WALTER B. CANNON

Professor of Physiology, Harvard Medical School

DIGESTION AND HEALTH

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George Higginson, Professor of Physiology,
Harvard Medical School

Dr. Cannon, internationally known for his scientific investigations in bodily activities, Professor of Physiology at Harvard Medical School, here sums up his extensive experience in an account of the ways in which appetite, hunger, thirst, general health, and emotional excitement such as fear worry or anxiety, affect the digestive processes.

In lively and entertaining style he answers such questions as: Is it a good thing to take a snack before retiring, how does a lemon help to relieve thirst, is it important to chew thoroughly before swallowing, what value is there in enjoying what you eat, should water be taken with meals, is it wise to eat immediately you get back from work, etc.

Bodily welfare, he argues, depends directly on the proper use of food. Hence the contents of this volume are of primary concern to everyone.

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DIGESTION

AND

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DIGESTION AND HEALTH

THE WISDOM OF THE BODY

THE MECHANICAL FACTORS OF DIGESTION

BODILY CHANGES IN PAIN, HUNGER, FEAR AND RAGE

A LABORATORY COURSE IN PHYSIOLOGY

TRAUMATIC SHOCK

Digestion and Health

By

WALTER B. CANNON

George Higginson Professor of Physiology
Harvard Medical School

A good digestion turneth all to health.

GEORGE HERBERT, *The Church Porch* (1633)

The health of the people is really the foundation upon which all their happiness and all their powers as a State depend.

BENJAMIN DISRAELI, *Speech,* June 22, 1877

LONDON

MARTIN SECKER & WARBURG LTD.

22 Essex Street, Strand

1937

PRINTED IN THE UNITED STATES OF AMERICA

TO

GEORGE W. PIERCE

One of the three "best doctors"

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Illustrations

INTRODUCTION

Books are conceived in hope and sometimes in joy; they undergo slow and gradual development until they are ready for birth; and then, with some travail, they are put forth. Many die in infancy or after a brief existence of a few years. Three score months and ten commonly mark a ripe old age. After the circulation has largely ceased a resting place in the vaults of a library is the destiny of the best. And only a very few become immortal.

We all know instances of the celebration of the hundredth anniversary of the birth of a great man. But how many are aware of a similar celebration of the birth of a book? And yet it occurred in various cities in the United States in 1933. A century earlier—in the autumn of 1833—an insignificant newspaper office in Plattsburg, New York, brought out a small octavo volume. It was rough and homespun, and was protected only by pasteboard covers. It appeared without any preparatory acclaim; it was not featured in extensive advertising or reviews. And yet, the next year a German translation was published in

Leipzig, and four years later an English edition was issued. By 1843 it had called forth reverberations in France and Russia. In 1876, the eminent French scientist, Claude Bernard, testified that the book had opened a new epoch in its special field of interest. And at the centenary of its first appearance, as already noted, the event was the occasion for meetings and speeches and historical displays in New York, Boston, Detroit and St. Louis, and other important centers throughout the land.

In the century lying between 1833 and 1933 thousands of other books were written and published and praised, and had their brief day and ceased to be. But this Book had permanent value. What was its quality? It was a simple, straightforward report of a scrupulously honest man, who used his senses cautiously in an important scientific inquiry, who recorded exactly how he used them and what they revealed to him, and who drew carefully limited inferences from the observed facts. And the report became a classic in the history of medicine.

The author of the Book, William Beaumont, was a Connecticut Yankee who, after studying medicine with a country doctor, had entered the Army and become a United States Army Surgeon. He was the sort of man Americans like to regard as typical of their people—

frankly outspoken, enterprising, independent and, when confronted by difficulties, resourceful. During the years 1826-1832 he was stationed at Fort Crawford on the upper Mississippi River, then an outpost set up against the Indians. Prairie du Chien, Wisconsin, now covers the site where the old Fort used to stand. In Beaumont's time that region was at the very fringe of the western frontier.

To Fort Crawford Beaumont persuaded a former patient, a Canadian, named Alexis St. Martin, to come and serve him. St. Martin had received in the left side of his body a gun-shot wound which tore away the lower ribs and made a ragged opening into the stomach and chest that caused bystanders to look upon him at the time of the accident as an "appalling and hopeless case." The accident happened in June, 1822, at a fur-trading station on Mackinac Island, Lake Michigan. Fortunately at Fort Mackinac Beaumont was then in service. He was called to attend the mortally wounded man, and, not despairing, he applied his surgical skill and his devotion as a nurse, until, after many months, St. Martin's health and strength were fully restored. The opening into the stomach, however, refused to close. Thus the opportunity was presented of studying the obscure process of digestion by peering through the aperture into the mysterious organ where and while the food was being transformed. At a backwoods Army post on the Mississippi, surrounded by savages and rough pioneers, working under most unfavorable conditions, having none of the aids of a modern laboratory, with no journals or other helpful literature for reference, with no scientific companions to encourage him or to lend a hand, with no experts to consult or to create a favorable "atmosphere" for research, Beaumont carried on a series of observations on the gastric juice and the digestive process which for more than a hundred years has not failed to call forth the admiration of all who have read the record. He was a frontiersman in a new realm of intellectual interest, while surrounded by the most grim and forbidding environment in the frontier of a civilization. And because, as he wrote, he conducted his investigations in "the true spirit of enquiry," without any "particular hypothesis to support," and because he "honestly recorded the result of each experiment exactly as it occurred," his little volume, "Experiments and Observations on the Gastric Juice and the Physiology of Digestion," has been a lasting monument to his single-minded search for the truth.

In 1929 the thirteenth International Physiological Congress was held in Boston. The hosts on that occasion were the organized physiologists, biological chemists, pharmacologists and experimental pathologists of the United States; and the members from abroad included eminent investigators from many lands and all parts of the world. When a Congress meets in any country, it is customary for the members therefrom to select one of their countrymen, who has been an outstanding contributor to the advancement of their science, to be commemorated in a medal. In anticipation of the Boston meeting various non-living Americans who had played a worthy part in revealing new knowledge of bodily functions were considered for that honor. Finally Dr. William Beaumont was selected, "the pioneer American physiologist," as Sir William Osler called him. Among Americans this choice met universal approval, for Beaumont not only initiated physiological investigation in the United States, but also he was an admirable representative of devotion to an old science in the new world, where the westward advance of frontier conditions, under which he labored, had long been typical.

Fort Crawford was located in the early days of the West in Michigan territory. In recognition of Beaumont's services to medicine the Wayne County Medical Society, with headquarters at Detroit, has for years arranged for annual "Beaumont Lectures." At the centenary celebration in 1933, the honor of giving these lectures was extended to me. The invitation was one which I accepted with interest and pleasure for I too had studied the activities of the alimentary tract, and had developed a high regard for the scientific caution and the careful reporting of my predecessor.

It was in 1896, when I was a first-year medical student, that my interest in digestive processes was first aroused. Dr. Henry P. Bowditch, then Professor of Physiology at the Harvard Medical School, suggested that we use the newly discovered x-rays to study the phenomena of swallowing. The study was started in the late autumn. The tubes and the electrical apparatus were absurdly inefficient, but by the last week of December, 1896, we were able to demonstrate to a gathering of physiologists the movement of material through the gullet of a goose. The bird was placed in a narrow box, provided with a sliding cover through which the long neck protruded. A high, card-board collar attached to the cover held the neck straight and kept it from wandering about. It gave the goose a most dignified and pompous air. Such were the beginnings of the use of the x-rays in tracing events in the digestive tract.

Soon we were mixing with the food a heavy inert powder, subnitrate of bismuth, which was opaque to the x-rays, in order to render visible the shadow of the material as it moved slowly along the esophagus. Later, as apparatus improved, we began to study the process in cats and dogs. The swallowed food gathered in the stomach, where it was worked over by the visibly churning waves. We could see it driven thence into the intestines to be mixed and kneaded and pressed and pushed onward, until almost all the good in it had been extracted. Thus, step by step, the progress of the food through the alimentary canal was followed. The new method of study, whereby the events in the canal could be seen without disturbance of the sensitive organs which are in action, offered the opportunity, as has been remarked, for every doctor to be a William Beaumont and his patient to be an Alexis St. Martin. Now throughout the civilized world the x-rays are used to examine readily in man the movements of the walls of the stomach and intestines, the changed contours of the food-shadows caused by disease, and the effects on digestion of many factors that were first noted in studies on lower animals.

In the course of studies on lower animals the effects of emotional excitement and of the general bodily health on the digestive process were incidentally observed. Subsequently they were examined in detail. These investigations led in turn to an interest in the phenomena of hunger and thirst. The researches which for many years were carried on in the Harvard Laboratory of Physiology could be regarded in some respects as modern extensions of Beaumont's labors. Accordingly the title chosen for the lectures at the centennial celebration of the publication of the famous Book was "Some Modern Extensions of Beaumont's Studies on Alexis St. Martin." With the hope that an account of our researches, as well as related researches and suggestions, may have interest for the lay reader, I am presenting, in the pages which follow, a modified arrangement of the Beaumont Lectures.

Chapter I

THE NATURE OF APPETITE AND HUNGER

New dishes beget new appetites.

JOHN RAY, *A Collection of English Proverbs* (1670).

Make hunger thy sauce as a medicine for health.

THOMAS TUSSER, *Hundredth Good Pointes of Husbandrie* (1557).

I

WE SHOULD be greatly bothered if in addition to attending to the business of other people we had to attend to our own. I mean here the real business of managing the personal affairs inside each one of us. Fortunately various automatic and highly efficient devices attend routinely to these matters. In our bodies, as in complex machines, necessary actions are made certain by regulatory agents. Machines are provided with gauges and governors and safety valves which keep the steam pressure at a fairly even level, maintain a uniform speed of the engines and provide for a proper supply of fuel. Similarly in us the continuance of existence, with vigor and achievement, is not left to the casual notice of a rambling intelligence, but is assured by an internal self-regulation. When we are in need of food, the fuel which supplies the energy for our daily work, we are led automatically by appetite or hunger, or both, to replenish our reserves.

Commonly the words "appetite" and "hunger" are used interchangeably. They name, however, quite different conditions. *Appetite* implies wishing, longing or yearning for something specially desirable. In relation to food we may at times have an appetite for a juicy beefsteak smothered in onions, or peaches and cream, or apple pie *à la mode*. Appetite, therefore, arises from the experience of previous pleasures. If, while eating an artistically prepared viand, we have had delightful tastes and odors, they leave a trace in memory, a trace that invites repetition of the experience. And if the invitation leads to taking the food again, the organs of taste and smell are again the source of enjoyment. As an accompaniment of such enjoyment, and as a part of one of the self-regulatory devices of the body, the pleasurable tastes and odors excite the flow of the digestive juices. "That makes my mouth water" is the common expression which testifies to both the anticipated delight of eating and the readiness of the digestive agencies for an attack on what is eaten. We now know from observations on persons who, like Alexis St. Martin, have had to live with a side-opening into the stomach, that the delights of the palate not only cause the mouth to water but also cause the stomach to water. In other words, saliva is poured out for the digestion of starchy food, and likewise gastric juice is secreted in order that protein food, such as meat, may be dissolved and made suitable for passage through the intestinal wall into the body itself.

Most readers of this book, living in circumstances where food-supplies are plenteous, doubtless find that the daily satisfaction of appetite may completely meet the requirements of the organism for nourishment. Indeed, whenever I have described the sensation of hunger to a hundred or more listeners I have almost always found a few who declare that they have never felt it! As prosperous people we eat because meals are announced, or because eating allows us to avoid a feeling of faintness or a headache, or because of the tempting aroma of food as it is placed before us, and not because of hunger.

Hunger is a primitive, elemental sensation. It is felt as a dull ache or gnawing pain, referred to the mid-chest region or somewhat lower. Unlike appetite it is not associated with desire for any particular food. It does not invite men to eat, it drives them to do so. Indeed, it may be so imperious in its control of human actions as to force civilized men to become cannibals, or may become so insistent as to impel the chewing and swallowing of nutriment which is actually disgusting. The hungry wood chopper or longshoreman, after a hard day's work, cares little for the pleasures of the palate. He wants quantity rather than quality. When hunger pangs are grinding, pork and beans are more satisfying than would be a dainty woodcock with green peas.

Because both appetite and hunger incite to the taking of food they are, as already noted, frequently confused. We have seen, however, that they are different in their sensory quality, in their bodily reference, in their relation to experience and in their effects on behavior. The first few mouthfuls of a meal may abolish hunger, but we continue eating because the tastes are so pleasant. We do not feel hungry when at the end of a meal ice cream or a delicious pudding is served. Yet we accept one or the other with relish because appetite is tempting us. On the other hand, "hunger is the best sauce," for hunger eliminates the requirement of appeals to an over-nice and fastidious taste. Although appetite and hunger may exist separately, they ordinarily coöperate or replace one another in their service to the organism. Only by keeping the distinction between them quite clear shall we understand their nature.

II

Hunger is so urgent in its demands and has so important a relation to the bodily economy that men interested in the workings of the organism have long sought to explain the phenomenon. As we have noted, faintness or headache may follow failure to have a meal at the customary time, or there may be lassitude and drowsiness, or restlessness and irritability. These states differ markedly with different individuals. The common experience, reported by almost all persons, is the dull, pressing pang. And that was the central fact which called for explanation.

The amount of real knowledge of a subject can be roughly judged by the amount of theorizing about it—the less knowledge, the more theories. Until relatively recent years theorizing about the nature of hunger was the usual mode of treating the subject. Two classes of "explanations" were advocated: one, that hunger is a "general sensation" having no local origin; and the other, that hunger, like many other sensations, is started by some change in the body which sends nerve impulses to the brain and thus arouses the characteristic unpleasant pangs.

The notion that hunger is a general sensation was supported by the older theories. It was supposed that lack of food led to a lessening of nutritive material in the blood and that tissue cells throughout the body, and specifically the cells of the brain, disturbed by shortage of provisions, gave rise to the sensation. Hunger would have, therefore, a diffuse origin, mainly in the central nervous system, and would be called a general sensation. Though this supposition is now discredited, an examination of some of the reasons for and against it will bring forth useful testimony.

The claim was made that the common experience, that hunger increases if one does not eat, is in accord with the idea that the blood becomes progressively impoverished as a fast is continued. That claim, however, has limits. If it were valid, hunger should become more and more distressing until death. There is much evidence that the sensation is not thus intensified. Many observers have noted that during a prolonged fast the feelings of hunger disappear after the first two or three days. Frank Gallagher, who kept a diary during a hunger strike in a Dublin jail in 1920, wrote, "Noticed in yesterday's papers that some French journalist spoke of our 'pangs of hunger.' Nobody would ever believe that there are none. There is a revulsion at death, a wild longing to live, but no physical call for food—that ceased on the second day." The theory that hunger is an outcry from ill-nourished cells would require the fantastic assumption that, while a person is starving, his cells are mysteriously not in need after the third day, and that therefore the disagreeable ache of hunger vanishes.

It has been claimed that hunger feelings must have their origin in the brain because, even when all the nerves connecting the stomach and intestines with the brain have been severed, so that changes in the gastro-intestinal tract cannot rouse conscious states, animals may eat eagerly the food placed before them. But, as we have seen, hunger is not required for eating. Appetite is a quite adequate inducement. The fact that an animal eats is no proof that he is hungry, and therefore, after nerves have been severed, it is no proof that the sensation of hunger has a central, not a peripheral source.

A number of minor arguments likewise oppose the explanation of hunger as a general sensation. First, the brain, though sensitive in the breathing center to slight increases of carbonic acid, is relatively insensitive to other forms of chemical stimulation which have been tried. Again, it is clear that when the first stages of hunger appear, the blood has not undergone any noteworthy change, either chemical or physical. Moreover, in fever, when there may be great wasting of the body because of rapid use of the nutritive reserves, the sensation of hunger may be wholly lacking. Furthermore, when a person is hungry and takes food the feeling disappears long before food could be digested and absorbed in sufficient amount to be useful in restoring a disturbed state, even if it existed. And finally there is testimony from persons who have been exposed to privation that the swallowing of indigestible materials, such as scraps of leather, bits of moss, or clay—all incapable of providing nourishment—will temporarily suppress the hunger pangs. These observations combine to weaken markedly the claim that the sensation of hunger has a diffuse and general origin.

III

In American slang one of the meanings of "grub" is food. There is an expression, "grub-struck," which picturesquely defines the onset of hunger. A person may be on a long tramp or busy with other routine labor, when, abruptly, he feels a pang. It is the suddenness of the arrival of hunger that makes the designation, "grub-struck," authentic and vivid. Nothing that we know in the processes of chemical change in the organism justifies the surmise that suddenly a critical point is reached, or a sharp shift of condition occurs, which would explain the instantaneous appearance of the sensation. As we shall see later, there is in another bodily event good reason for the quick pang.

My own interest in the phenomena of hunger began in 1904 when, by means of a stethoscope, I was listening to the rhythmic sounds produced by what Robert Hooke called the "several Offices and Shops of a man's Body" (mine!), during the processes of digestion. At that time I noticed that the sensation of hunger was intermittent, it might come and go repeatedly within a relatively short period. Also while the sensation was present it did not have a uniform intensity, but was marked by ups and downs. In some instances the ups and downs changed to a periodic recurrence of the pang with intervals of total absence. Both the pangs and the intervals between them lasted for varying periods, ranging usually from a half-minute to a minute and a half. It is obvious that this intermittency would be hard to reconcile with a theory that hunger is a general sensation. The bodily supplies would have to be one moment plenteous, the next moment deficient. There is no evidence whatever for such zig-zag shifts of the nutritive state. And thus further evidence was provided, hostile to the idea that hunger has an extensive source in the organism.

The last objection to the theory that hunger is a general sensation is its failure to account for the common testimony in favor of a local reference, i.e., to the region of the stomach. The claim has been made, to be sure, that the assignment of an ache to a special region does not prove that the stimulus which arouses it has its origin there. An inflammation of the ear may be felt as a toothache, a pull on the pelvic nerves may cause a pain localized in the small of the back, and an armless man may experience tinglings which seem to arise in fingers which have long ceased to be a part of his body. The force of this contention, however, depends on whether there is accessory evidence which would explain the sensation. If a tooth is sore when pressed and if the tissues around it are inflamed, the ache which apparently arises in that region actually does arise there. If we see a finger-tip touch a hot stove, the quickly resulting pain which we refer to the finger-tip is justifiably assumed to be due to the contact with the stove and not solely to a central change which we incidentally attribute to a spot on the body surface. Similarly in the problem of explaining hunger—the local reference of the sensation to the region of the stomach is explained if we find conditions occurring there, simultaneously with hunger pangs, that we may reasonably regard as giving rise to those pangs.

IV

In the rather luxurious investigation previously mentioned, during which I lay in bed listening through a stethoscope to the sounds accompanying my digestive activities, I not only observed that the sensation of hunger was inconstant and recurrent, I also noted that its momentary disappearance was often associated with a rather loud gurgling sound. The gurgling was due to the forcing of air upward into the esophagus, for a moment later it could be heard as it was driven back into the stomach by esophageal contraction. The passage into the esophagus, and the attendant sound, could be accounted for as resulting from such pressure in the stomach as to drive its air content out against resistance. And this pressure, which coincided with the sensation of hunger, could be regarded as the occasion for the sensation. On January 17, 1911, at a meeting in Boston, I presented this indicative evidence that hunger pangs arise from strong contractions of the "empty" stomach.

It is interesting to note that the same suggestion had been offered before. More than a hundred years ago Beaumont reported that when he introduced food through the opening into St. Martin's stomach the sensation of hunger promptly disappeared and therewith disappeared the "croaking noise, caused by the motion of air in the stomach and intestines,...almost always observed when the stomach is empty." One of the famous Weber brothers declared, thirteen years after Beaumont's publication, that strong contraction of "the wholly empty stomach, whereby its cavity disappears, makes a part of the sensation which we call hunger." Later two or three others writers supported this view, but they brought forward no direct evidence for it.

