conducted by the Columbia-Greystone group\(^1\) on the effects of symmetrical bifrontal cortical ablations from different sectors of the frontal lobes in 24 psychotic patients. It should be stressed that visceral disturbances following these operations were temporary, lasting 1 to 21 days (Table 1 and Fig. 2).

![Diagram of the brain showing various regions for visceral effects and their corresponding functions.]

**Fig. 2.** Visceral effects, usually transitory, following symmetrical bilateral ablation of cerebral cortex at sites indicated. In Case 7 of the series herein reported the resection was unilateral.

For the sake of brevity, ablations are described as to their approximate location in terms of Brodmann’s cytoarchitectonic chart.\(^2\) Table 1 summarizes certain groups of patients, such as all those having had removal of a significant part of area 6, under one heading (e.g., urinary incontinence). It should be added that all ablations involving the superior frontal gyri (SFG) or any part thereof also included resection of its medial aspect.

### III. ELECTRICAL STIMULATION

Electrical studies were carried out during the course of brain surgery for the relief of mental illness because it was believed that any information so derived might ultimately prove of benefit to that particular patient, as well as to others. At the time these studies were commenced, moreover, relatively little information was available regarding functions of the anterior cingulate cortex and related structures in man. Papez had pointed the way...
Temporary visceral disturbances following bilateral symmetrical ablations of frontal cortex*

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Site of Cortical Ablation (Brodmann's Areas)</th>
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<tbody>
<tr>
<td>Salivation</td>
<td>Immediate Postoperative Period</td>
</tr>
<tr>
<td></td>
<td>Area 44 (both cases)</td>
</tr>
<tr>
<td>Vomiting</td>
<td>Area 44</td>
</tr>
<tr>
<td></td>
<td>Areas 8, 9</td>
</tr>
<tr>
<td></td>
<td>Area 24 (fecal vomiting)</td>
</tr>
<tr>
<td>Intestinal motility (increased)</td>
<td>Immediate Postoperative Period</td>
</tr>
<tr>
<td></td>
<td>Area 44 (bloody diarrhea 1 case, several days)</td>
</tr>
<tr>
<td></td>
<td>Area 11 (1 of 2 cases, diarrhea 1 day)</td>
</tr>
<tr>
<td>Vasomotor (peripheral circulation improved)</td>
<td>Area 24 (for approx. 2 weeks)</td>
</tr>
<tr>
<td>Urinary incontinence</td>
<td>Area 6 (all area 6 cases)</td>
</tr>
<tr>
<td>Urinary retention</td>
<td>Area 8-9 (1 case this series, 3 cases other series;</td>
</tr>
<tr>
<td></td>
<td>for 3-14 days)</td>
</tr>
<tr>
<td>Gastric motility (faster emptying time)</td>
<td>Later Postoperative Period</td>
</tr>
<tr>
<td>(slower emptying time)</td>
<td>Area 6, 8 (also after prefrontal lobotomies)</td>
</tr>
<tr>
<td>Gastric acidity (HCl)</td>
<td>Area 24</td>
</tr>
<tr>
<td>Gastric acidity (free acid decreased)</td>
<td>No consistent findings</td>
</tr>
<tr>
<td></td>
<td>Area 9</td>
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</tbody>
</table>


To this type of study in 1937, and subsequent laboratory data had lent support to his theory that the anterior cingulate and medial temporal cortex were especially important components of a neural system that participated in the regulations of emotions. Additional laboratory data indicated that these parts of the brain may have a considerable effect on visceral and autonomic functions also. With a view to improving psychosurgical procedures it therefore seemed important to find out whether corresponding regions of the human brain reacted in a similar way.

Source of Data. Visceral or respiratory responses to electrical stimulation of the human cerebral cortex have been obtained in more than 100 cases by the writer and his colleagues. Most of these were cases of non-epileptic psychotic patients; 2 were examples of psychomotor epilepsy, while in 1 case (malignant brain tumor) the subtentorial cerebellar cortex was exposed and stimulated (Table 2) after occipital lobectomy.

Data have also been accumulated from other sources. Penfield et al., for example, working mostly with epileptics or patients with brain tumor.
### TABLE 2

<table>
<thead>
<tr>
<th>No. of Cases</th>
<th>Site of Stimulation</th>
<th>Type of Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Anterior cingulate&lt;sup&gt;31&lt;/sup&gt;</td>
<td>↑</td>
</tr>
<tr>
<td>75&lt;sup&gt;*&lt;/sup&gt; (±8 more)</td>
<td>Anterior cingulate&lt;sup&gt;32&lt;/sup&gt;</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Posterior orbital</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Anterior temporal</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Uncus&lt;sup&gt;38&lt;/sup&gt;</td>
<td>↑</td>
</tr>
<tr>
<td>3</td>
<td>Hippocampus (intraventricular)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Lateral mid-temporal†</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Paracentral lobule&lt;sup&gt;25&lt;/sup&gt;</td>
<td>♯↑</td>
</tr>
<tr>
<td>1</td>
<td>Cerebellum (subtentorial)&lt;sup&gt;77&lt;/sup&gt;</td>
<td>♯</td>
</tr>
<tr>
<td>106</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>*</sup> These 4 cortical regions were not all stimulated in every case.

<sup>**</sup> Borborygmi; flatus.

† Cases not yet reported.

‡ Rectal tonus.

Note: The darker arrows indicate the predominate effect.

have elicited epigastric aura from frontal intermediate cortex on the superior mesial aspect of the frontal lobe anterior to the motor cortex (Figs. 1, 3) and from the anterior temporal cortex or the insula. Penfield has elicited no alimentary response from stimulation of other parts of the frontal cortex, including the orbital gyri.<sup>70</sup> Foerster<sup>29</sup> reported singultus and oral movements on stimulation of anterolateral temporal cortex. Chapman, Livingston and Poppen<sup>17,18,53</sup> recorded changes in blood pressure, pulse rate, and respiration on electrical excitation of posterior orbital and anterior temporal cortex, confirmed by Liberson, Scoville and Dunsmore,<sup>50</sup> who obtained similar results, as we have, on stimulating these areas as well as the uncus. These data have been incorporated with ours in Fig. 3.

**Technique.** In all of our cases electrical stimulation was done with bipolar electrodes 2.5–3.0 mm. apart. Prior to 1949 several stimulators were used.<sup>77,81</sup> Since 1949, when the bulk of this work was done, a stimulator has been employed that delivers a square-wave pulse alterable as to frequency, pulse width and intensity.<sup>32,33,92</sup>

All but a few of our patients have been operated upon under general anesthesia (intravenous pentothal sodium supplemented with intratracheal oxygen-nitrous oxide). Pre-operative medication for these patients, as well
as those operated on under local novocain anesthesia, consisted of morphine sulphate 10 mg. and scopolamine 3 mg. Thus far we have noted no consistent differences in current characteristics required to elicit visceral responses in patients under general anesthesia as compared with those operated upon under local anesthesia only. The operative exposure of cortex was generally achieved by the bifrontal craniotomy flap used for topectomy except for the few obviously different types of exposure used for motor cortex or temporal lobe operations.

Stimulation was begun at subthreshold intensities, allowing at least a 1-min. interval between stimuli, which were applied for 15 sec. unless a response was obtained sooner. Control stimulations up to 22 volts were carried out on the convex, ventral and mesial aspects of the frontal and temporal cortex in areas adjacent to those yielding visceral or respiratory responses. These control stimuli did not elicit any observable effects.

Prior to 1949 blood pressure changes were recorded by frequent determinations with a standard cuff aneroid manometer, while respiratory and pulse changes were noted by the anesthetist. Since 1949 continuous blood pressure recordings have been made using the extremely sensitive Lilly capacitometer connected to a needle in the femoral artery. This apparatus also indicated alterations in pulse rate and rhythm.

The respiratory rate and rhythm were continuously recorded by a kymograph attached to an accordion type chest tambour. Changes in the peripheral circulation were recorded by a digital pneumoplethysmograph.

Prior to frontal lobe surgery in a few cases, attempts were made to test the effects of electrical stimulation of the paracentral lobule and adjacent cortex including the cingulate, with regard to bladder tone. Although a water manometer was used attached to an indwelling urethral catheter, no
definite responses were obtained. However, increased rectal tone was noted by digital examination in 2 of 4 patients during stimulation of the caudal extent of the paracentral lobule.

Electrocortical activity (EEG) was studied, using bipolar silver electrodes 2 mm. in diameter and approximately 6 mm. apart. These were placed in pairs close to the stimulated sites as well as on other parts of the fronto-temporal cerebral cortex bilaterally.

RESULTS

The temporary visceral, respiratory, and other effects elicited during stimulation studies by the writer and his colleagues have been described in detail elsewhere,80,81,92 and are indicated in Fig. 3.

Significant changes in blood pressure lasted 8 to 45 sec. and were generally in the direction of an elevation ranging from 10–20 mm. of mercury, and usually occurred during the 15-sec. period of stimulation, often without other effects such as a change in cardiac or respiratory rate. Occasionally, however, blood pressure changes took place after the cessation of stimulation, but in such cases, since temporary apnea also occurred, the delayed alterations in blood pressure may have been secondary to changes in pulmonary circulation.