The time and opportunity for securing direct testimony as to the cause of the periodically recurring hunger pangs, which had roused my interest in 1904, did not come until February, 1911. It was then that one of my medical students, Arthur L. Washburn, expressed a desire to participate in a physiological investigation. I proposed that we undertake a study of the nature of hunger and suggested that he accustom himself to having a rubber tube in his esophagus. He earnestly seized the suggestion. For days he serenely carried on his work as a student in the laboratory, with a tube reaching down to his stomach and being prevented from going further by the firm pressure on its upper end in his clenched teeth. The preparations were then nearly complete for obtaining further information concerning the character of the pangs of hunger.

V

In order to learn whether the stomach did indeed contract when hunger was felt we fastened to one end of the rubber tube a small balloon and connected the other end to a curved tube ending in a glass cup (see fig. 1). On the water in the cup floated a cork which, moving up and down with the water level, raised and lowered a lever. A writing point on the end of the lever recorded these movements on a turning cylinder or kymograph. It was Mr. Washburn's custom to come to the laboratory without breakfast on the days when observations were made. We would empty the thin-walled balloon by sucking out the air and then thrust the collapsed bag into the stomach by pushing it down on the end of the esophageal tube. (When one is used to it, this procedure causes no distress.) The balloon was then inflated and the tube attached to the float-recorder (see fig. 1). Of course, when the stomach contracted and squeezed the balloon the water level would rise and lift the float, and *vice*

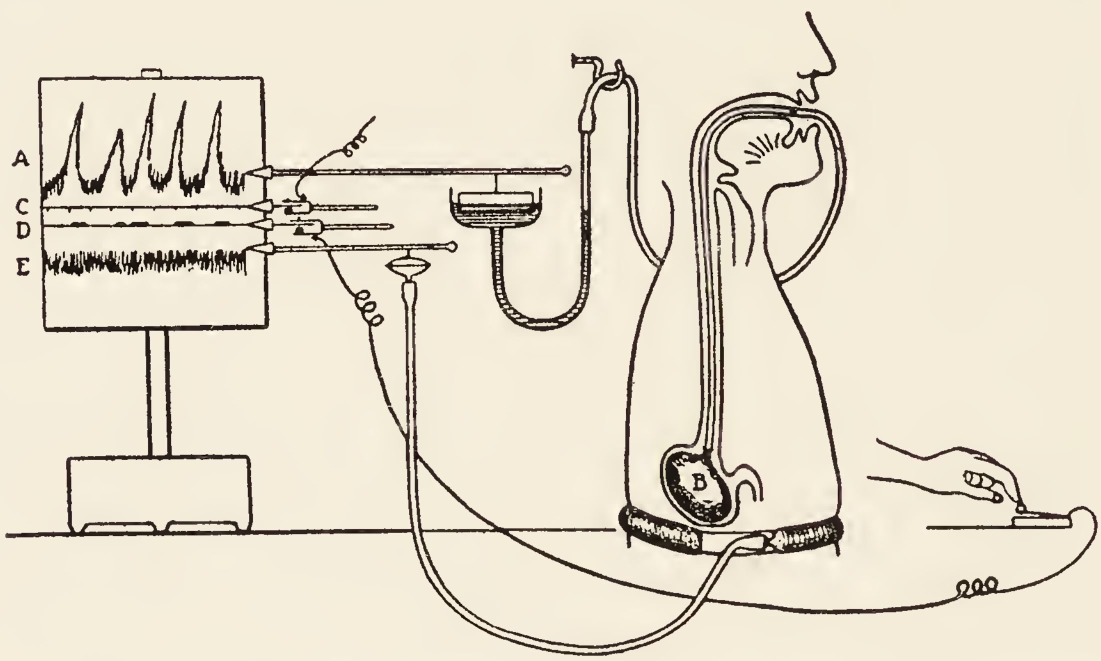

FIGURE 1. *Diagram showing the method used to record the gastric hunger contractions. A, kymograph record of the increase and decrease of volume of the gastric balloon, B. C, time-record in minutes. D, record of the periods when hunger pangs were felt. E, record of the pneumograph placed about the waist.*

versa when it relaxed. Now with a device around his waist, to report on movements of the abdominal muscles (thus eliminating them as the cause of irregular pressure on the balloon), and with a key under his finger, to be pressed when he felt hungry, Mr. Washburn was all ready for the test. As a glance at figure 1 shows, the lever moved by the volume-changes in the balloon, the time-marker registering intervals of a minute, the signal which told when the sensation occurred, and the writing point for contraction of the abdominal muscles with each breath were all recorded in the same vertical line on the rotating cylinder. In figure 2 is reproduced the first record thus obtained, on May 17, 1911.

Figure 2 reveals that powerful periodic contractions of the fasting stomach recur at intervals varying from 30 to 90 seconds—the average is about 60—and last from 30 to 60 seconds. These time relations were surprisingly like those which I had observed in my own experience in 1904 (see p. 27). As shown in figure 1, Mr. Washburn sat with his back to the recording apparatus, and therefore was not able to see the evidence that gastric contractions were taking place. All he knew was that he felt periodically hungry, and all he did was to press the key when the feeling began and release the pressure when the feeling ended. The sensation of hunger, as the reader will observe, was associated with the acme of the contraction; the sensation, therefore, was not the cause of the contraction, the contraction occasioned the sensation.

Thus it was that the first direct evidence was obtained that hunger pangs are due to a cramp-like tightening of the muscle in the wall of the stomach.

At about the time when these observations were pub-

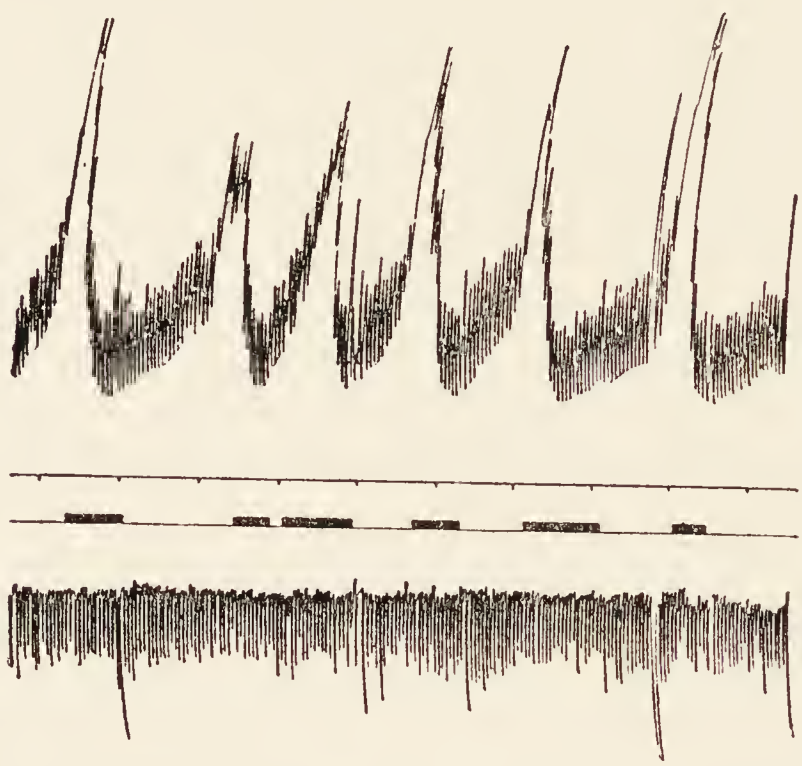

FIGURE 2. *Copy of the first record of hunger contractions associated with hunger pangs, taken May 17, 1911 (one-half original size). (From Cannon and Washburn, "An Explanation of Hunger,"* Am. J. Physiol., 1912, xxix, 450.)

lished (in March, 1912), there appeared in the laboratory of Professor A. J. Carlson, the physiologist at the University of Chicago, a second Alexis St. Martin, a man with a gastric fistula through which it was possible to examine the events occurring in the stomach just as Beaumont had done many years before. This favorable incident allowed Carlson to study the phenomena of hunger in a highly convenient manner. Since at that time I was much interested in the effects of emotions on the body, I turned my attentions to that field and left further investigations of the nature of hunger wholly to Carlson and his students.

In a series of interesting researches on human beings, some of whom, like Mr. Washburn, had their gastric contractions recorded by means of a tube in the esophagus, and also in experiments on various kinds of lower animals, Carlson and his collaborators have intimately examined the phenomena of hunger in health and disease. They not only confirmed the observations which were made on Mr. Washburn, but they brought out many new aspects of the hunger pangs and the relation to them of gastric squeezings and pressings. For example, I had noted only the separate rhythmic recurrences of the strong gripping of the balloon by the stomach muscle. They were able to show that this is only a part of the total picture. Cycles of hunger experience occur. A cycle usually begins with occasional weak contractions; these become gradually more vigorous and appear at shorter intervals until a supreme degree of activity is reached, which may culminate in an actual spasm (see fig. 3). Both the single contractions and the spasm are associated with the typical disagreeable ache, or pang, or gnawing sensation, which has long been recognized as the experience of hunger. After the acme of activity has been reached the stomach usually relaxes and remains

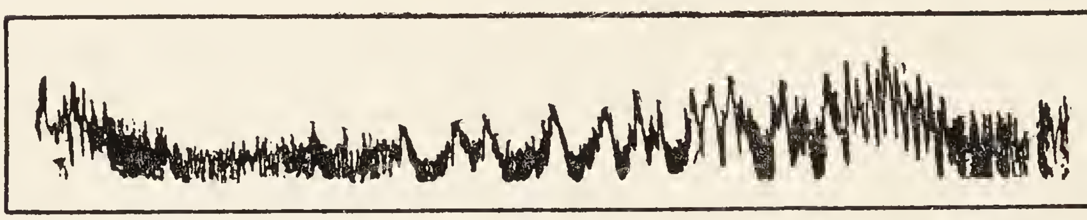

FIGURE 3. *A cycle of gastric hunger contractions. The record (38 minutes long) was taken from a normal infant nine hours old, before his first feeding. The cycle is shorter than in adults. (From Carlson and Ginsburg, "Hunger Contractions in the Stomach in the New-Born,"* Am. J. Physiol., 1915, xxxviii, 30.)

quiet for a period, whereupon it starts again with occasional weak squeezes, and the cycle of increasing activity, followed by quiescence, is again repeated. One might suppose that the balloon, as a foreign object, could be the stimulus for the sensation. Carlson's second Alexis St. Martin declared, however, that he felt no pang when the balloon was blown up inside him, or even when the lining of his stomach was rubbed with a smooth instrument, unless these procedures induced gastric contractions. The contractions, therefore, are definitely the sources of the hunger pangs.

It is possible to record the pressure changes in the stomach, as shown in figure 1, and at the same time to watch by means of the x-rays the movements of the gastric walls. This feat has been performed by Martin and Rogers. They found that there may be two types of activity in the stomach during a hunger pang. As an essential feature it is associated with a powerful, at times obliterative, gripping in the lower third of the stomach (the antrum), and, in addition, a deep constrictive ring may form in the upper portion of the organ (see fig. 4).

The conditions which may influence the hunger contractions have also been investigated by Carlson and his colleagues. Sleep, for example, does not check the contractions, but they may interfere with sleep and produce restlessness. Hence the strategy of a snack before retiring at night, especially if one is, or is likely to be, hungry. Curiously enough, chewing movements will stop hunger pangs; just why is unknown. Many years ago Lieb and I demonstrated that when one swallows anything, the active digesting stomach, squeezing and pressing its contents, will stop, relax and admit the swallowed material without opposition. Then it sets to work again (see fig. 11, p. 99). In 1910, I called attention to the disappearance

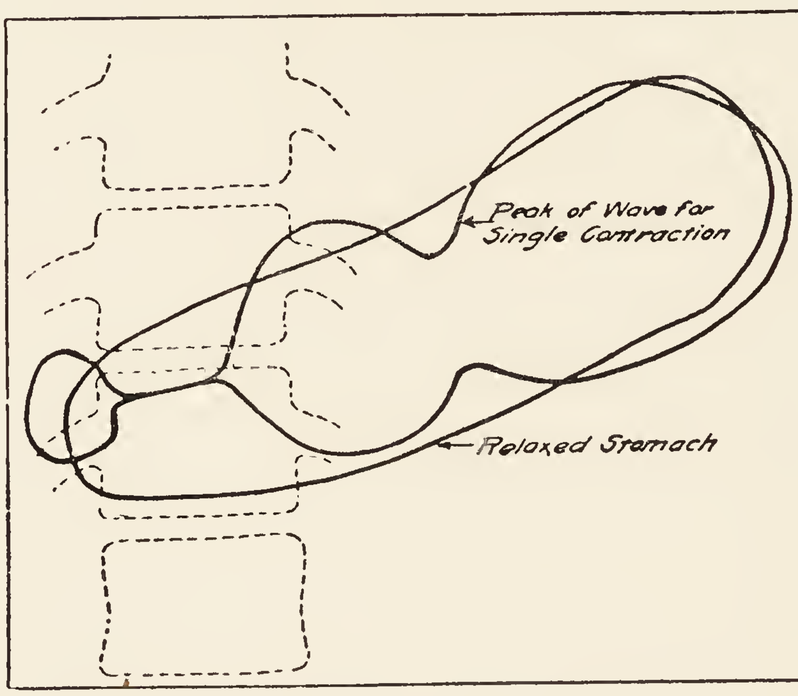

FIGURE 4. *Outlines of the Röntgen-ray shadows of the stomach when relaxed and when at the peak of an unusually strong hunger contraction. (From Martin and Rogers, "Hunger Pain,"* Am. J. Röntgenol. and Radium Therapy, 1927, xvii, 223.)

of the sensation of hunger when one swallows—an effect which might indicate that, just as the movements of the digesting stomach are thus stopped, so likewise are the movements of the hungry stomach. Such, indeed, was shown to be true. Not only swallowing, however, but also great emotional excitement arrests the digestive functions; it arrests as well the muscular grippings associated with hunger. Smoking weakens them and may completely stop them; apparently the degree of effect depends on the "strength" of the tobacco. By direct introduction of alcoholic beverages—undiluted beer or wines—through a gastric fistula, it was found that the hunger contractions were checked and the muscular "tone" of the stomach was lessened. Very vigorous exercise also inhibits the recurrent constrictions, but after such inhibition they are likely to return with greater intensity than before. We have all heard of the advice to tighten the belt when hunger pangs become annoying, in order to abolish them. Tightening the belt does, indeed, stop them if they are weak or of moderate intensity. The stoppage, however, may be only partial, and even when complete it lasts but a brief time, from 5 to 15 minutes, whereupon the contractions reappear despite continued pressure around the waist. With excitement and exercise, smoking and drinking, and belt pressure—not to mention the taking of food—as means of getting rid of the unpleasant sensation of hunger, one has a rather wide variety of modes of relief. But sometimes we may wish to establish hunger or intensify it; later we shall learn how that may be done.

I have already remarked that occasionally a person will testify that he has never experienced hunger pangs. And it is known, furthermore, that when a fasting man ceases to feel hungry, after the first few days without food, the typical squeezings and pressings are still going on within. These facts appear to minimize the importance of the contraction as the source of the hunger pang. They are, however, not decisive. Many circumstances may prevent a stimulus from having its usual effect. A ticking clock, for example, may not be heard because other events are influencing the brain, or because the brain, perhaps, is dulled in sleep. If for such reasons the ticking is at times not heard, that does not prove that it does not produce the sensation when it is heard. Even though the rhythmic pressings of the empty stomach may be going on without inducing pangs, there is the positive testimony of investigators who, since Washburn's testimony first disclosed the relationship, have found that the dull gnawing sense of being hungry results from powerful pressures produced by the gastric musculature.

The pertinent question presents itself as to why the stomach when empty contracts with so much greater power than when engaged in digesting a meal. Is there something which the body lacks after digestion is finished that makes the stomach constrict vigorously? We know that the preferred source of energy for doing muscular work is a sugar, glucose. The concentration of glucose in the circulating blood can be sharply reduced by giving insulin, the agent used in the treatment of diabetes. If the concentration is reduced about 25 per cent below the normal percentage, hunger contractions begin to appear and within limits they become more intense and more frequent as the percentage falls to lower levels. And if now glucose is injected into the blood the stomach becomes quiet again. Although this evidence, obtained by Carlson and by La Barre and their collaborators, is suggestive, it cannot be regarded as definite proof that the strong grippings in the stomach are due to a drop in the concentration of circulating sugar. In the first place, the excess of insulin in the blood, used for experimental purposes, is abnormal; also no proof has been offered that, when hunger contractions start, the blood sugar has been reduced to a noteworthy degree; and moreover, evidence has been gathered that the natural, spontaneously occurring contractions—*not* induced by insulin—are not lessened or checked by the intravenous injections of glucose. Finally, although the hunger contractions induced by insulin result from nervous influences flowing from the brain, the natural contractions appear when all nervous connections between the stomach and the brain and spinal cord have been interrupted. It seems clear that some condition, arising outside the digestive period, drives the stomach itself into special activity when it is prepared to receive more food. What that condition is and how it may work are still riddles. We must wait for the results of further study before the riddles can be solved.

The efficacy of insulin injections as stimulators of gastric constrictions has provided physicians with a means by which hunger pangs can be induced at will. When a person is suffering from weakness and wasting and absence of desire for food, an amount of insulin which will reduce only slightly the blood sugar evokes the pangs, and they are allayed only by eating. There is evidence that insulin serves also as a means of rendering the ingested food more serviceable to the body. Reports of the use of this strategy in the undernourished, who are indifferent to food and who eat little, indicate that it is highly effective in building up the bodily reserves.

What is the meaning of the hunger contractions in relation to the normal digestive functions? A possible interpretation is based upon an idea which will be presented later—the idea that some activity of the muscles of the stomach is the condition for doing their work. Thus the very state which causes hunger and leads to

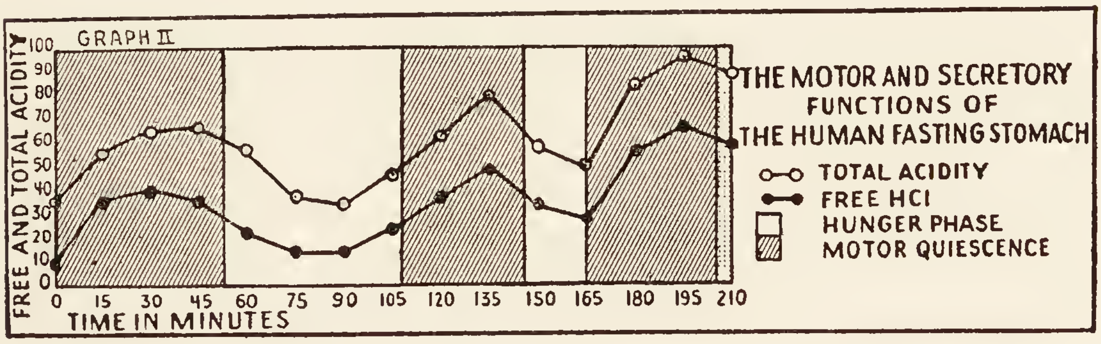

FIGURE 5. *Diagrams showing successive hunger cycles of the stomach of a fasting human being and the variations of the acid gastric juice. (From Hellebrandt, "The Relation between the Motor and Secretory Functions of the Human Fasting Stomach,"* Am. J. Physiol., 1935, cxii, 164.)

the taking of food is the state which, after the food is swallowed, would be most favorable for natural digestion. The observation reported by Hellebrandt that the recurrent hunger cycles of the stomach in fasting human beings are associated with recurrent increases of the hydrochloric acid (HCl) of the gastric secretion (see fig. 5) brings support to this idea. In other words, hunger is normally the signal that the stomach is ready for action. The unpleasantness of the hunger pangs leads to eating; and eating starts gastric digestion, with its mild, progressive constriction-rings or peristaltic waves, and abolishes the disagreeable sensation.

The pangs of the hungry man may be closely mingled with his appetite for particular viands. While he eats he can have relief from the pangs and at the same time can be satisfying his palate. As mentioned earlier, most of us, as civilized human beings, find that the pleasures of gratifying appetite assure the needed supply of food. If, however, the requirements of the body are not met in this mild and incidental manner, hunger pangs normally arise, powerful, persistent and tormenting, and imperiously demand the taking of nourishment.