The pulse rate was usually slowed by 10 to 20 beats per min. for a few seconds and occasionally extrasystoles were produced. When a striking increase or decrease in finger volume was indicated by pneumoplethysmographic tracings, such changes in the peripheral circulation were also transitory, lasting for only a few seconds. Vasomotor changes were not necessarily associated with respiratory changes as noted below.

Respiratory changes were characterized by apnea lasting 5 to 45 sec. and rarely longer. They were invariably associated with a local electrical after-discharge in the cortex immediately adjacent to the stimulated site, and sometimes occurred during the expiratory, at other times during the inspiratory phase of respiration. Essentially no changes in the rate or rhythm of respirations occurred in any of these tests, responses usually being all (apnea) or nothing. In one early case, however, acceleration of respiratory rate occurred, lasting about 3 min., but this occurred when an unsatisfactory type of stimulator was used.91 Operative manipulation might also produce such changes.40,81,90

Profuse lacrimation was elicited in 1 case (Fig. 4) under general anesthesia on stimulation of the anterior lateral extent of the hippocampus (within the temporal horn of the lateral ventricle). No coincident respiratory changes occurred and there was no pupillary dilatation, although this phenomenon was being looked for. In 2 similar cases lacrimation was not elicited. Stimulation of anterior cingulate cortex in 2 cases was associated with plainly audible borborygmi and in 2 others with violent passage of gas by rectum.

Mid-transtentorial cerebellar stimulation close to the midline was carried
out under local anesthesia in 3 cases prior to 1949 following occipital lobectomy for malignant tumor. In 1 of these cases (Fig. 4) the blood pressure temporarily became unobtainable coincident with cerebellar stimulation, which also yielded phasic leg movements. No changes occurred in the blood pressure in the other 2 cases. This single observation, however, suggests that there is autonomic representation in the cerebellar cortex of man as Moruzzi has shown in animals.

Pupillary dilatation, which was obtained only upon stimulation of anterior cingulate cortex, is not a visceral response and is therefore omitted from this discussion.

It is important to note that all the responses that have just been described did not occur in any given patient. Certain types of vasomotor responses might occur independently of other types and in the absence of other changes such as apnea. Apnea, on the other hand, was frequently elicited without vasomotor changes, and so on.

It also became clear that stimulation of given points might give rise to only one type of response while stimulation only 2 mm. distant would yield a totally different response. Thus, for example, intraventricular excitation of the hippocampus (Fig. 4) resulted in lacrimation without apnea in 1 case, while in the same case with stimulation 2 mm. caudally by the same current parameters, temporary apnea ensued. At 2 mm. further caudally no responses were detected.

Finally it should be stated that effective current thresholds were lowest for the uncus and hippocampus, and comparable to motor cortex thresholds, higher for the anterior temporal and posterior orbital cortex, and highest, as a rule, for the anterior cingulate gyri.

DISCUSSION

The ablation and stimulation studies just reported tend to substantiate many of the clinical observations on cerebral localization of visceral phe-
nomina in man. At the cortical level of both the human and sub-human brain, the most widespread visceral representation appears to be in the limbic system or "visceral brain,"\textsuperscript{55-57} which includes the anterior cingulate, anterior temporal and posterior orbital cortex as well as the insula, uncus, amygdaloid nuclei and the hippocampal gyri. Anatomical studies\textsuperscript{5-7,15,20,31,76,86} and the spread of electrically induced after-discharge,\textsuperscript{49,57,83,92} indicate close structural and functional linkage of these component parts of the visceral brain. Its importance in emotional as well as visceral control\textsuperscript{33,56,58} makes the visceral brain or limbic ring\textsuperscript{57} therapeutically significant with regard to psychosurgery, and diagnostically significant with regard to earlier localization of intracranial lesions.

Laboratory data described by Anand and Brobeck\textsuperscript{3} and MacLean,\textsuperscript{57} together with some of the clinical data reported above, suggest the probability of even more discrete localization of many important visceral and emotional functions in the human brain than indicated thus far. Further investigations should prove of great value.