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Chapter II

THE NATURE OF THIRST

Hunger is bitter, but the worst
Of human pangs, the most accursed
Of Want's fell scorpions, is Thirst.

Eliza Cook, *Melaia* (1838)

I drank at every vine
The last was like the first
I came upon no wine
So wonderful as thirst.

Edna St. Vincent Millay, *Feast.*

I

Though the sensations of hunger and thirst are easily distinguishable they have common features. Both arise from highly potent inner stimuli or goads. Both are nagging and disagreeable experiences, associated with powerful impulses, the so-called "drives," which impel us to act in such ways as to obtain relief. And both are related to our essential needs. We can live without oxygen for only a few minutes. We can live without food for weeks, using the reserves of sugar and fat until they are gone, and finally tearing down parts of the structure of the body itself. Intermediate between the brief existence of the victim of asphyxia—the drowning man, for example—and the long-drawn wastage and attenuation of persons who are starving, is the length of life without water. How long it will be depends on the environment and the degree of activity. In the extreme heat and dryness of a parched desert a man who struggles to find water may not last more than two or three days. Under more favorable conditions, when the water stores in the body are not so lavishly spent, life may continue much longer, but always with increasing misery and distress. An Italian political prisoner, Viterbi, who committed suicide by combining a hunger-strike with a thirst-strike, died on the eighteenth day of his voluntary deprivation. During that period he was not required to move, and possibly his prison surroundings were moist and cool. In these circumstances the rate at which water was lost from his body might be low. It is noteworthy that, although he did not suffer from hunger pangs after the first few days of his strike, as reported in his diary, the torments of thirst became constantly more insistent and more nearly intolerable.

II

We shall have more respect for water, perhaps, if we consider that we live in it. Separating us from the air which surrounds us is a layer of horny scales, the scurf of the skin. Inside this lifeless covering are the parts of us that are alive. Wherever we look inside the body we find fluid (blood or lymph) bathing the masses and meshes of cells which constitute the living tissues. Indeed, we reside in a sort of fluid matrix, composed mainly of salty water.

As the chief constituent of the out-poured juices and the liquid parts of the organism water serves a variety of functions. It is the vehicle by means of which food, after being digested, is carried from the alimentary canal into the body, for while in the canal the food is only surrounded by the body. It is the vehicle, also, which transports essential materials, food and oxygen, from the surfaces where they are received, to deeply hidden structures, remote from direct supplies. It engages in the lubrication of moving parts, as in the joints and around the organs of the chest and abdomen, where friction would be disturbing and painful. And it plays a rôle of primary importance in helping to maintain a uniform body temperature when, because of the heat of the day or the vigor of exertion, the temperature tends to rise. Water is then secreted as sweat and, by evaporation, removes heat from the skin where the warm blood is flowing.

Other functions which water performs we need not now consider. The examples which have been mentioned suffice to prove that it is in the highest degree indispensable. We who live where water may be had in abundance become thoughtless about it. In arid deserts, however, the dangers of uninterrupted drouth become a central thought, a nucleus of fear and hope around which all other ideas revolve. There water is the ultimate standard of value, more valuable than gold. Among the American Indians of the dry areas of Arizona and New Mexico prayers for rain are expressed in elaborate ceremonies; and still other ceremonies, after rain has fallen, are symbolic of joy and gratitude.

III

The essential element, water, is continuously being lost from the body. Some leaves with every breath, as we commonly note when we blow on our eye-glasses, and the cool glass precipitates the moisture in a foggy film which we use for cleansing. And some is going forth day and night through the sweat glands as "insensible perspiration." Some must accompany the waste products discharged through the kidneys, a loss which occurs even in the last stages of thirst. Of course, if the breathed air is already moist, and the weather is cool, and the non-volatile waste from digestion and from the wear and tear of bodily structure is minimal, the loss will not be rapid. Even if water is passing away slowly, however, but constantly, it must be renewed. The supply is restored, as we all know, by occasional drinking. And because of this occasional restoration, associated with continuous drainage, there must be water reservoirs which are filled in times of plenty and reduced in times of need.

The reservoirs of the organism are found in the fine meshwork of connective tissue directly under the skin and also in the muscles. If salty water is injected into the blood vessels, it is stored especially in these parts; and if bleeding or other abrupt removal of body fluid occurs, the water content of these parts is especially reduced. The reservoirs do not empty directly into the lungs, sweat glands and kidneys where water passes away. They supply the blood, keeping its quality fairly uniform as it loses water, even though they may not preserve its volume.

Nature of Thirst

In considering hunger we had occasion to observe that provision for essential needs of the organism is assured by automatic devices. Commonly we drink as we are eating a meal, and thus we may keep the reservoirs so nearly filled that no special demand arises for extra fluid. Or we may have an "appetite" for a drink, just as we may have an appetite for a particular viand—a desire for some special beverage because of pleasant previous experience with it. Thus hot tea on a cold afternoon, or cool lemonade or beer on a warm summer day, may be peculiarly satisfying because it is just what we wish. In the gratification of an appetite for drink, the amount taken may be much more than enough for bodily needs, for, unlike food, fluids do not stay long in the stomach, and therefore they do not induce a sense of fullness or satiety that checks the intake. Therein lies the danger from harmful beverages.

Conditions may arise in which the routine modes of supplying water may not be sufficient to balance the loss—the air may be very dry, or the weather hot, or the exercise violent, and the consequent drainage may be excessive; or the opportunity of obtaining a drink may be lacking. Then thirst develops.

IV

Different degrees of thirst have been distinguished by McGee, an American geologist, who had many occasions to study the phenomena in the desert regions of the southwestern part of the United States. The first stage is characterized by a disagreeably dry mouth and throat and an urgent craving for water. Later, in a second stage, the mouth becomes sticky, the tongue cleaves to the teeth and to the hard palate, a sensation as of a "lump" is felt at the back of the throat that causes endless swallowing, and water becomes the supremely desired possession in all the world. The still later pathological stages we shall not consider—stages in which the eyelids cannot be moved over the dry eyeballs, the eyes are stiffened in a sightless stare, the tongue swells and hardens to a senseless mass, and the wretched victim has illusive visions of lovely lakes and running streams.

The feature of thirst which practically all observers agree upon is the unpleasant sensation of dryness in the mouth and throat—a local dryness. It is noted when one is continuously breathing desiccated hot air. It is noted also after prolonged singing or speaking when air has been moving repeatedly to and fro over the tongue and mouth-parts; the lecturer's glass of water testifies to the common experience. This basis for the sensation is confirmed by the records of thirsting men. King, a medical officer in a cavalry troop of the United States Army, lost in the torrid "staked plains" of Texas for nearly four days, has reported that on the third day mouths were so parched that sugar would not dissolve on the tongue, and food when chewed gathered in the teeth and could not be swallowed. The evidence of local dryness has naturally led to the suggestion that thirst has a local origin in the mouth.

Certain general states occur, however, which are characterized by a lessening of the fluid content of the body and which are typically associated with thirst. Profuse sweating on a July day may be mentioned, together with the full jug taken to the hay-field to renew the water supply. The water loss from excessive diarrhea in cases of cholera, and from the excessive flushing of the kidneys in cases of diabetes, is accompanied by such an unquenchable desire for beverage that almost incredible amounts may be swallowed. And when there has been any considerable hemorrhage, again the call for water becomes demanding. Even when the reduction of body fluid is relatively slight as it is in nursing a child, the thirst which results makes a drink desirable. There are, then, these general conditions which occasion thirst, and which have led to the idea that the sensation has a widespread source in the organism.

V

Lack of evidence regarding the basis of hunger, as we have seen, resulted in a variety of theories directed towards explaining it. Similarly, and for the same reason, diverse theories have been proposed to account for thirst. And likewise, in accord with the indications of a local origin and a general origin of the sensation, there have been two views as to its nature.

Curiously enough, in spite of the common testimony of ingenuous observers that thirst seems to arise from a dry mouth and throat, the view that it has this definite source has had few advocates. Magendie, an eminent French physiologist contemporary with Beaumont, had gone so far as to declare that "thirst is an instinctive sentiment, the result of organization, and does not admit of any explanation." With characteristic independence Beaumont utterly rejected the limitation which Magendie had laid down. He wrote, "Thirst is no more an 'instinctive sentiment' than any other sensation of the economy; to say that it is the 'result of organization' gives no explanation, amounts to nothing, and is certainly, to say the least, a very unsatisfactory way of disposing of the question." Beaumont declared that thirst is a sensation arising from the mouth and fauces, a feeling of dryness due to evaporation of moisture from the surfaces of those regions because the passage of the respired air takes up the moisture more rapidly than it can be supplied. Only slight experimental support for this idea could be adduced. Observations might be cited on a case of diabetes insipidus—a disease in which water passes through the kidneys as through a sieve. When a patient, tormented with the distressing thirst of this disease, had the back of his mouth rendered insensitive by brushing it with a weak solution of cocaine, he experienced a comfortable respite which lasted sometimes a half-hour, until the effect of the drug wore off. It has been noted also that dogs deprived of water for several days did not drink when given the chance, if the tongue and pharynx were cocainized. In other words, when the nerves of the dry areas were benumbed, both thirst and the impulse to slake it disappeared. In addition to these experiments are certain common experiences which are suggestive. For example, sipping a small amount of water and moving it about in the mouth will temporarily stop the sensation. Also, holding in the mouth a substance which causes a secretion of saliva—a bit of lemon serves effectively—will lessen thirst. No water is supplied to the body, and yet the distress is mitigated. All these observations are favorable to the idea that the sensation of thirst arises from the mouth and throat. They do not, however, even hint at any explanation of the way in which the local situation is related to the extensive bodily need for water.

The theory that thirst is a general sensation—i.e., that the state of the organism as a whole is involved—was for a long time widely accepted. It was noted that injection of fluids under the skin or into a vein would abolish thirst, both in man and in lower animals. The French physiologist, Claude Bernard, following the suggestion offered by Beaumont's report on Alexis St. Martin, made a gastric fistula in a dog, and found that if the fistula was left open, so that the swallowed water ran out, the dog drank till "tired" and, when "rested," drank again; whereas if the fistula was closed, the dog drank his fill and stopped. Bernard drew the conclusion that thirst is a general sensation because water crossed the mouth and pharynx as the animal drank, but there was no evidence of satisfaction until the water was absorbed. Incidentally we may note that the terms "tired" and "rested" express the judgment of the investigator and not the testimony of the dog! The animal may have stopped drinking because he was not thirsty, and he may have started again because he became thirsty. When, after the fistula was closed, the swallowed water was absorbed, it may have altered local conditions in the mouth, just as injected fluid may have done. We shall soon see that this suggestion has a sound basis.

VI

It is a commentary on the occasional blindness of scholars that in facing the phenomena of hunger and thirst they overlooked the obvious. In each condition a general bodily need is signalled by a well-defined sensation. In each the simple testimony of ingenuous people regarding this common sensation has been reported and then explained away! The hunger pang, localized near the region of the stomach, was dismissed as an incidental part of a generalized experience; later it proved to be a real and natural consequence of gastric contraction. In thirst the unpleasant dryness of the mouth and throat has been the central fact, always emphasized, and that, like the hunger pang, was likewise long dismissed as incidental. The question arose as to whether lack of moisture in the fauces might not be associated with the need for water in the body, and, in fact, whether it might not be the automatic indicator of that need.

In puzzling over this question two ideas occurred to me that seemed reasonable. First, there should be at the back of the mouth an arrangement or condition which would lead to that special region becoming desiccated when the water reserves are reduced. And second, this arrangement might be expected to be operative only in animals which lose water rather rapidly and therefore require repeated renewal of the supply.

In accord with the second of these ideas we might assume that animals—fish, for example—which live immersed in water, and which pump an almost continuous stream of that water into the mouth and thence out past the gills, could not experience thirst as we do. In the evolution of vertebrates, however, organisms have changed their surroundings from water to air. The surface of the body among reptiles, birds and mammals has become dry and scaly. The mouth and pharynx continue moist, but a new feature has been added—the nasal chambers. Through these channels an air current now flows, in and out with every breath, crossing the ancient water course in its passage (see fig. 6). It is a striking fact that the nasal chambers and the wind-pipe are provided with moistening glands, so that they are not easily

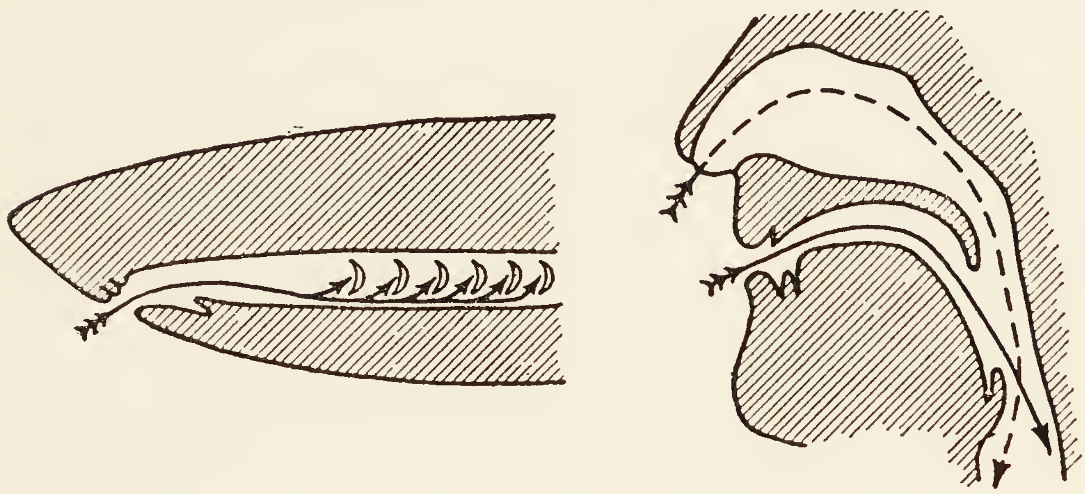

FIGURE 6. *Mid-line sections of the head of a fish and the head of a man to show the changed relations of the water course from the opening of the mouth to the gill region in animals surrounded by air. Note that in the pharynx the air-current (indicated by a dash-line) passes to and fro across the ancient water course.*

dried by the indrawn air. In the pharynx, however, where the air channel crosses the old water course, few such glands are found. This is, therefore, a region which is peculiarly liable to desiccation. And if the air moves repeatedly to and fro along the water course, i.e., through the mouth, as it does in prolonged speaking, singing or smoking, the liability is increased. As the area becomes dry and sticky the disagreeable sensation develops which we call thirst.

Now further questions arise. Why does not this region always feel dry and sticky? And why does it feel especially dry and sticky when the body needs water? And what makes the pharynx, which is peculiarly prone to lose its surface water, an indicator of low aqueous reserves in the organism? Again suggestions came from a comparison of animals surrounded by water with animals surrounded by air. The water inhabitants have no special glands secreting into the mouth—such organs are not required. The air inhabitants, on the contrary, are well supplied with buccal glands, which in mammals are elaborated into three or more pairs of salivary glands. The saliva which they produce and which they send through their ducts into the mouth, to lubricate its moving parts and serve other functions, is almost pure water. The other materials present constitute only 1 to 3 per cent.

We are now ready to put together these hints and inferences from comparative anatomy and make a theory of them. The theory may be stated thus. When the water supply of the body begins to run low, the salivary glands, because they require water to produce saliva, are particularly affected. If they fail to pour out their product in a sufficient amount, the back of the mouth becomes dry and sticky, i.e., thirst is experienced. Now when water is swallowed, in consequence of the thirst, it is absorbed into the body; and the salivary glands, sharing with the rest of the organism the abundance of the fresh supply, are again able to keep the pharynx moist,—and thirst disappears.

When I broached this theory in 1918, I offered in support of it evidence which in the years since then has been largely confirmed and augmented. In the main the evidence has developed in two directions. If the water content of the body is reduced, the salivary flow is lessened and therewith thirst appears. And, though the body may not have lost any noteworthy amount of water, conditions which check the discharge of saliva induce the sensation.

VII

Before considering these two lines of evidence I wish to call attention to a reflex which is highly suggestive of the important rôle of the salivary glands in keeping the mouth moist and lubricating its surfaces. The reflex, first described by Zebrowski in 1905, can readily be demonstrated by anybody and quite simply. One has only to breathe through the mouth for five minutes. At first the moving air gradually dries the buccal lining. As it becomes dry the reflex begins to operate, and saliva is poured forth in an amount which is greater than that which results from movement of the jaws as in chewing. In performing this experiment I added long columns of figures during the five minutes in order to prevent an interest in the result from having any possible influence on the secreting glands. At the end of the period about 5 cubic centimeters of saliva had collected —a little more than a teaspoonful. The motions of chewing, for the same length of time, called forth only about a fifth as much. My colleague, Dr. Gregersen, confirmed this result, and, as we shall see, used the method for testing the effects of general bodily states on the functioning of the salivary glands. We may call this reflex the "dry-mouth reflex."

Now as to the performance of the salivary glands when the water supplies of the body are reduced. In one of the first experiments on myself I learned that mastication of a tasteless gum for five minutes, at intervals of an hour, brought forth a fairly uniform amount of saliva.

If no water was taken for many hours, however, mastication for the standard period evoked a gradually smaller output. In my experience the reduction after 20 hours of abstention from drinking was about one-half. Winsor, who performed the much more difficult feat of going without water for nearly three days, found that the discharge from one of the glands (a parotid), as a consequence of chewing gum, was reduced to only one-sixth of the usual amount (see fig. 7). When Gregersen employed the dry-mouth reflex to induce a salivary flow he noted that deprivation of water for 48 hours lessened the secreted fluid from about 5 cubic centimeters to less than 1 in the five-minute test. These results on man, which by themselves should be accepted with some caution, Crisler and also Gregersen have confirmed by similar observations in dogs, in which the possibly disturbing factor of interest could not be involved. In all the experiments—on men and on dogs—the important fact was demonstrated that shortly after water was drunk and thirst was relieved, the normal salivary flow in response to the standard stimulus was wholly restored (see fig. 7).

Another way in which the water reserves of the organism can be lowered is by sweating. In carrying out this

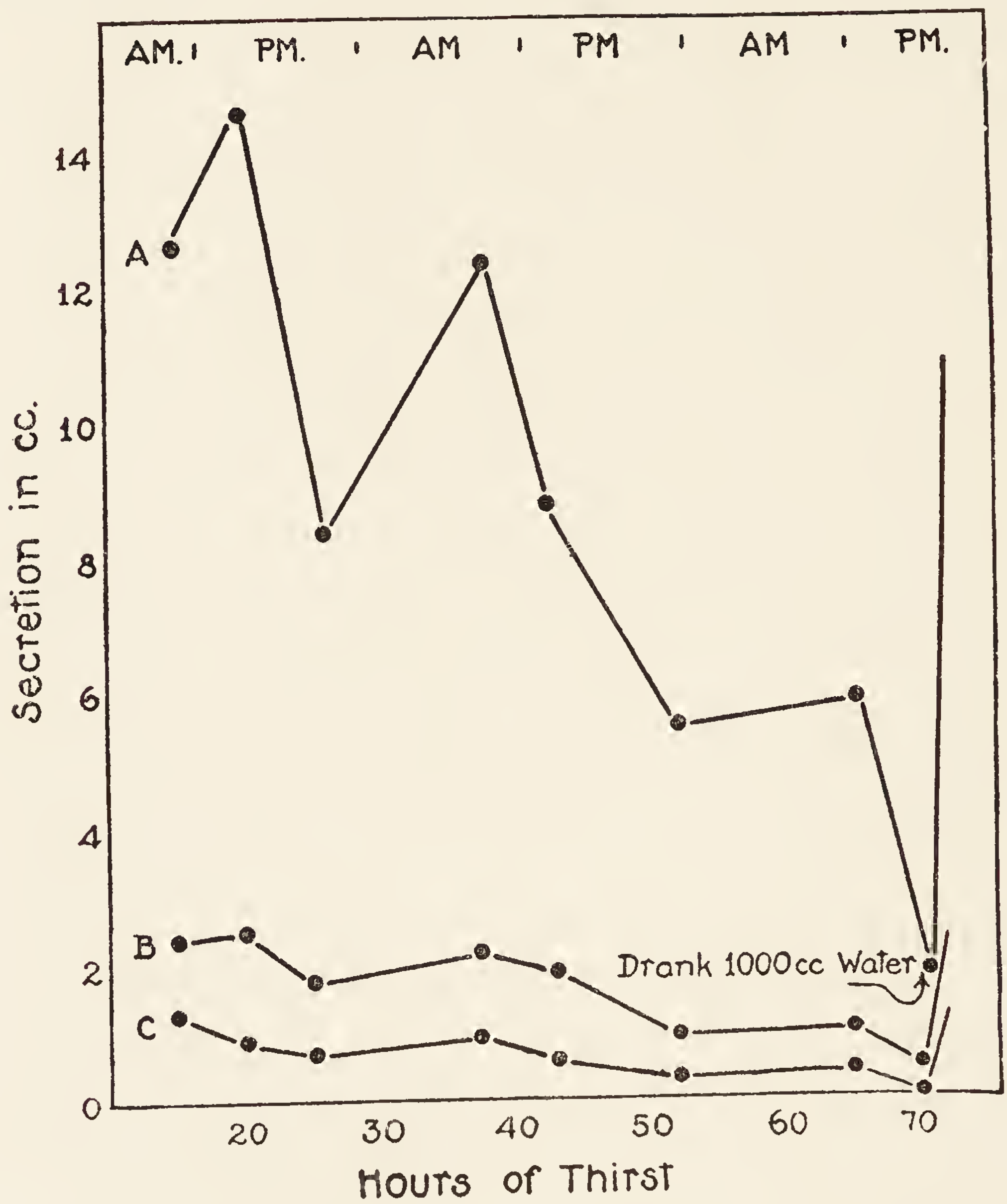

FIGURE 7. *Graphs showing the influence of deprivation of water on the secretion of* one *parotid gland. A, the volume of saliva secreted in successive periods when tasteless gum was chewed for 15 minutes; B, the volumes in the same periods when the subject breathed through his mouth for 30 minutes; and C, the normal amount secreted in 15 minutes. (Redrawn from Winsor, "The Effect of Dehydration on Parotid Secretion,"* Am. J. Psychol., 1930, xlii, 605.)

experiment I wrapped myself in thick woolen blankets and had hot-water bottles placed about me. After a half-hour of profuse perspiration and a weight loss which indicated that about a pint of water had gone out through the lungs and skin, I found that the salivary secretion which was excited by the standard procedure of chewing gum was lowered about 50 per cent. Winsor has reported more recently a similar experiment. He placed a subject in a tub of hot water for an hour. Sweat, of course, passed out to the water. The standard act of chewing resulted in only half the previous production of saliva. Drinking water promptly restored the normal rate.

Earlier, I mentioned hemorrhage as a cause of thirst. Wounded men after a battle call incessantly for water. We now have a reasonable explanation of the phenomenon. Bleeding is quickly compensated for by contraction of the blood vessels so that the capacity of the circulatory system fits tightly around its content. As time passes, the blood volume is restored by the entrance of fluid into the vessels from the tissue spaces. Until that process is complete, however, the vessels remain in a constricted state. Such constriction lessens the blood flow to superficial organs, among which are the salivary glands. With a reduced delivery of blood there is a reduced secretion. The correctness of this explanation was

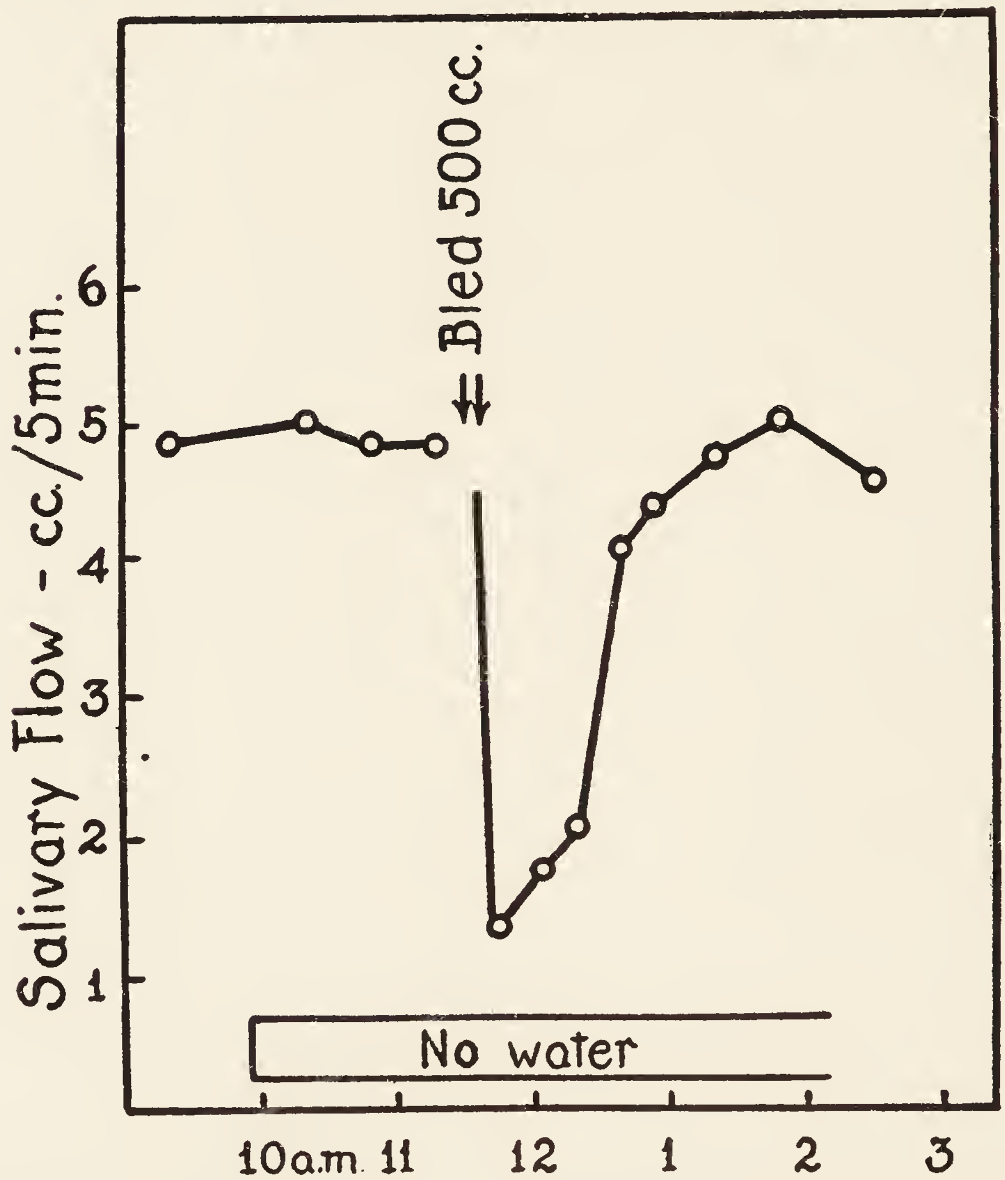

FIGURE 8. *Graph showing the effect of hemorrhage on the secretion of saliva. After removal of 500 cc. of blood from a vein, the rate of salivary secretion, excited by the dry-mouth reflex, was reduced about four-fifths; gradually, without increase of fluid in the body, the former rate was restored. (Experiment by Gregersen, not previously published.)*

proved by Gregersen in an experiment on himself. After about a pint (500 cc.) of blood had been removed from his veins the saliva flow resulting in five minutes from the dry-mouth reflex quickly fell about 80 per cent (see fig. 8). In the course of an hour, although no fluid was taken, the original response gradually returned—just the result which was to be expected from relaxing of vascular constriction as the blood volume was slowly regained.

All these methods used to lessen the water content of the body—sweating, hemorrhage and avoidance of drinking—were accompanied by a reduced output of saliva. Associated therewith, I can testify, was the typical feeling of dryness and stickiness in the mouth. And shortly after water was drunk and the natural salivary flow was restored, thirst was abolished.

We can now account for some of the experiments cited in support of the theory that thirst is a general sensation. Bernard's dog with an open gastric fistula continued to drink frequently until the fistula was closed. He continued not because there was a general demand for water throughout the body so long as the fistula remained open, but because it was only after escape through the fistula had been stopped that the body received water and thus the salivary glands were supplied with what they required for their proper functions. Furthermore, the abolition of thirst by injecting fluid into the veins of thirsty animals would be expected, for, as shown in figure 7, by furnishing an adequate water supply the saliva flow is promptly re-established, and the parched mouth and throat are again continuously moistened.

VIII

The other line of evidence pointing to local dryness of the pharyngeal region as the occasion for thirst we shall follow in noting what happens when dryness there is produced in various ways without altering the water content of the body. The simplest way of artificially depriving the mouth of moisture is by use of the drug atropine. It acts in such manner as to stop the secretion of saliva. In an experiment with atropine, which I performed on myself, the salivary output, resulting from mastication for the standard period, fell to approximately *one-fourteenth* of the previous amount. There was, of course, no noteworthy loss of water from the body. Nevertheless, all the feelings of ordinary thirst were present—the sense of dry tongue and throat, the stickiness of the moving parts, and the difficulty of speaking and swallowing. Now, without addition of water to the body, the mouth and throat were washed with a weak novocaine solution. The immediate disappearance of the sensation of thirst was doubtless due to the water in the wash. But the relief lasted much longer than when water alone was used and therefore the anesthesia of the nerve endings, produced by the novocaine in the wash, must have been an important factor. The reader will note that this effect was confirmatory of the observation previously mentioned that the tormenting thirst of diabetes insipidus can be temporarily abolished by brushing the pharynx with a weak solution of cocaine. In spite of these demonstrations of close dependence of thirst on local dryness, or respite from that discomfort during local anesthesia, the theory that thirst must be a general sensation was so strong that the effects of drugs were attributed to changes which they produced in the brain or in the blood.

The possibility of interference by a central action of drugs seemed to be ruled out by evidence obtained by Bidder and Schmidt about the middle of the last century. They reported that if the ducts leading from the salivary glands into the mouth were closed, the animal thus deprived of the benefits of saliva was always ready to drink. Here again there was no reduction of the water content of the body, only a reduction of the local moisture of the buccal cavity, such as is produced by atropine. Under the circumstances the animal acted as if thirsty, as if he had been long in need of water. Unfortunately Bidder and Schmidt did not describe the conditions which prevailed in their experiments. Recently Montgomery has performed experiments similar to theirs. She found that if moist food is fed and no special demands are made on the organism, the fluid produced by the glands in the lining of the mouth is enough—there is no increase in the average daily water intake. If the conditions are altered in one respect, however, so that the surrounding air is dry and warm and tends to desiccate the mucous surfaces as the animal breathes, the water intake, as Gregersen and I showed, may rapidly increase well over 100 per cent above the usual amount in the same circumstances. In the absence of bodily dehydration, therefore, and also in the absence of drugs, a deficient salivary flow causes animals to drink much more than they otherwise would drink—i.e., they act as if thirsty.

Another illustration of the appearance of thirst when the mouth becomes dry, though the water supply of the body remains unchanged, is found in the common experience of the effect of fear. A child called upon to "speak a piece," or an adult, confused and bewildered as he faces an audience, may have insatiable thirst. Fright or terror is accompanied by constriction of the peripheral blood vessels. That reduces the blood supply to the salivary glands. That in turn, as we have already seen, lessens the flow of saliva. A vivid instance of the effect of fear in causing thirst, all the more striking because it was reported without regard to its illustrative value, occurred in the adventures of Dr. H. J. Howard when he thought he was about to be killed by Chinese bandits. "So I was going to be shot like a dog," he wrote. "My tongue began to swell, and my mouth to get dry. This thirst rapidly became worse until my tongue clove to the roof of my mouth, and I could scarcely get my breath. The thirst was choking me.... I was in a terrible state of fear." He prayed for strength to meet his doom, and as he determined to die like a man, his fear vanished. "Instantly my thirst began to disappear," he continues. "In less than a minute it was entirely gone and by the time we had reached the gate I was perfectly calm and unafraid." Here again is living evidence that thirst, intense and tormenting, may not be associated with a real need for more fluid in the body, but may arise from a local condition in the mouth.

IX

A highly interesting phenomenon relative to the theory of thirst which we are considering is that which occurs after a meal—a postprandial thirst. In tests made on himself Gregersen demonstrated that for a considerable time after a dinner has been eaten, with care to drink only a moderate amount of fluid, the dry-mouth reflex will call forth much less saliva than usual (see fig. 9). And then, surprisingly enough, the response from the reflex gradually returns until it is as great as ever, although meanwhile no water has been swallowed! This remarkable observation was better understood after it was confirmed in studies on dogs. For that purpose Gregersen devised a "potometer," an instrument which registers automatically, at any time of the night or day, when a dog drinks and how much. Thus he learned that, when dogs are quiet, almost all the water they drink in 24 hours is taken within the first few hours after feeding, regardless of when the food is given them. In other words, the dogs act as if they had a postprandial thirst. Now, if they are not allowed water for eight or nine hours after feeding they drink much less than when water is continuously at hand for them to take freely.

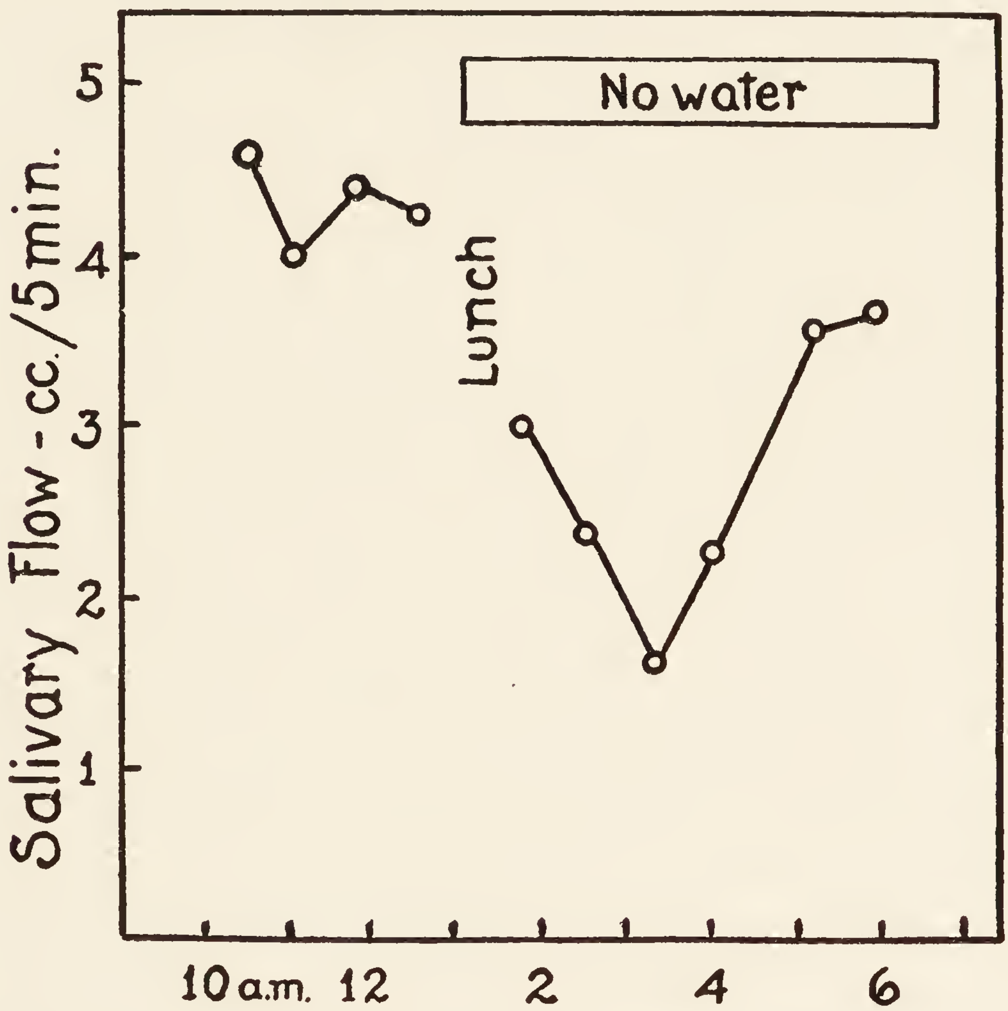

FIGURE 9. *Graph illustrating the effect of digestion on the flow of saliva. After a meal the dry-mouth reflex excites less saliva than before; as time passes, the amount evoked in a given time returns to the previous level, although meanwhile no fluid has been taken in. (Experiment by Gregersen, not previously published.)*

An example will make the difference clear. On April 13, 1932, a dog was fed at 4:00 p.m., and the potometer record showed that during the next five hours he drank nearly 500 cubic centimeters of water (about a pint).

Only a negligible amount more did he take until 3:30 the next day. Then, after feeding, he drank, within four hours, about 350 cc. Again, that practically sufficed until the following afternoon. At 3:30 p.m. on April 15, he was given food as before, but was not provided with water until midnight, i.e., eight-and-a-half hours later. One might suppose that after so long a delay he would be eager for a drink. Not at all. Although an abundance of water was available the dog drank immediately less than 50 cc., and for the next thirty-six hours the total consumption was scarcely more than 100 cc. Within four hours after feeding again he drank about 700 cc.

These curious observations, indicating that thirst is present after food is eaten, and that if the thirst is not then slaked it disappears, were at first puzzling. They have a reasonable explanation, however, in the loss of water from the body as the digestive glands secrete their juices into the contents of the stomach and intestines. The gastric juice, the pancreatic juice and the bile are all delivered in large volume into the alimentary canal when a meal is being digested. These juices are mostly water. Of course, some of this water soon begins to go back into the body, as the digested food is being absorbed. A large part of it, however, remains mixed with the unchanged nutriment in the alimentary canal, rendering easy its passage through the canal and serving as a medium in which the chemical changes of digestion can occur. All the water which is contributed to this mixture is as if actually lost from the organism. It reduces the volume of the blood quite as much as an equivalent amount of sweating or an equivalent hemorrhage would reduce it. After a meal eaten without drinking, actual measurement showed a reduction of blood volume amounting to approximately 20 per cent. The loss of water into the digestive tract is, of course, only temporary. As soon as the food is prepared for absorption, it is carried through the intestinal wall into the body, dissolved in the watery juices. That process continues until almost all of the fluid which was secreted has been restored.

We are now able to understand postprandial thirst. When the digestive glands have abstracted a large amount of fluid from the blood and discharged it into the alimentary canal, the salivary glands are not provided with the means for continuing their secretion—the dry-mouth reflex reveals a fall in salivary output. The mucous membranes of the mouth, therefore, are not kept satisfactorily moist. Thirst is the consequence. Thus is explained the behavior of dogs when, a few hours after a meal, they drink abundantly. Thus is explained the custom of passing glasses of water in the evening after a repast. Thus is explained, also, the indisposition to drink if food has not been eaten. And thus is explained the disappearance of postprandial thirst if one—man or dog—endures it without drinking, for after the delay the fluids, temporarily loaned to the digestive process, come back into the blood stream, and the need for water is no longer pressing.

Naturally, in our routine habit, we take fluids with food as we eat. Often persons are warned against that habit. Experiments on human beings by Ivy and others have shown, however, that within limits taking water at meals is not objectionable. Two to four glasses drunk during a repast increase instead of decreasing the acid of the gastric juice, essential for gastric digestion. Such amounts also increase the rate of discharge of food from the stomach. Water, after going through the stomach, is soon absorbed. It serves to compensate for the loss of fluid from the blood while the digestive juices are being secreted after eating has ceased and while digestion is continuing. Ordinarily, therefore, we do not experience acutely the postprandial thirst which was manifest in the dogs under experimental conditions. It is an interesting fact that as a rule after a large meal there is relatively small passage of water from the body through the kidneys. The reason for this phenomenon is now clear—the organism is using water in the digestive process. Only when that process has been completed, and the valuable parts of the food have been absorbed, and the waste parts have been pushed onward into the large intestine, is the water restored to the body in amounts which make an excess. As soon as there is excess it overflows through the renal tubules.