The temporary nature of visceral symptoms following cortical ablations in animals\textsuperscript{13} and man indicate that other remaining parts of the brain (not necessarily part of the limbic system or visceral brain) also regulate some of these functions, as illustrated by the widespread cerebral representation\textsuperscript{1,27,96} of autonomic regulation, the fact that gastric aura may be elicited from...
frontal intermediate cortex\textsuperscript{15} as well as from the insula and anterior temporal cortex, or that the peripheral circulation may be influenced not only by portions of the visceral cortex, such as the uncus and anterior cingulate cortex (cf. above), but also by the motor and premotor cortex.\textsuperscript{14}

As to control of the urinary bladder, it appears that incontinence or retention of urine may depend rather on the localization of bilateral superior frontal ablation (cf. above) than on a shock factor,\textsuperscript{47} although more study is needed to settle this point. The posterior extent of the superior frontal gyri also seems to be important in regulation of gastric and intestinal motility as indicated by ablation studies, some of which were preceded and followed by barium meal studies.\textsuperscript{19} Gastric acidity may likewise be altered by ablation of frontal cortex, particularly of posterior orbital or posterior superior frontal gyri.\textsuperscript{16,19} These findings are in keeping with laboratory data indicating gastro-intestinal regulation by frontal cortex in animals.\textsuperscript{4,9,24,36,61,102}

Perhaps there is a relation between these findings and the occasional occurrences of a gastric ulcer after frontal lobotomy,\textsuperscript{54} relief of ulcerative colitis by topectomy (personal observation), or gastric hemorrhage in association with intracranial lesions.\textsuperscript{42,84}

With further regard to alimentary functions it is pertinent to mention taste and the sense of smell. It has of course been made clear by Papez\textsuperscript{68} von Bonin\textsuperscript{11} and others that while olfactory perception is represented in the medial anterior aspect of the temporal lobes, this rhinencephalic portion of the brain is by no means exclusively concerned with the sense of smell but deals also with visceral and emotional functions. While disturbances of taste may be caused by deep temporal lobe pathology, Shenkin and Lewey\textsuperscript{91} and von Bonin\textsuperscript{11} pointed out that taste may be represented in the lower parietal sensory cortex of man as in the corresponding cortical area of the primate brain\textsuperscript{14} and the related portion of the thalamus.\textsuperscript{69}

Parenthetically it may be worth noting that vasomotor changes may be induced by stimulation of the cerebellar cortex in man\textsuperscript{77} as in animals\textsuperscript{64} and that piloerection may be represented in the frontal cortex in man.\textsuperscript{93} It may be ultimately found, furthermore, that all cortically represented visceral functions have specific areas for activation and adjacent areas for inhibition, as demonstrated for other phenomena\textsuperscript{28,38,101} and many autonomic functions.

Since the subcortical localization of visceral functions is beyond the scope of this discussion, the reader may be referred to the summaries of Fulton\textsuperscript{27} and Hess,\textsuperscript{34} the work of Wang\textsuperscript{67,98,99} on medullary centers for salivation and vomiting in cats, and White’s\textsuperscript{100} account of autonomic disturbances upon electrical stimulation of the hypothalamus of man.

Subcortical connections between the frontal and temporal cortex to the thalamus, hypothalamus, brain stem and spinal cord have been demonstrated in laboratory animals\textsuperscript{2,13,26,42,46,59,60,82,86,94,96,57} and man.\textsuperscript{10,38,62,63,104} The complexity and close juxtaposition of many of these fibre paths make accurate application of this knowledge, as in psychosurgery for example,
difficult if not impossible with present techniques. Obviously there is need
for further study.

As to emotional changes effected by isolation or ablation of parts of the
visceral brain, these have usually been beneficial, as emphasized by several
writers with reference particularly to the anterior cingulate and orbital
gyri in psychotic patients and the anteromedial temporal cortex in
cases of psychomotor epilepsy. The effects of medial temporal isolation
or ablation on emotional reactions in man, however, are not as striking as
in animals, perhaps because present knowledge and techniques do not per-
mit sufficiently accurate pinpointing of crucial structures. The fact that
juxta-limbic lesions, such as certain temporal lobe lesions or those effected
by frontal lobotomy or topectomy, may result in visceral and/or emotional
changes may in part be caused by a "release" phenomenon exerted on the
adjacent closely related limbic system. It is also possible that visceral or
emotional effects may be masked or cancelled by simultaneous juxta-limbic
surgical procedures if it can be assumed that both an effector and inhibitor
function may be sacrificed simultaneously.

SUMMARY

1. Pathological and surgical lesions, together with electrical studies of
the cerebral cortex, have been described with regard to efferent and afferent
visceral representation in the human brain.

2. These observations suggest that the "visceral brain" or limbic system
has essentially the same general structure, properties and functions in ani-
imals and man.

3. Visceral representation in man is also found in non-limbic cortex, and
is prominent in the motor and premotor cortex.

4. The fragmentary nature of the data described indicates the need of
further study.

5. The importance of some of these observations with regard to psycho-
surgery is mentioned.

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THE VISCERAL BRAIN OF MAN