If we survey the foregoing evidence as a whole we are led to the rather banal conclusion that thirst is what it seems to be—a disagreeable sensation due to drying of the mucous membranes of the fauces and pharynx. The real interest in localizing the origin of thirst at the back of the mouth is found in the relation of the salivary glands to that area. The area, set where the moving air tends to dry it, is normally kept moist by secreted saliva—a liquid which is almost pure water. If the salivary glands do not have water supplied to them they cannot function, the area dries and we experience thirst. As soon as requisite water is available, the glands function and thirst vanishes. Thus the glands, serving strategically a region readily desiccated, become sensitive and delicate indicators of the general bodily need.

As already mentioned, the organism manages its necessary affairs automatically. When needs arise annoying or distressing sensations appear. By getting rid of them we act in a way which promotes bodily welfare. Among these sensations are asphyxia when, in asthma, for example, the oxygen supply is insufficient; pain when harmful conditions are present; and fatigue when brain or muscle has been excessively employed. To this group belong also hunger and thirst. Relief from such states of distress yields experiences which are especially happy and comforting. Great sweeps of fresh air after difficult breathing, the blissful sense of release after severe pain, and the rest which follows healthful fatigue, are among the deep delights. And the satisfaction of real hunger and real thirst brings pleasures so keen that they almost warrant the deprivation which makes them possible!

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Chapter III

DIGESTION AND BODILY VIGOR

Nature works on a method of all for each and each for all.

RALPH WALDO EMERSON, *Society and Solitude* (1870).

Taking food and drink is a great enjoyment for healthy people, and those who do not enjoy eating seldom have much capacity for enjoyment or usefulness of any sort.

CHARLES WILLIAM ELIOT, *The Happy Life* (1896).

I

THE central idea in this chapter is old. It is best expressed in a well-known parable—"Now there are many members, yet but one body. And the eye cannot say unto the hand, I have no need of thee, nor again the head to the feet, I have no need of you.... And those members of the body, which we think to be less honorable, upon these we bestow more abundant honor.... The members should have the same care one for another. And whether one member suffer all the members suffer with it; or one member be honored, all the members rejoice with it." Among the members commonly regarded as less honorable are the stomach and intestines. Here we pay them tribute. By means of the processes which take place within them the energy-yielding food, which is absolutely essential for every motion we make, is rendered useful; and if they fail or are deficient in their services, all the rest of the organism is involved. As in the parable, however, the digestive organs do not form an isolated system—they are one of a company of related systems. They serve the other systems and are in turn served by them. Thus it is profoundly true that not only do the digestive organs suffer when other members of the body suffer, but when the digestive organs are disordered the other members must share the consequences.

The most important connections unifying and coördinating the various organs and groups of organs in the body are those supplied by the nervous system. The elaborate and intricate organization of nerve filaments in that system allow any part of the living organism to be brought into quick communication with any other part, much as a vast telegraph and telephone network may be used to join together distant regions in a large country. Through the nerves which reach from the brain and the spinal cord to the gastro-intestinal canal conditions highly favorable to proper digestion, or highly unfavorable to it, may be produced.

II

In order to understand how the nervous system may affect the digestive processes we must survey the main features of its organization. Like learning the alphabet this survey makes up in later usefulness what it lacks in temporary interest. First, the nervous system is divisible into two grand divisions—one concerned with the outer world, the other with the inner world of the organism. The portion which relates us to the external environment is known as the voluntary system; through sense organs on the body surface we receive impressions —contacts, sounds, odors, light waves—which give us information about things at our finger-tips, about neighbors and friends, about current events, and about objects thousands of light years distant from us. By use of this information we adjust ourselves to our material and social surroundings, changing them as we may wish, or altering our relations to them. These adjustments are made by control of striate muscles, most of which are attached to the levers of the bony skeleton. In figure 10 the striate or skeletal muscles, which are under voluntary government, are not represented.

The portion of our nervous organization which is

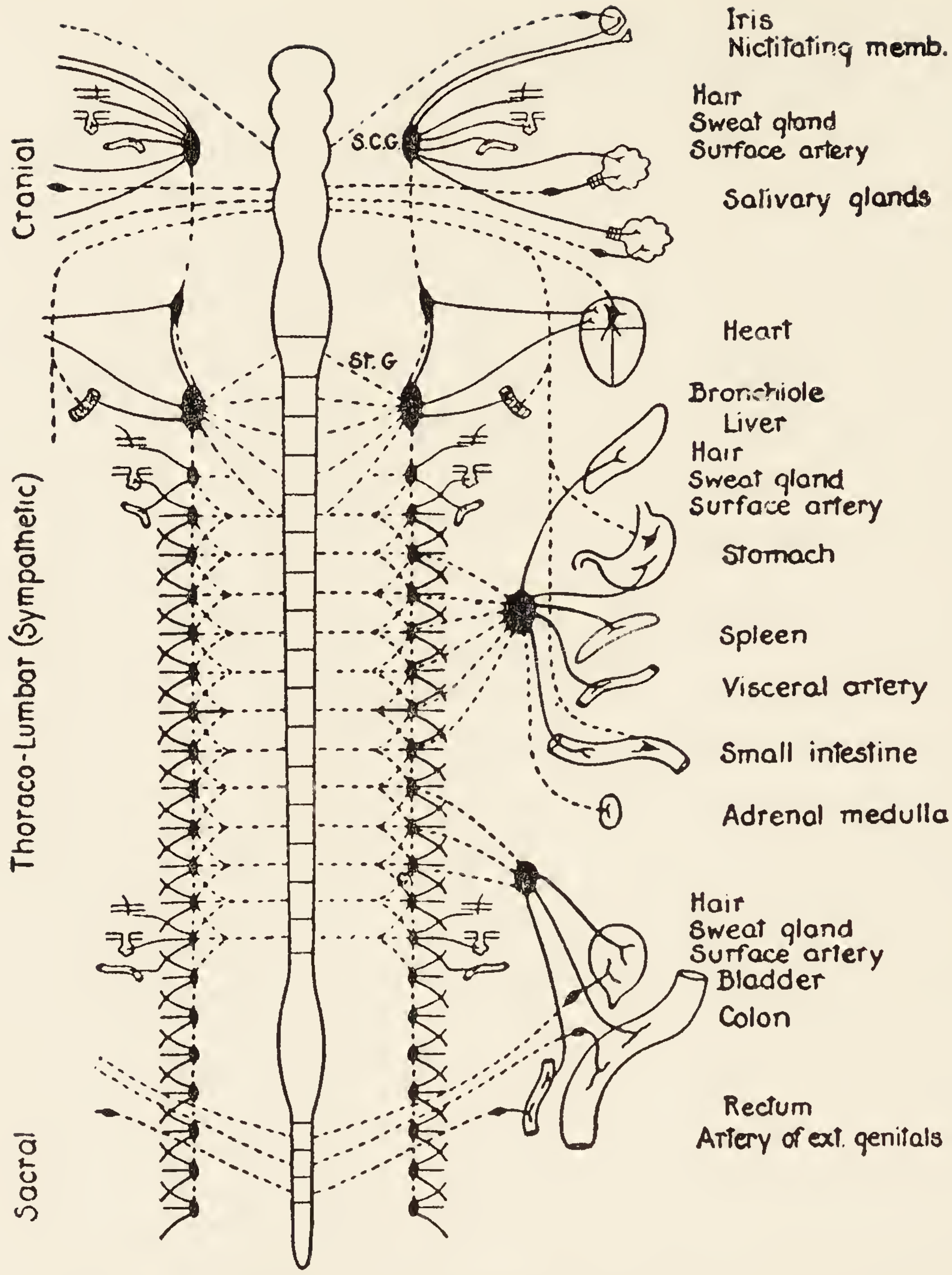

FIGURE 10. *General arrangement of the autonomic portion of the nervous system. The brain stem and the spinal cord are represented in the middle. The cranial, sacral and sympathetic preganglionic fibers (represented in dash-lines) and the chains of sympathetic ganglia are symmetrically distributed to the two sides of the body, but the distribution is represented more completely on the right than on the left of the diagram. The large* unpaired *prevertebral ganglia, connected with the abdominal viscera, are indicated on the right.*

concerned with the inner world of the organism is sometimes called the involuntary or vegetative or autonomic system. It operates so routinely and so automatically within us that only by its effects are we aware of its actions. It causes blanching of the face in fear, it brings forth the red blush of shame; it speeds the heart rate during excitement and slows it during rest; it makes the salivary glands secrete when savory food is chewed, it stops their secretion in times of terror. As these examples indicate, the autonomic or involuntary system affects the heart, the digestive glands, and muscles—the smooth muscles—of blood vessels, altering their state *in either direction,* plus or minus. It likewise affects abdominal viscera—the glands and smooth muscles of the stomach and intestines, and the spleen as well, and the liver and the bladder—usually having here also both an excitatory and an inhibitory influence.

As shown diagrammatically in figure 10, the autonomic nervous system is composed of three parts, the mid-part or thoraco-lumbar or sympathetic division, and the two others (cranial and sacral), sometimes called the parasympathetic divisions. We need not consider all the operations of the autonomic system. We are chiefly interested in its functions as it affects the digestive organs. Specifically, at this stage of our inquiry, we shall attend to the parasympathetic connections. The lines in figure 10 represent nerve pathways reaching out from the brain stem to the salivary glands; they show the long vagus or wandering nerves which pass down either side of the neck and, after sending branches to the heart, innervate the stomach and small intestine; they represent also the sacral autonomic supply to the large intestine (colon) and rectum. The reader should note that each of these organs has also a nerve supply from the sympathetic division. In these two separate nerve connections—cranial and sympathetic—is found the explanation of the positive and the negative, i.e., the excitatory and the inhibitory, effects of the autonomic impulses; for, as a rule, whenever representatives of either the cranial or sacral division meet representatives of the sympathetic division in any organ, they are opposed in action. Thus the sympathetic impulses accelerate the heart beats, and those of the vagus (the vagal impulses—from cranial sources) check or inhibit the beats. Exceptions to this general statement we shall note later.

As we continue our consideration we shall repeatedly refer to the rôle of the autonomic system in the regulation of the functions of the digestive organs, for these functions are carried on through the agency of glands and smooth muscle.

III

Although sympathetic and parasympathetic filaments conduct nerve impulses from the central nervous system to the digestive tract, they are not essential for the performance of digestive functions. Just as the heart will continue its services as a pump and keep the blood circulating through the blood vessels after both external nervous connections, sympathetic and vagal, have been removed, so likewise the stomach and intestines are capable of carrying on their activities without external control from the spinal cord and brain. Many years ago two German investigators, Hofmeister and Schutz, removed the stomach of an animal after death and placed it in a warm, moist atmosphere under glass. They observed that the peculiar rings of constriction, the "peristaltic waves," coursed downward along the axis of the stomach toward the opening into the intestine, i.e., the pylorus, in a quite normal fashion. Similarly, in 1906, in studying by means of the Röntgen rays the motor activities of the gastro-intestinal canal after the vagus and sympathetic nerves had been severed, I noted that the characteristic movements of both the stomach and the small intestine continued quite normally, although these organs were completely deprived of any extrinsic nervous support.

Since the digestive organs are capable of conducting their own affairs in a fairly satisfactory manner in the absence of influences from the central nervous system, the question arises as to the utility of the connecting nerves. I hope to present evidence in this chapter and in the next that the rôle of the extrinsic nerves of the alimentary tract, in so far as its motions are concerned, is that of affecting the "tone" of the smooth muscle of its walls. The word "tone" or "tonus" or "tonicity" is one that is rather loosely employed by laymen, by physicians and by professional physiologists. When we employ it we should understand fairly definitely what we mean.

The word "tone" signifies, at least in its unqualified use by physiologists, a persistent, moderate degree of activity. We speak of the tone of the blood vessels as a continuous, moderate state of contraction of the muscles in their walls, that is maintained by the tone of the nervous center affecting them, the vasomotor center. The great advantage of a moderate state of activity is that it can be varied in either direction—the tone of the blood vessels, for example, can be increased by stimulating a so-called "pressor" nerve, or can be reduced by stimulating a "depressor" nerve. Likewise, we speak of the vagus nerve as exercising a tonic control over the beat of the heart, keeping the rate rather steadily at an intermediate stage between great rapidity and extreme slowness. Again the advantage appears; by increasing vagal tone the heart is made to beat less frequently, by decreasing it the heart is made to beat more frequently. When the idea of tone is applied to the control of skeletal muscle it becomes somewhat more precise. We understand by the tonicity of skeletal muscle the continuous, moderate *tension* in which the muscle is held so long as it receives a proper delivery of nerve impulses. This tension makes the difference between the slightly stiff feeling of a muscle which is normally innervated and the soft, flabby feeling of one that has recently lost its nerve connections, or the difference between the consistency of muscles in a living and those in a dead body.

The idea of "tone" may be extended further, however, and applied to the body as a whole. Here the significance of the word becomes less precise. We speak of health as being a state of tonic well-being. Definitions of health are at best somewhat vague and unsatisfactory. Perhaps as good a concept of health as any is that of the condition of the body in which, when the body is at rest, the various organs continue their functions at a moderate rate, and in which disturbance or stress is met promptly and is followed fairly promptly by a return of the organs to their former moderate activity. The conditions which are requisite when we undergo a test for "basal metabolism," with its attendant medium rate of cardiac and respiratory rhythm, has familiarized us with this concept. We may recognize that the idea of a basal state is similar to that of tone as above described; it is a state of persistent, moderate activity in quiet conditions that can be varied in either direction—increased or decreased.

We may seem to have wandered far from our starting point, but I wished to consider the different ways in which the word "tone" may be understood. When I use the word "tone" in describing the effects of the extrinsic nerves of the alimentary canal on its muscles, I shall employ it in its narrower sense of indicating the continuous degree of tension or pressure which these muscles are exercising. With this explanatory preparation we may now proceed to consider the rôle of the extrinsic connecting nerves of the digestive tract, and specifically, at present, the vagal and the sacral nerves as representatives of the parasympathetic divisions.

IV

The two vagus nerves are distributed throughout the alimentary tract from its beginning in the upper esophagus to the end of the small intestine. We shall restrict our interest, however, to the effects which these nerves have on that portion of the tract which is composed of smooth muscle. Since their importance for the establishment of a tonic state in the smooth muscle of the alimentary tract was first observed by means of the Röntgen rays in the lower esophagus, the evidence of their function in that region will be particularly emphasized. As we shall see, the services of the vagi disclosed in the esophagus are true also for the stomach and intestines.

Almost one hundred years ago the Scotch physiologist, Reid, declared that if the vagus nerves are paralyzed there is a consequent paralysis of the esophagus, and swallowing becomes impossible. This doctrine was transmitted through the decades until relatively recent time. Two important considerations were overlooked by Reid. First, he did not recognize the difference between the immediate paralytic effect of the failure of vagal influence, and a later recovery of functional efficiency by the smooth muscle; and second, he appears to have been unaware of the fact that in many animals the lower half of the esophagus in the chest has a coat of smooth muscle. In 1907, while observing a cat, I had occasion to note that for some time after interruption of vagal impulses there is a total absence of peristalsis in any part of the esophagus. This observation confirmed that made by Reid. The paralyzed state, however, is followed by a gradual and quite remarkable restoration of contractions in the part of the tube which is equipped with smooth muscle. The first effect, which lasts for at least a day, is complete inactivity. By means of the Röntgen rays it was possible to see that the food, which was swallowed and forced onward into the gullet by the effective upper portion of the esophagus, stagnated in the lower thoracic part and remained there for many hours. As mass after mass of food was swallowed the lower esophagus became filled with a distending accumulation which bulged its walls outward until it had a sac-like form. Most careful observation by means of a fluoroscope revealed no sign of movement. In short, as a consequence of abolition of vagal influence, the esophagus utterly lost all muscular tone—it relaxed to the limit without any instant tensile or contractile reaction. But when the animal was examined the next day the accumulated mass had been forced onward.

Now food was again given repeatedly. When the esophagus had been distended to about twice its natural diameter, but not so much as on the day before, there occurred a slight ring-like constriction of the tube in the lower portion where smooth muscle was present, and this traveled as a peristaltic wave toward the stomach. The first wave was followed by other similarly weak peristaltic constrictions. Gradually these progressive waves pushed more and more of the esophageal contents into the gastric cavity, until the amount that was left was considerably reduced. On the third day the same experiment was repeated, and it was found that then the esophagus need be only slightly distended before a peristaltic wave started and quite effectively propelled the food mass along the tubular channel, wholly clearing it.

A review of these observations brings out a fact of cardinal significance for our immediate interest. They demonstrate that an important condition for arousing persistent activity in the lower esophagus is the stretching of the muscular wall. The esophageal tube, soon after it has been deprived of vagal support, is relaxed. When in that state a slender mass of food, spread along its length, may lie for some time unmoved. An addition to the first mass, however, that causes some stretching of the wall, results in an appearance of peristaltic waves, rather ineffective but recurrent. And now, as repeated reductions of the accumulated food make more and more slender the remaining strand, it lies for longer periods uninfluenced by esophageal contractions. In the course of time after the vagus nerves have been severed the smooth muscle of the esophagus becomes in some manner more responsive to the presence of the material which it surrounds, because the material is driven into the stomach with progressively increasing speed, and even slender masses are sufficient to stimulate peristalsis. It seems that the recovery of this functional service of the lower esophagus is due to a restoration of the tone of the smooth muscle, i.e., to the development of a moderate state of contraction, so that the muscle has a capacity for displaying tension when it is stretched. Ordinarily this capacity is maintained by vagal influences. In their absence, however, the smooth muscle, and perhaps the local nerve net associated with it, develop an intrinsic tone which compensates for the influences which have been lost.

V

I have described in detail the esophageal experiments because they are illustrative; the facts brought out by them are applicable to other parts of the alimentary tract. For example, an effect similar to that observed in the lower esophagus may be seen also in the stomach after it has been deprived of its vagal innervation. The condition in the stomach, however, differs in one important respect; in the esophagus the vagal control is not opposed by sympathetic impulses, whereas in the stomach the two sets of nerves, vagi and sympathetic, may both be effective. In order to learn about the function of the vagus nerves alone, therefore, the sympathetic nerve impulses must be previously excluded. When this condition has been met, blocking of vagal impulses is found to result in a marked depression of peristaltic activity of the gastric muscles. For some hours thereafter the food introduced into the stomach by a tube may rest in that organ wholly undisturbed by peristalsis; and often in these circumstances, when the peristaltic waves begin and are recurring at their normal rhythm, they are characterized by being unusually shallow and weak as they course along the gastric wall. Sometimes they are hardly visible. At other times they can be seen only when near the pylorus. As days pass these signs of tonelessness largely disappear, and after about a week the waves start at the usual period after a meal and show much of their natural vigor. These observations, which I first reported in 1906, have been confirmed by Borchers, who reported that only after five days were the normal conditions fully restored. They have also been confirmed by M'Crea, M'Swiney and Stopford, who noted that all motor functions of the stomach disappeared immediately after severance of the vagi and that complete recovery required seven days or more.

The similarity between the effects of denervation on the stomach and on the esophagus is quite remarkable. The immediate result on the esophagus is paralysis. Gradually, however, the muscles of the esophageal wall recover a tonic state, and simultaneously there is a recovery of the ability of the muscles to respond to the contents which stretch them. Thereupon effective peristalsis is restored. In the stomach, likewise, there is a gradual and extraordinary development of an intrinsic tone after the sympathetic nerves and the vagi have been excluded from action. The resting stomach may contract to a smallness of size which is almost incredible. When this degree of inherent tonicity has been developed, the conditions which are normally provided by vagal impulses have been restored or perhaps somewhat exceeded, and the stomach, like the esophagus, when distended with food, is capable of exhibiting its normal peristaltic contractions.

The evidence which we have surveyed now permits us to summarize the outstanding natural functions of the vagus nerves in relation to the smooth muscle of the esophageal and gastric walls. These nerves are not "motor" nerves, as they are sometimes called; they are more properly designated *"tonic"* nerves. At proper times they exercise a positive influence, an influence which causes the muscle to exert tension and which therefore is a prerequisite for rhythmic recurrence of peristalsis. If the tonic activity of the vagi increases, the vigor of peristaltic contraction increases. If the nerves are severed, muscular tone is temporarily lost; the activities of the tract are for some time in abeyance, and even when peristalsis reappears the constriction rings are at first shallow. This recovery of peristaltic activity is associated with a gradual restoration of a tonic state, an intrinsic tonic state, in the smooth muscle itself. We may conclude, therefore, that the most important alimentary function of the vagi is that of setting the smooth muscles of the digestive tract in continuous, moderate contraction, of making them press on the material which they surround so that in relation to the contents, for example, the muscles are as if stretched by those contents.

VI

Although the vagus nerves serve to maintain tonicity in the gastric musculature, they may have in addition an inhibitory, relaxing effect. In other words, they must be recognized as composite nerves. In relation to the stomach their chief function, that of causing a state of moderate muscular tone, produces during digestion a considerable intragastric pressure. Suppose now that while this condition is prevailing one desires to swallow more food. Obviously the muscles of the esophagus would have to force the swallowed mass into the stomach against the pressure which exists there if no arrangement were provided to lessen it. In the organized control of skeletal muscles possible antagonism is usually suppressed. When we bend the arm at the elbow, for example, the muscles which might oppose that act are reciprocally relaxed.

Likewise between the esophagus and the stomach there is a nice adjustment which obviates a conflict of opposed muscle groups. In 1911 Lieb and I found that whenever

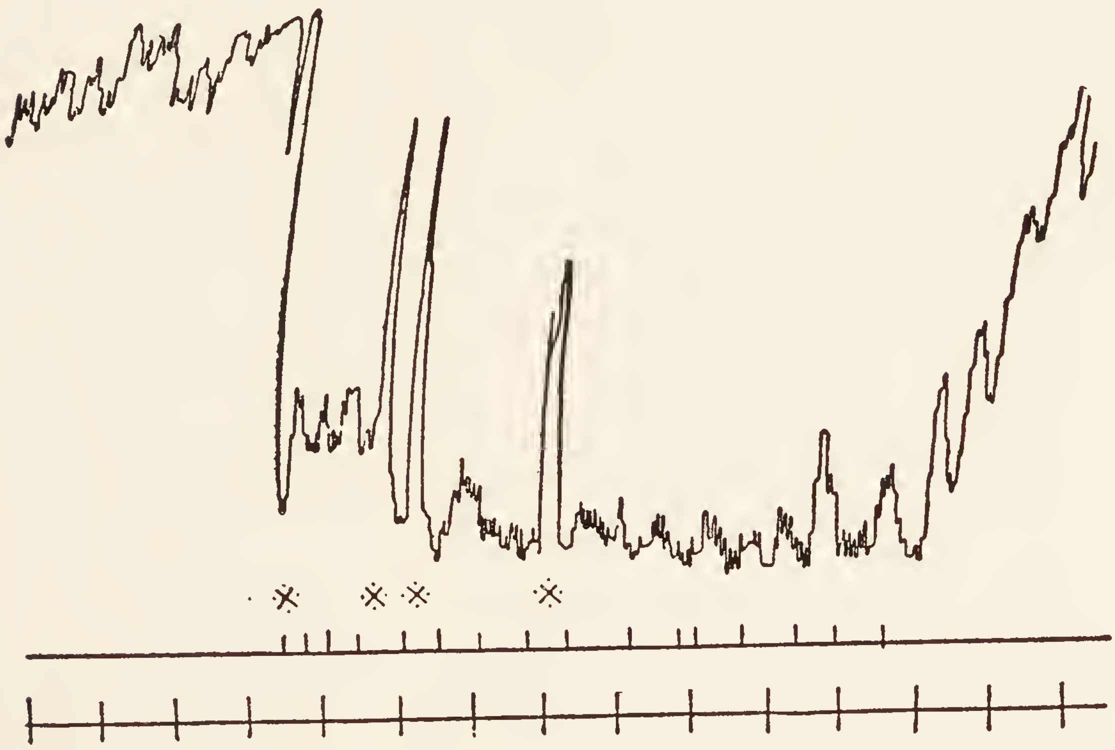

FIGURE 11. *Record of the receptive relaxation of the stomach. The top line registers pressure in the stomach. Each vertical mark in the middle line indicates an act of swallowing. Each asterisk indicates slight bodily movement of the animal. The bottom line records time in half-minutes. (From Cannon and Lieb, "The Receptive Relaxation of the Stomach,"* Am. J. Physiol., 1911, xxix, 270.)

a swallowing movement occurs, the intragastric pressure drops gradually almost to zero (see fig. 11). The drop starts between two and five seconds after the larynx is lifted in the act of swallowing and is reduced to the lowest point (in the cat) between six and ten seconds after the swallowed mass leaves the mouth. The admirable nature of this receptive relaxation of the stomach can be best appreciated if we consider that the time required for passage through the esophagus varies between seven and ten seconds. Thus whenever a tonic state of the gastric muscles has raised intragastric pressure, an automatic mechanism exists for lowering that pressure while the esophagus is pushing freshly swallowed food into the stomach. This remarkable reciprocal adjustment between the esophageal muscle and the gastric muscle wholly disappears after the vagus nerves are rendered inactive. We must recognize, therefore, that whereas some vagal fibers convey tonic impulses, others convey impulses which are inhibitory in their effects.

As already noted, the vagi are distributed throughout the small intestine from the pylorus to the sphincter at the end. Along this great extent they apparently exercise on the small gut, as well as on the lower esophagus and the stomach, a tonic influence. On completely excluding inhibitory sympathetic impulses, I found that the rate of passage of food through the small intestine was much accelerated; but thereafter, when vagal impulses were also excluded, the passage was slower than usual. This is the result to be anticipated if we assume that the vagi affect tonically the muscular wall of the intestine as they affect the muscular wall of the stomach.

The alimentary canal may be regarded as having two reservoirs connected by a long tube, the small intestine. The first reservoir, the stomach, receives a large amount of food at one time and discharges it gradually into the intestine, where the final stages of digestion occur. The second reservoir, the large intestine or colon, receives gradually the waste material left from the digested food and discharges it at one time. The tonic innervation of the colon is quite as important as that of the other parts. It is provided by nerves belonging to the sacral division of the autonomic system (see fig. 10). Stimulation of these so-called "sacral visceral nerves" causes contraction of the muscles of the colonic wall. The extent of distribution of these nerves in the large intestine of man has not yet been determined. In the cat, however, they affect only the distal two-thirds of the colon. When they are stimulated they cause at first an increase of tone about midway of the length of the large intestine. Continued stimulation results in a shortening of the strong, lengthwise muscular coat of the final half of the colon, and thereafter in a deep contraction of the circular coat which moves downward as a peristaltic wave in a manner characteristic of the natural evacuation of the bowel. Section of the nerves results in changes which are typical of a loss of tone. The waste matter of digestion accumulates without

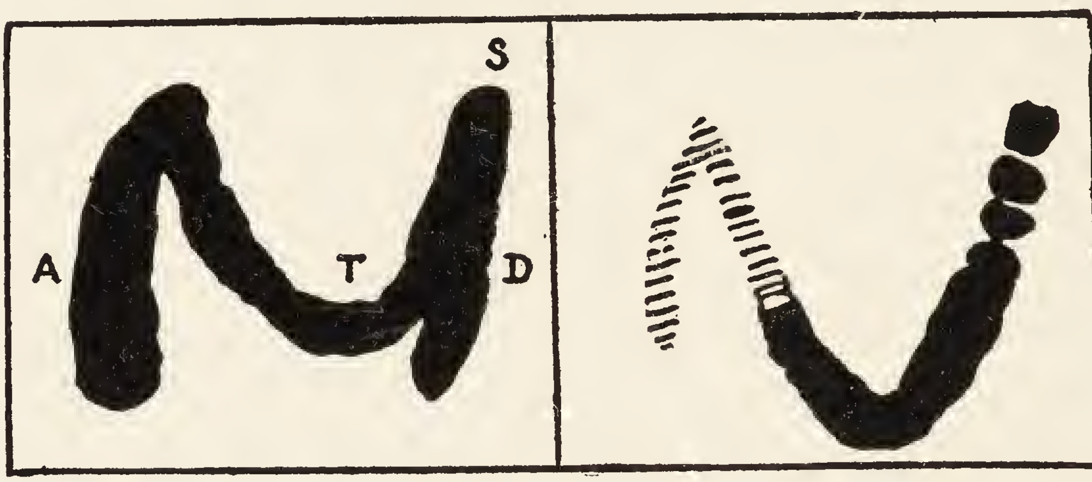

FIGURE 12. *Röntgen-ray shadows showing the conditions in the human colon before and immediately after defecation. A, ascending colon; T, transverse; D, descending; S, splenic flexure.* (From Hertz, *"Constipation and Allied Intestinal Disorders,"* 1909, 31.)

being discharged and the contractions of the muscles of the gut are sluggish and weak. These observations, made by Elliott and Barclay-Smith, were unfortunately not preceded by exclusion of sympathetic effects, and therefore indicate merely that the sacral visceral nerves offer tonic opposition to the inhibitory sympathetic influences.

VII

Related to the tonic state of the colon is the act of defecation, an important act of personal hygiene, too often regarded quite casually because of hurry, social conventions and ignorance of the consequences. In man the changes which occur in defecation have been observed particularly by Hertz, who used the Röntgen rays in his scrutiny. As shown in figure 12, the entire large intestine in man below the turn from the transverse to the descending part, i.e., at the "splenic flexure," is normally evacuated in a single movement. Thereafter, usually during the next twenty-four hours, waste material accumulates in the distal colon. It first stops at the junction between the pelvic colon and the rectum, where an acute angle seems to offer some obstruction to progress. Gradually the pelvic colon fills from this point upwards, and as more waste arrives it gathers progressively in the descending colon. On becoming distended the pelvic colon rises and widens its acute angle with the rectum and thus obviates the check on the advancement of the fecal matter. When some of this matter enters the rectum the impulse to defecate occurs. The usual performance of the act regularly after breakfast is probably due, at least in part, to stimulation of peristalsis in the colon by the taking of food—a tonic effect—although the muscular activities which attend rising and dressing may play an additional rôle. If these conditions do not result in a natural "desire to defecate," voluntary contraction of the muscles surrounding the abdominal cavity may be employed to cause some feces to enter the rectum and thus evoke the call.

When the call for defecation has come, the further performance of the act is commonly attended by increased intra-abdominal pressure, a result of voluntarily contracting the abdominal muscles and the diaphragm simultaneously. As the diaphragm contracts the entire transverse colon is pushed downward, and the ascending colon and cecum are forced into an almost globular form. Intra-abdominal pressure, as measured in the rectum during this stage, may rise to a considerable degree; it may be sufficient to support a column of mercury ranging between 100 and 200 mm. in height. The pressure causes more feces to enter and distend the rectum and reach the anal canal. The distension now excites reflexes which start strong peristaltic contractions of the large intestine, continues the tendency to press with the voluntary muscles, and produces a relaxation of the anal sphincters.

Although the process of defecation, as I have described it, involves voluntary factors, such factors are not actually requisite. The act is sometimes performed, indeed, without volition, and can occur in human beings in whom accident has completely severed the lower spinal cord from the brain.

The relation of tone to the important function of ridding the digestive canal of waste, which is an unavoidable residue of the food we eat, lies in the fact that only when there is tonic shortening or contraction of the smooth muscle of the rectum is it stretched by its contents. The stretching sets up the reflexes which cause it to contract and empty itself. If the lower spinal cord is destroyed or if the sacral visceral nerves are severed, feces accumulate and the contractions of the gut are sluggish and weak, as already noted. Now for the moral of this story! Observations on man have shown that if the call for defecation is not responded to, the rectum accommodates itself to the presence of fecal accumulation. There is a lessened excitability of the sensory nerves of the region. Quite as important a consequent is a lessened tone of the smooth muscle, so that the accumulated mass no longer produces the normal stimulus of stretching. In these circumstances a bad situation is likely to develop—

the call for defecation may disappear. Thus if the signal for emptying the rectum is not promptly obeyed it may cease to be given. The feces may then remain for a long period without being discharged, because the efficacy of the reflexes is so profoundly impaired. The discomforts and distress of constipation are the natural result.

It is well to remember that our bodies, including the digestive tract, become habituated to actions and processes by repeated experience. According to an old English proverb, "when your belly chimes it's time to go to dinner." We may accustom ourselves to having one, two or three meals a day. The number is not of great importance, but the regular recurrence is likely to be. If the usual time passes without the taking of food, hunger pangs, faintness and possibly headache may result. Likewise the discharge of accumulated waste from the colon can be made habitual. I recall the testimony of an elderly clergyman who attributed his remarkable vigor to setting aside with scrupulous care a fixed time for morning prayers and for the disposal of his digestive refuse. His devotion to routine was most commendable. And if one does not engage in morning prayers, one should at least follow the good man's example in the other respect. The habit once started, and strictly adhered to, is easily preserved.

VIII

The considerations thus far presented regarding the influence of the vagal and sacral visceral nerves may seem only remotely concerned with the promise given in the title of this chapter that it would be devoted to the relations of digestion and bodily vigor. All that we have been learning, however, is closely concerned with those relations. The reason for confidently making that statement is that the parasympathetic nerves participate with the rest of the body in any debilitation due to illness. For example, while the vagal connections between the central nervous system and the alimentary canal are intact, the general bodily weakness which is associated with a serious infection, and which is characterized by soft, toneless skeletal muscles, is characterized also by a toneless state of the musculature of the stomach and intestines. Cats in such a condition I have observed repeatedly with the Röntgen rays, and throughout a whole day I have recorded the food stagnating in the stomach without the slightest sign of a peristaltic wave passing over it; or if food had entered the intestine I have noted that it was similarly unaffected by any motions of the gut. The animals manifested no signs of appetite or hunger, and did not eat spontaneously. From what we have learned of vagal influences on the muscles of the stomach and intestines, we may assume that the indolence or total inactivity of the muscular wall of these organs is due to lack of the tone necessary for peristalsis.

The observations made on the lower animals are easily duplicated in man. My former colleague, Dr. Alvarez, has reported autopsies on patients who died from the toxin of botulism; in their stomachs food was still present which had been eaten many days before, when the trouble commenced. Similar stagnation is often noticed in men and women who have died from tuberculosis and other infectious diseases. It is a tribute to the sure vision of Beaumont that he noted this phenomenon in his studies on Alexis St. Martin. Occasionally, as he looked into the stomach of his patient through the artificial opening or fistula, he observed a disturbed appearance of the gastric lining; this was associated with symptoms of general bodily disorder such as dryness of the mouth, thirst, and exaggerated pulse. In these circumstances, he states, "no gastric juice can be extracted, not even on the application of alimentary stimulus...food taken in this condition of the stomach remains undigested for twenty-four or forty-eight hours, or more, increasing the derangement of the whole alimentary canal, and aggravating the general symptoms of the disease." On one occasion when St. Martin "complained of headache, lassitude, dull pains in the left side, and across the breast—tongue furred, with a thin, yellowish coat, and inclined to dryness—eyes heavy, and countenance sallow," Beaumont reported that the stomach was still full of food six hours after a small breakfast of fried sausage, dry toast and a pot of coffee. About three hours later Beaumont suspended a roasted oyster in the stomach and his patient ate twelve more of them. After two hours he found on withdrawing the suspended oyster that it was not half digested. Evidently the symptoms of general indisposition were associated with a marked disturbance of the processes in the stomach.

Debilitating disease is not the only state which is accompanied by a failure of proper action of the digestive organs. Severe and exhausting labor may interfere with their functions. In a man with a gastric fistula Mantelli noted that very strenuous and prolonged muscular effort brought about a condition of fatigue in which the stomach did not respond in a normal manner to the intake of food for as long as two hours. Hellebrandt and Miles, who found that gentle exercise was favorable to digestion, reported that exhaustive muscular exertion, whether it precedes or follows a test meal, is associated with a diminished amount of the natural acid of the gastric juice. In one well-trained subject exhausting exercise reduced the acid about 80 per cent. The interesting fact was noted that as the bouts of severe muscular work were repeated the depressing influence on gastric secretion progressively lessened.

As we shall see later, vigorous effort is attended by activity of the sympatho-adrenal system (see fig. 10), and the effects of such activity do not quickly pass away. It is possible that prolonged and extreme exertion may affect the digestive organs by such inhibitory influences. There is also the possibility that the central nervous system is depressed by exhausting activity and that consequently a tonic state is lacking in the stomach and intestines, accompanied by lack of normal secretion from the digestive glands. As Alvarez has remarked, "One ought to be at least as careful of oneself as an experienced horseman is of his steed when it brings him home from a long journey. He would never think of watering or feeding it immediately, but always ties it up for an hour or two so that when it feeds it will not be seized by an attack of colic." And he declares that the man who in a mountain camp comes in exhausted from a climb and at once sits down to a hearty meal will occasionally suffer afterward for several days with abdominal pain, flatulence and diarrhea. Sometimes the food will pass through the whole digestive tract, decomposed but not digested. Here is further evidence that the gastro-intestinal canal participates with conditions in the rest of the body.

IX

Besides the effect of the vagi on the musculature of the alimentary canal there is the effect of these nerves and of associated nerves (those governing the salivary glands) on the digestive secretions. Many years ago Pavlov reported that in addition to the well-known psychic secretion of saliva there is also a psychic secretion of the gastric juice—a secretion due to the pleasant taste of food, i.e., to the satisfaction of appetite. Later it was discovered that there is also a psychic secretion of pancreatic juice. The discharge of digestive fluids from the glands of the stomach and from the pancreas is dependent upon the vagal nerve supply to these organs. These psychic secretions are useful, of course, in starting the process of digestion in a satisfactory manner.

Associated with the delights of the palate is the act of chewing. The teeth are arranged like a mill, with the cheeks on the outside and the tongue within, acting together as a hopper to keep the food between the grinding surfaces. By pressing and crushing the ingested nutriment it is broken into small bits—or should be—before it is swallowed. This process of comminution enormously increases the surface area of what we eat. Thus the hidden deliciousness is brought forth and thus also the digestive juices, which can act only on the surface of the food, have immensely greater opportunity for effective attack. Furthermore, unless food is thoroughly broken up by the teeth, the task is put upon the delicate lining of the stomach, an agent quite unsuited to that function.

In 1911 I suggested that attendant on the psychic stimulation of the digestive glands, due to the pleasurable odors and flavors of food, there might be in the stomach and intestines a psychic increase of muscular tone—a state resulting from vagal impulses when food is relished in anticipation or at the time it is eaten. At that time this suggestion was based on the discovery that whereas section of the vagi before feeding was not followed by gastric peristalsis, section of these nerves shortly after feeding did not seriously interfere with the digestive process already going on. It seemed, therefore, that the pleasurable eating of food was associated with some influence of the vagi on the gastric muscle; indeed, that when food is taken with satisfaction and enjoyment the vagi establish a tonic state in the muscle, much as they establish a secretion from the digestive glands.

The suggestion and the evidence for a psychic tonus of the gastro-intestinal muscle have been supported by Alvarez. He had a patient with a large opening, or hernia, of the abdominal muscles; in that region the intestines were so thinly covered by skin and deeper membranes that their contractions could be easily seen. The remarkable fact appeared that whenever a nurse brought food, peristaltic waves could be seen as they rushed along the bowel, and also active kneading movements. Other observers have noted with the Röntgen rays that food will advance more rapidly in the intestines if a second meal is given a short time after the first. In these circumstances the second meal acts to increase the tone of the intestinal tube, and therefore serves to stimulate peristaltic activity. It is an observation of considerable importance that digestion progresses more expeditiously if the viands which are eaten are palatable than if they are not. Bearing on this evidence is the testimony of Alvarez that intestinal contractions were seen to be much more active when one of his patients ate by himself than when he was plainly annoyed by being fed by the nurse. Another pertinent instance was that of a patient who suffered from a defective anal sphincter; this unfortunate individual had to be extremely circumspect in noticing, smelling or even thinking about delectable food, except when conditions were appropriate, because of the stimulating psychic effects on the tone of the intestinal musculature and therefore on peristalsis.

All these observations point to the highly important relations between the proper functioning of the gastrointestinal canal and the general state of the organism. If the tract functions satisfactorily the energy-yielding food, pleasant in aroma and savor, when chewed thoroughly, with relish and enjoyment, and then swallowed, becomes the means of supporting all the activities of the organism in a highly efficient manner. If there is any interference with the digestive processes, this inflow of energy for the performance of bodily functions is disturbed and in consequence the whole organism suffers.

On the other hand, if there is a state of debilitation or weakness as a consequence of exhaustion, whether from excessive labor or prolonged disease or acute infection, so that the normal moderate degree of nervous activity or tone is greatly reduced, the musculature of the gastro-intestinal tract shares the tonelessness of other parts of the body; and in consequence the organs are not able to carry on vigorously the processes of digestion. It is clear that in these circumstances a vicious circle may be established such that the debilitated organism does not receive the nutriment which is necessary for its upbuilding, and therefore the debilitated state becomes accentuated. When this condition prevails the service of a skillful physician is required, who understands the essential need of serving food delicately and in small amounts, food which is easily digested and which is tempting to the appetite, and which can therefore excite to some degree the fundamentally important, tonic vagal impulses.

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Chapter IV

INDIGESTION FROM PAIN, WORRY AND EXCITEMENT

What avails it to us to have our bellies full of meat if it be not digested?

MICHEL DE MONTAIGNE, *Essays, Book* i, *xxiv* (1580).

The best doctors in the world are Dr. Diet, Dr. Quiet and Dr. Merryman.

JONATHAN SWIFT, *Polite Conversation* (1738).

I

THE stomach and intestines are devoted servants of the body. When well supported and permitted to have their way they do their work well. Most of their difficulties come from the outside. They have trouble, for example, when the voluntary part of the nervous system, which directly controls the entrance into their realm, overtaxes them. Thus the delicious taste of food may mislead the intelligence and tempt to gluttony. The stomach, charged with too heavy a load, then has to labor against great odds. Or there may be interference at the exit from their realm. Then the colon may have to accommodate itself to an increasing mass of waste material because the brain will not attend to signals and coöperate for an evacuation. In short, the "intelligence," so-called, can act most unintelligently by neglecting or disturbing the beneficent services of the digestive organs.

The voluntary part of the nervous system, however, is only an incidental disturber of digestion. The involuntary part commonly bears the greater guilt, and that because of positive interference by the sympathetic division of the autonomic system (see fig. 10, p. 84). That division, as we have seen, is ordinarily opposed to the parasympathetic divisions (cranial and sacral); as a rule it has, therefore, a relaxing effect on gastro-intestinal muscle and an inhibitory effect on the secretions of the digestive glands. Like the other divisions of the autonomic system, the sympathetic is not directly under voluntary control. It can be stimulated to activity, widespread and agitating activity, by a variety of conditions, among which are pain and profound emotional experience.

The extreme sensitiveness of the stomach and intestines when emotions are involved has long been recognized. The biblical references to "bowels of compassion," Shakespeare's scornful phrase, "Thou thing of no bowels," and Jeremy Taylor's characterization of a hangman as being "bowelless," are testimony to a common belief, centuries old, that the intestines participate in the expression of deep feelings. Modern experimental studies have fully justified this ancient belief. Borchardt, who observed a loop of dog's intestine, arranged so that it could be seen under the skin, noted that its tone and activity were constantly changing with such affective stimuli as approaching footsteps, a pat on the head, a word of reproof, or the mew of a cat. When the nerves of the loop were severed it was no longer "sympathetic" and "compassionate."

Innumerable instances could be cited to illustrate abolition of movements of the stomach and intestines in man as a consequence of strong emotion. The influence of extreme anger upon gastric digestion Beaumont noted as he watched the process in Alexis St. Martin. Violent passion, Beaumont declared, is likely to cause a reflux of bile into the stomach, a change in the properties of the gastric contents and a retarded passage of the contents into the small intestine. Alvarez has described a patient—an excitable young man—who, as the Röntgen rays revealed, still had in the stomach the meal eaten six hours before; examination showed that no organic fault existed, and then inquiry brought out the fact that all day the patient had been greatly distressed by a political quarrel in a society to which he belonged, a quarrel coming to a climax within a few hours. A woman examined by Rossbach had intestinal coils which could be seen under the thin abdominal wall; he noticed that momentary fright or anger would stop all activity of the coils for about ten minutes.

Strong emotions may bring to a standstill not only movements of the stomach and small intestine, but also the movements of the colon. A man seen by Hertz was the victim of a bad railroad accident, in which he was for more than half an hour buried in the wreckage of the cars. Although of most regular habits he was so deeply affected by the horror of the experience that through several days his bowels could not be made to act, in spite of the use of all sorts of agents to stimulate them.

The effects of emotional excitement on the colon, however, may be quite perverse. If the sympathetic impulses prevail they check action, but the sacral (parasympathetic) impulses may dominate and then the large bowel may be uncontrollably voided. Fear especially, whether in man or lower animals, is likely to have this drastic effect. I have seen chimpanzees purged abundantly when intensely excited. Furthermore, the greater activity of the muscles of the colon may at times be expressed as a sort of spasm, which has an effect just the opposite of expulsive peristalsis—the spasm causes the waste to be retained. This condition of "spastic constipation" is likely to occur in attacks, often induced by worry or by definite shock. How it happens that emotional expression, which typically employs the sympathetic system, can at times use effectively the opposed parasympathetic, remains one of the unsolved mysteries of bodily functioning.

II

Coincident with an interference with the muscular activities of the alimentary canal, produced by strong feeling, is an interference with the secretions of the digestive glands. In olden times in India the ordeal of rice was a customary mode of determining who in a group of suspected persons was the guilty one. Each member of the group was given rice to chew. The guilty person, beset by fear, would have a dry mouth because the salivary glands could not secrete; and when all were asked to put forth the chewed rice on the leaf of a sacred tree, his rice alone would not be moistened. Such, at least, was the theory. It is easy to imagine, however, the "bowelless" criminal chewing with gusto while one of the innocent but timid suspects could not muster enough saliva to wet a grain!

Emotional perturbations also stop the flow of gastric juice. Opportunity to observe this effect is offered by persons who, like Alexis St. Martin, have an artificial opening into the stomach through the side of the body—a device of the surgeons which permits a person to be nourished although accident may have closed the esophagus. The condition occurs in children who by mistake drink a corrosive liquid, and who, after the damaged esophagus has been shut by healing, must chew their food as usual but must let it enter the stomach by a tube outside instead of inside the body. In one such instance, studied by Hornborg, it was noticed that when the boy chewed agreeable food there followed a characteristic outpouring of secretion from the stomach wall. If the boy became vexed, however, and began to cry, the chewing of the food shortly thereafter was not accompanied by the usual appearance of gastric juice. This observation was confirmed by Bogan, who had a chance to examine another child with a fistula in the stomach. He found that if the child flew into a passion the effect was lasting;

even after serenity was restored the taking of food did not for some time have its usual stimulant effect on the gastric glands.

Many of us have had experiences suggested by the results reported by Bogan. We note that if we have been agitated by an emotion-provoking incident we do not immediately recover our previous calm. In a lower animal it is possible to study quantitatively the inhibitory influence of excitement on the digestive secretions. A dog, excited for five minutes by the presence of a cat, and then fed, produced during the twenty minutes which ensued only a few drops of gastric juice; the usual amount produced in that time was nearly two teaspoonfuls. By studying a dog, also, it has proved possible to learn the effect of excitement on the flow of pancreatic juice. Oechsler was able to demonstrate that when, in a dog, pancreatic secretion was well established it could easily be stopped by bringing a cat into the room. The digestive glands appear to be as readily deranged as the digestive muscles.

Psychologists have pointed out that fear may be regarded as anticipated pain. We might expect, on that score, that pain would produce the same effects as fear. This, indeed, is true. Painful stimulation brings the sympathetic system into action much as great excitement does, and consequently has similar influences on the alimentary functions. Alvarez has written of an instance which he recalled from a time when he was helping his father in his medical practice. A little girl had fallen from a mango tree early one morning and had broken her arm. The distance to the doctor's office was long and the journey, with horse and buggy, was painful. About noon the parents and their daughter reached their destination. At the first whiffs of the anesthetic the little girl vomited. Alvarez states that he remembers well his "surprise at seeing the fruit, eaten hours before in the tree, still untouched by digestion, and with the marks of her teeth clearly chiseled on the surfaces." Other instances of the disturbing influence of pain on gastro-intestinal functions could be cited.

III

In 1897, when using the then newly-discovered Röntgen rays to study the motions of the stomach, I was annoyed to find that, while some of the cats under observation showed quite normal peristalsis, others revealed no gastric movements whatever. The clue to the difference was presented when a mother cat, removed from her kittens and held in a position which allowed me to look through her body at the recurrent gastric waves, became restless. Immediately the waves entirely disappeared. She was petted reassuringly and then she began to purr. Thereupon the waves began again. Many times later I noted that any condition which was accompanied by signs of worry or anxiety stopped completely the movements of the stomach. It was clear that the reason for the absence or cessation of peristalsis in well-nourished and robust animals was a degree of emotional disturbance which characteristically inhibited them.

When I first observed that manifest emotion would inhibit gastric motility, and afterwards when I learned that it would also depress for a considerable period the function of the digestive glands, I thought that as a method of avoiding these interferences surgical interruption of the sympathetic nerve filaments would be quite reasonable. Thus the beneficent and fundamentally important process of digestion would have permanence and security. At that time, however, I did not understand the organization of the sympathetic system and the arrangements for a diffuse distribution of its influence, and therefore did not realize how widespread the effects of its activities might be. Only gradually, as new evidence came in, was there disclosed, in addition to the well-known acceleration of the heart and rise of blood pressure which result from emotional disturbance, an elaborate complex of other changes. Hairs stand erect, pupils are dilated, sweat glands secrete, there is an increase of blood sugar, an increase of red blood corpuscles, a considerable shift of the blood flow from the stomach and intestines to the voluntary skeletal muscles, and a dilation of the bronchioles—all signs that excitement causes a widespread distribution of sympathetic impulses.

The question arises as to whether there is a discharge from the inner portion of the adrenal gland in these circumstances. This question has some importance because the internal secretion, adrenine, poured into the circulating blood by the adrenal medulla, mimics almost everywhere in the body the action of sympathetic impulses. By coöperating with them, therefore, it might prolong the effects of an emotional upset. In order to obtain evidence regarding emotional discharge of adrenine, the "denervated heart" was employed. All nerve connections uniting the heart with the central nervous system were severed under strict surgical precautions. Animals thus operated upon live indefinitely in the laboratory in excellent physical condition. The heart, released from the control of the nervous system, still performs its function, pumping the blood continuously through all the myriads of arteries, capillaries and veins. The blood stream, however, is now the only connection of the heart with the rest of the body. When thus isolated from its nervous government the heart becomes extraordinarily sensitive to adrenine. An addition of one part of that remarkable substance in 1,400,000,000 parts of blood will make the denervated heart of the cat beat more rapidly.

The pulsations of the heart can be registered quite simply by holding a small, shallow cup covered with rubber (a tambour) against the chest wall and letting the cardiac impulses beat against the rubber cover; each pulsation is transmitted through a tube reaching from the tambour to a recording lever which writes on a moving surface (see fig. 13). The denervated heart allows definite evidence to be obtained in answer to the question of augmented adrenal secretion accompanying emotional stress. The animal with heart denervated can be observed any number of times in given experimental circumstances while the adrenal glands are normally connected with the sympathetic system, and can be observed in the same circumstances any number of times after the adrenal glands are deprived of their sympathetic connections. The difference in the response of the heart can be clearly and permanently registered, and offers a decisive demonstration that the discharge of adrenine into the blood stream is increased by excitement.

When such experiments as those just suggested were performed, not only did strong emotion cause a faster beat of the denervated heart, but even slight activity had that effect. Thus, if the cat spontaneously arose from a cushion and walked across the floor, there was an increase in the heart rate. As shown in figure 13, this mild exercise caused the rate to increase about 20 beats a minute. Later, when the cat was resting on a cushion and a dog was brought near, the hairs of the tail were erected, the cat hissed in a simple emotional reaction, and there was a larger increase—approximately 40 beats a minute. When now the animal was placed in a cage and the dog barked loudly and made aggressive movements which elicited a vigorous response from the cat, the heart rate, as soon as the animal could be removed from the cage and the cardiac impulses registered, displayed an increase of more than 70 beats a minute above the resting rate. After the adrenal glands had been ren-

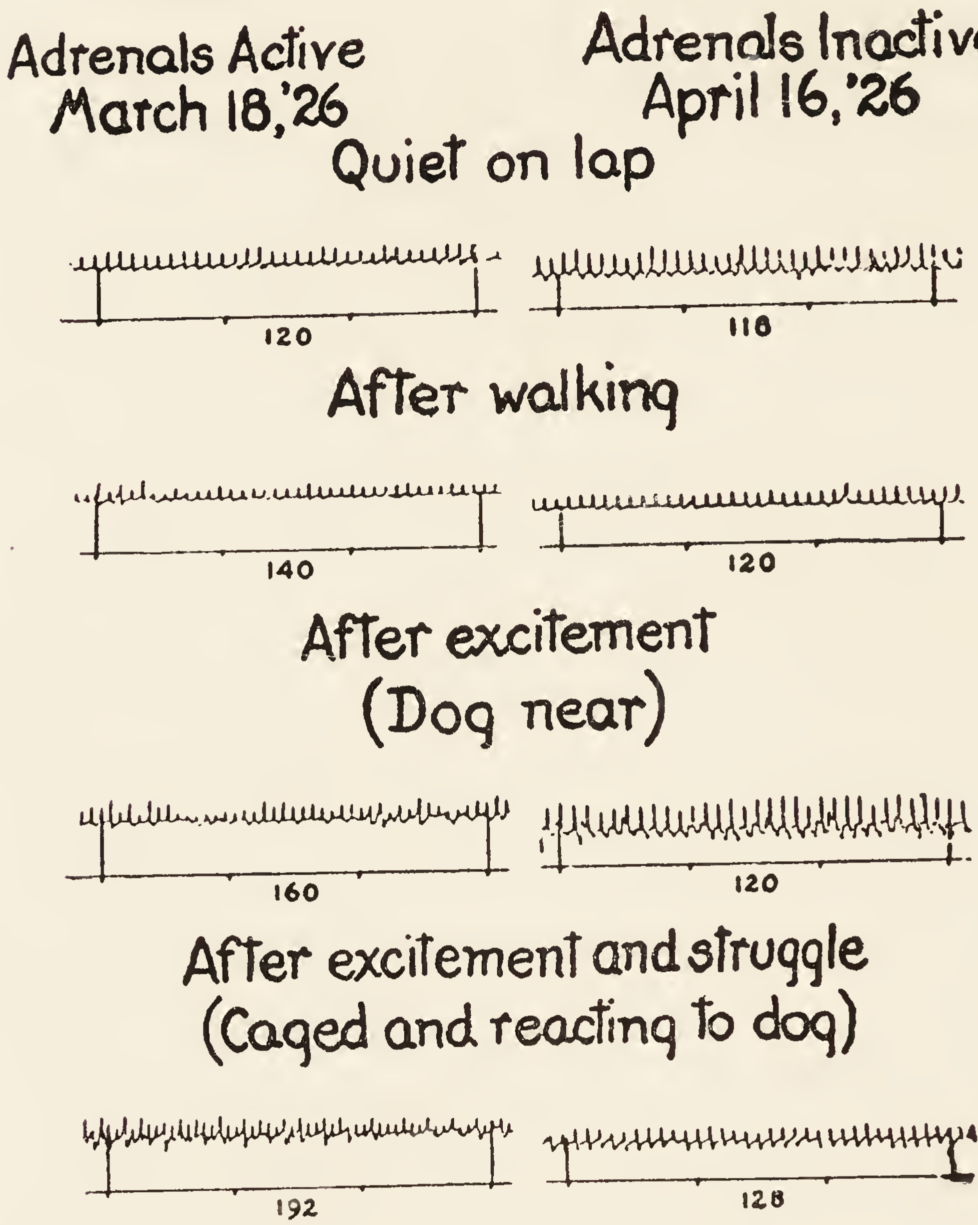

FIGURE 13. *Original records, demonstrating the effects of adrenine secretion on the denervated heart. The records in the left column were taken while the nerve connections of the adrenal glands were intact; in the right column, after the glands were rendered inactive. (From Cannon and Britton, "The Influence of Motion and Emotion on Medulliadrenal Secretion,"* Am. J. Physiol., 1927, lxxix, 444.)

dered inactive by surgical interruption of their nerve supply and the animal had fully recovered from the operation, it was put through the same series of experimental tests. Slight exercise caused no increase in the heart rate, instead of an increase of 20 beats. Simple emotional excitement raised the rate 2 instead of 40 beats a minute. And excitement with struggle resulted in an increase of only 8 beats instead of 72 (see fig. 13).

The important fact which emerges from these experiments is that both motion and emotion are accompanied by an extra discharge of adrenine from the adrenal medulla. The adrenal medulla is controlled by sympathetic nerves. In these circumstances, therefore, a coöperative sympatho-adrenal system is at work. Profound emotional disturbances such as fear and rage excite the sympatho-adrenal system to action. It is this system which produces the changes already noted—the more rapid heart beat, the increased pressure of the blood in the arteries, the extrusion of extra red blood corpuscles from the spleen, the redistribution of blood in the body (such that it is sent away from the stomach and intestines and driven in greater volume through the brain and the muscles), the discharge of sugar from the liver, the

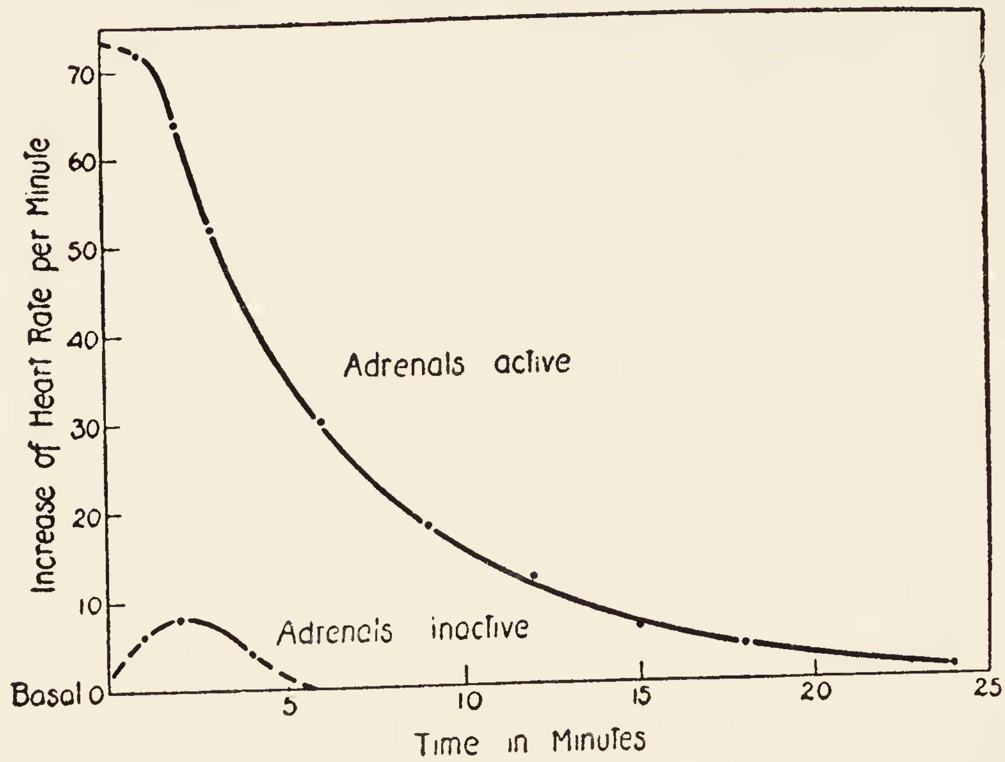

FIGURE 14. *Long persistence of the faster rate of the denervated heart, when the adrenal glands were active, after the animal (cat) was excited by a barking dog for one minute. Only slight increase of heart rate, and a relatively rapid restoration of the rate, after the adrenal glands were made inactive, although the cat was excited twice as long as before. (From Cannon and Britton, "The Influence of Motion and Emotion on Medulliadrenal Secretion,"* Am. J. Physiol., 1927, lxxix, 459.)

hastening of the process of coagulation of the blood, the dilation of the bronchioles, and the secretion of sweat. Besides coöperating with the sympathetic impulses, adrenine prolongs their effects (see fig. 14), thus explaining the common experience, already noted, that the perturbed state persists after the occasion for it has gone.

The combination of the phenomena which occur as a result of excitement led to the suggestion of the "emergency theory" of sympatho-adrenal activity. That theory was based on the view that powerful emotions are linked with instinctive behavior which may involve maximal muscular effort. Thus, the emotion of rage is associated with the instinct to attack, and the emotion of fear with the instinct to escape. When under natural conditions enemies confront each other, one or other of these two emotions may be supremely aroused and the instincts lead to a supreme struggle for existence. In decisive conflict, bringing triumph or disaster to the individual, lies the clue to the bodily changes which accompany great excitement. All the adjustments of the circulatory system—the faster heart rate, the higher blood pressure (providing a larger flow per minute through brain and active muscles) and the increased number of red corpuscles—are useful in supplying a greater delivery of oxygen where supreme activity is required and where the rapid burning of waste material is of utmost consequence, i.e., in the neuro-muscular apparatus. The dilation of the bronchioles adapts these minute respiratory tubes for a greater ventilation of the lungs, to supply plenty of oxygen, and to discharge the extra carbon dioxide which results from the burned waste. The sugar freed from storage in the liver gives to the laboring muscles the source of energy which they need for continued action. And if in struggle there is damage to blood vessels, the faster clotting of the blood helps to check the loss of this precious fluid.

IV

The foregoing considerations point to the sympatho-adrenal system as a protective agency in times of crisis. Associated with the shift of the blood in the body, a shift which favors active muscles and their nervous governors at the expense of the stomach and intestines, there is necessarily a relatively meager delivery of blood to the gastro-intestinal tract. It is in these circumstances that the functions of the stomach and intestines are interrupted. Obviously they cannot continue effective action without the generous aid of oxygen-carrying blood. Now we are in a position to understand that the disturbances of digestion which we have been considering are part of a large group of related reactions in the organism, and that in the development of higher animal forms these reactions have doubtless played a highly important rôle in the struggles which have determined continued existence. When a critical juncture arises, and life itself may be at stake, quite appropriately the digestive processes, though they are beneficent, are set aside temporarily—set aside in order that the organism as a whole, by adaptive changes in organs required for struggle, may have every favorable chance to meet the decisive demands of the moment.

Under the conditions which prevail in civilized society the emotional disturbances of digestion commonly occur when the traditional dangers in the long history of our race are not present or urgent. Only occasionally are we greatly excited by circumstances which require supreme muscular effort. On the other hand, we may become intensely perturbed while watching a stock ticker, or seeing a race, or facing an examination, or on being wheeled to an operating room, i.e., when no effort is called for, or when effort is meaningless or impossible. Deep down in our nervous organization, however, is the ancient pattern of adaptive emotional response. The digestive processes, therefore, may be profoundly affected by inert and idle excitement, almost as much as if the utmost physical exertion were anticipated. Only by understanding the wider aspects of the reactions to fear and anger can we perceive the meaning of an emotional derangement of digestion and realize how foolish it is to allow the organism to mobilize its forces for struggle and thus interfere with the work of the digestive organs, when no struggle is demanded or even possible.

V

The ideas which we have just surveyed have been extended in recent studies made on animals from which the sympathetic system has been removed. As stated earlier, the outlying nerve units of this system are arranged in two chains (see fig. 10, p. 84). These bilaterally symmetrical chains are made up of ganglia—collections of the cell bodies of the outlying nerve units—and the fine nerve filaments which unite the ganglia. Long ago Langley and Anderson proved that if the ganglia are removed the nerves which connect them with the spinal cord cannot grow out and act effectively on the smooth muscle and glands which are normally supplied by post-ganglionic fibers. Removal of the sympathetic chains, therefore, definitely eliminates sympathetic control of glandular organs and the contractile viscera.

The first and most striking fact which becomes prominent in experience with animals deprived of the sympathetic system is that, in the environment of the laboratory, they live for an indefinite time—for years—quite normal lives without encountering any serious difficulty. They digest their food properly, they gain in weight, they grow quite naturally, and the chemical processes which take place within them continue at the usual rate. Although males are sterile, females can participate effectively in the process of reproduction. The animals show signs of fear and rage, except, of course, the sympathetic displays.

If continued existence, growth, normal metabolism and the natural emotions are unaffected by removal of the sympathetic system, what is its importance? We can understand better the service which the sympatho-adrenal complex renders if we consider briefly our two natural environments. As Claude Bernard pointed out many years ago, we not only have an external or surrounding environment—the environment consisting of the agencies in the outer world which affect our sense organs and which we use for our own purposes—but also a less well-known internal environment. Already, in considering thirst, we have noted this environment. It consists of the fluids of the body. All of us which is living, all of the kinds of cells which compose our active organs, are immersed in these fluids, the blood and the lymph. They are the product of the organism itself and are under the control of the organism. It is in the highest degree important that they be kept relatively constant. Just in so far as they are kept constant we are free from disturbing external and internal conditions.

A few illustrations will make these statements clear. Ordinarily the body temperature ranges within one or two degrees of 98.6° Fahrenheit. It cannot remain long at 108° or 109° without causing serious damage to delicate nerve structures of the brain; and although the temperature may fall as low as 75° without causing death, that temperature is incompatible with bodily activity. Or, consider the variations of sugar in the blood. Ordinarily the concentration is about 100 milligrams in 100 cubic centimeters. If the concentration rises to about 180 milligrams per cent or higher, it escapes from the body through the kidneys. On the other hand, if it falls as low as 45 milligrams per cent, convulsions are likely to occur; and a further fall may be associated with coma and death. Again, if the calcium content of the blood, which is normally 10 milligrams per cent, rises to 20 milligrams, the blood becomes so viscous that it will hardly circulate; whereas if it falls from 10 to about

5 milligrams per cent, convulsions supervene. Similar need for a fair degree of constancy is seen in the relation of acid and alkali in the blood. Ordinarily the reaction is slightly alkaline. If there is a change, even to a slight degree, beyond the neutral line in the direction of acidity, coma appears. If the reaction becomes to a moderate degree more alkaline, convulsive attacks appear.

The dangerous variations, mentioned in the foregoing instances, are not ordinarily permitted. When shifts occur in either direction, above or below the normal, they may be regarded, of course, as shifts to some extent in the direction of excess. Long before the excess is reached, however, protective devices are set at work which prevent the extreme stage from being reached. These devices are almost wholly provided by the sympatho-adrenal system. If the body temperature tends to fall the sympatho-adrenal system constricts the surface vessels and discharges adrenine, thus conserving bodily heat and increasing heat production. If the blood-sugar level is reduced beyond a critical point, the sympatho-adrenal system goes into action and sets free sugar from the stores in the liver. If muscular exertion is vigorous, and in consequence non-volatile lactic acid is produced in abundance, the sympatho-adrenal system accelerates the blood flow; thereby more oxygen is delivered to the active muscles for combustion, and the resultant excess of carbon dioxide is carried away to the lungs for discharge. Evidently the sympatho-adrenal system offers automatic stabilizing arrangements for maintaining uniformity of the internal environment. And just in so far as this internal environment, or fluid matrix, in which our living parts reside, is kept uniform, we are freed from care of the body itself and may attend to the affairs of the external environment.

VI

Further evidence of the importance of the sympatho-adrenal system in keeping the fluid matrix constant is found in the limitations of animals from which the sympathetic system has been removed. These limitations become evident when such animals are subjected to conditions of stress. If, for instance, they are exposed to cold, the hairs are not erected and the surface blood vessels are not constricted; the body heat, therefore, is not well conserved. Adrenine, which is capable of increasing the rate of heat production in the body, is not secreted. For these reasons exposure of sympathectomized animals to frigid surroundings might be expected to reveal definite deficiencies. Observation proves that to be true. When cats deprived of the sympathetic system are placed in a cold room their body temperature promptly begins to fall; it may drop 4 or 6° Fahrenheit, and then shivering (automatic muscular exercise which produces heat) may prevent a further drop to a lower level. Exposure of normal cats to the same low temperature has no such effects. Furthermore, the emotional preparations for action cannot occur. When sympathectomized animals are excited, there is no rise of blood sugar, whereas usually, in the normal cat for example, a brief period of excitement will cause a quick rise of more than 30 per cent. Furthermore, in the cat at least, the blood pressure, instead of being elevated by excitement and struggle, is actually depressed. The emotional increase of red corpuscles, which results from contraction of the spleen, is wholly lacking. And there can be no shift of the blood in the body from the abdominal organs to the active muscles and to the brain.

The defects of sympathectomized animals that we have just surveyed indicate emphatically the importance of the sympathetic division for keeping constant the conditions of the internal environment. If it were not kept constant in cold weather, for example, warm-blooded animals would be limited as the frog is limited—they would have to become inactive in hibernation. They are rendered independent of marked changes of external temperature by the service of the sympatho-adrenal mechanism as a protector of the uniformity of the fluid matrix. This mechanism likewise renders us independent of possible internal disturbances which might be caused by our own actions. In muscular struggle, for example, heat is produced in excess. Indeed, so much heat results from maximal muscular contraction that at the end of three miles of a boat race the oarsmen, if they could not get rid of the heat—please pardon the incongruity!—would be stiff from coagulation. Of course, this condition is not even approached; through the agency of the sympathetic system the surface blood vessels are dilated and sweat is poured out, and thus, by radiation, convection and evaporation, the extra heat is dissipated. Finally, vigorous physical effort develops a large quantity of lactic acid. The amount thus produced might easily overwhelm the alkali in the blood if that were the only protection against the shift to the acid side of neutrality. The danger which might result from that shift is obviated, as we have seen, by a faster heart beat, a higher head of arterial pressure due to contraction of the blood vessels of the stomach and intestines, and a discharge of stored red corpuscles from the spleen. These changes are managed by the sympatho-adrenal system and all are directed toward the delivery of additional oxygen to the active organs, the burning of the non-volatile lactic acid in those organs to volatile carbon dioxide and water, and the carriage of carbon dioxide to the lungs for discharge from the body.

VII

We are now able to understand fully why removal of sympathetic nerve influences, in order to avoid a disturbance of digestion, would be an irrational procedure. Since that system has as its primary function the maintaining of constancy of the fluid matrix of the body, any change which would lessen its influence would equally diminish its effectiveness in carrying on that essential function.

Also we can now place completely in their proper setting the bodily changes wrought by strong and persistent emotions—anxieties, worries and distress. As we have repeatedly noted, the changes which accompany emotional excitement are similar to those which occur in times of vigorous muscular effort. They have been interpreted, therefore, as preparations for such effort. If the excitement is transformed into action the changes have obviously been useful, because the body by anticipation has been protected against a low blood pressure, an excessive heat and a limiting shift in the direction of acidity of the blood. If no action follows the excitement, however, and the emotional stress—even mild fear or apprehension—persists, then the bodily changes due to the stress are not a preparatory safeguard against a disturbance of the internal environment, but may be in themselves deeply disturbing to that environment, and thus to the organism as a whole.

Woodyatt has described a patient with diabetes who was being carefully observed under rigorous conditions in a hospital, and whose diet was such that he was losing no sugar through the kidneys. Suddenly one day, without any alteration of his regimen, there was a large discharge of sugar in the urine. Inquiry revealed that he had just learned from the firm for which he had worked for many years that he had been dismissed from service. The worry and distress resulting from this direful news occasioned the marked exacerbation of his disease. In natural circumstances the increase of blood sugar due to fear might be serviceable. Under the conditions that prevailed in this case, however, it was altogether unfavorable. Similar instances might be offered in which there is a sensitive reaction of the heart or a sensitiveness of the center in the brain which governs blood pressure, so that even mild excitement sends the pulse bounding up to 150 beats per minute and makes the blood pressure jump 40 or 50 milligrams. Emotional "dyspepsia," so-called, including disturbances of gastric secretion and motility, or spasm of the sphincters at the cardiac and pyloric ends of the stomach, are other illustrations of perversion of emotional effects, for anger or worry can bring about these changes when there is no value to be derived from them, but, on the contrary, a real harm.

Like other involuntary responses in the body, the emotional responses can be "conditioned." The classical experiments of Pavlov have made familiar the meaning of that expression. A flash of light or the ring of a bell is a quite indifferent stimulus. If, however, it becomes associated with feeding, it acquires efficacy and is known as a conditioned stimulus. Then the flash or the ring will start the saliva flowing, an effect which is beyond voluntary control. Experiments on man have proved that indifferent stimuli can be similarly conditioned. They can then cause responses beyond voluntary control, such as narrowing of the pupil and rise of blood pressure. Likewise a relationship may be developed between an indifferent factor and a significant factor in the disturbances caused by emotional experience. The circumstances which attended the original occasion for the emotional upset may cause a recurrence of the upset. Thus the banging of a door may renew the horror of a shellburst and send the sensitized victim of war into a pitiable fright. The noise is only incidental. There are instances of associations of this type in the functioning of the alimentary tract. It happens that some persons are not infrequently sensitive to certain foods; for them eggs, milk or strawberries, for example, may be poisonous. A sensitiveness to lobster and its relatives in the zoölogical grouping is one of my own misfortunes. I well recall, in my own experience, an incident in which there was considerable digestive distress which was associated with eating lobster salad. The salad which caused the distress was seasoned with mayonnaise dressing. For weeks after the experience the sight or odor of that sort of dressing renewed to some degree the disagreeable original experience, although the dressing as such was quite innocent. Doubtless many who read this record will recall similar instances in their own memories.

VIII

What do these views regarding the influence of emotions on the digestive process suggest in the way of practical advice? It seems to me that inasmuch as we may now reasonably regard the total complex of bodily changes associated with fear or rage as preparations for struggle, we should attempt to take a rational attitude toward any exciting incident which may occur. If there is action to be engaged in the excitement should be allowed to run its full course without limitation. On the other hand, if nothing can be done in the circumstances it is obviously unwise to permit the organism to be deeply disturbed, and especially unwise to let the fundamentally important functions of digestion be inhibited. The reader may object that emotional excitement is not under voluntary control and that therefore its course cannot be checked. From personal experience, however, I can testify that since I have learned to interpret the preparatory service of emotions and have seen the profound perturbations which, in the presence of necessary idleness, they may uselessly cause, I have been able to take a rational attitude which has minimized the extent of their baneful influence.

If there is repeated occasion for emotional interference with digestion, its removal should be sought. A patient of Alvarez continued ill for a week with marked disturbance of digestion, and only recovered when he learned that she was worried about a tax bill and, as a therapeutic measure, paid the bill. And if some indifferent object or situation has become a conditioned stimulus which interferes with the digestive process, experience with it should be repeated until it loses its effect or it should be avoided altogether.

Another suggestion which may be offered is that when occasion arises which provokes a degree of excitement that cannot be controlled, the reasonable behavior is that of working off in hard physical labor the bodily changes which have occurred in preparation for vigorous physical effort. Often the excited state can thus be reduced, and the body, instead of being persistently disturbed, is restored to normal.

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EPILOGUE

I

In a volume concerned with the relations of digestion and health the reader may quite reasonably expect to find digestion considered, even though health may be treated rather incidentally. Thus far we have paid very little regard to digestion itself, at least in its essential features. Our attention has been directed to the *circumstances* of digestion. The real core of the digestive process is purely chemical. It is the intimate process by which the food we eat is transformed from its natural, complex, solid, semi-solid, or unsuitable fluid state into a state of being soluble in the juices of the small intestine. Since the chief constituent of these juices is water, digestion may be defined with approximate correctness as the changing of food so that it may be conveyed in a watery solution, through the intestinal wall, into the body.

In order to survey the changes occurring as nutriment passes through the alimentary canal we should have to examine the classes of food stuffs (carbohydrates, fats and proteins) and learn their chemical composition; we should have to consider the action of digestive enzymes or ferments and the ways in which they break down complex molecules, such as those of starch and fat and lean beef, into the simpler substances of which they are constructed; we should have to become acquainted with the progressive stages of this decomposition in different parts of the gastro-intestinal tract; and we should have to know the relations of the digestive juices to one another as they participate in the sequence of disintegrations which food undergoes on its way to usefulness. In the strict sense, these would be the central features in the study of digestion.

Beaumont was primarily interested in the gastric juice. He collected it through the fistula of St. Martin. He had it analyzed. He learned what it would do both inside and outside the body. Thus the interesting fact was demonstrated that within limits the gastric juice will dissolve such protein food as white of egg, for instance, almost as readily in a warm glass vessel as in the stomach itself. The other digestive juices, likewise, will perform their special acts under quite artificial conditions. It is obvious, therefore, that, given warm water and the digestive ferments, and food for them to work upon, digestion will progress quite automatically.

II

Since the essential digestive process is automatic, if the requisite factors are present, the disturbances of digestion must be due to perturbations in the physiological conditions which determine the presence or absence of those factors. For the understanding of digestive troubles, therefore, acquaintance with these conditions is more important than acquaintance with the process itself.

If insufficient water is taken in, saliva is not secreted in adequate amount, and probably gastric and pancreatic juices likewise are deficient. If appetite and hunger are lacking, apathy instead of interest characterizes our attitude towards the viands of the table. In these circumstances, even if food is chewed and swallowed, the absence of enjoyment is not propitious for a tonic state of the gastro-intestinal muscle and for a rich secretion of the digestive fluids. And if worry, anxiety or distress attends the intake of nutriment, the nutriment may not be really nutritious because the necessary secretions and the proper mechanical treatment of the alimentary substances may both be checked. These examples impress the point that the incidental circumstances are the actual disturbers of digestion. On the other hand, a hearty appetite, gusto and pleasure in eating, are highly advantageous conditions. They are typical of abundant bodily vigor and they contribute to perpetuation of that vigor.

Just as there may be a vicious circle of weakness, indifference to the pleasures of the palate, a trifling acceptance of nourishment, and a consequently continued weakness, so, contrariwise, there may be a beneficent circle of energetic activity, eager enjoyment of food, and a sufficient food supply, well digested, to sustain a further display of energy.

III

The fathers of medicine thought of the lungs, the heart and the brain as the tripod of life; if any one of the three fails the structure topples. Supporting the functions of the lungs, the heart and the brain, as well as the great bulk of muscle which ordinarily constitutes almost half the body weight, is the digestive system. Its fundamental importance has been recognized for many centuries. Some of the great names of the biological and medical sciences—Spallanzani, Bernard, Pavlov—have been associated with researches which not only have made clear the intimate nature of the process of digestion, but have also explained the circumstances which affect it favorably and unfavorably.

From the earliest days, when the change undergone by the food in the stomach was regarded as a sort of cooking, down to recent time, knowledge of the service of the alimentary canal to the rest of the organism has been slowly acquired. One observer finds that saliva can dissolve starch; another that the gastric juice is acid; another that acid stops the action of the salivary ferment; another that the protein-splitting ferment of the stomach works effectively in an acid but not in an alkaline medium; another that when the stomach discharges its contents into the small intestine the alkaline secretions of the pancreas and the liver neutralize the acid gastric juice and only thereafter do they start their special functions, and others prove that the pancreatic juice and the bile and the secretion from the intestinal wall coöperate in admirable ways as they perform their peculiar tasks. Thus, gradually, the mysteries of the workings of our deeply hidden organs have been solved.

The growth of knowledge suggests in some respects the development of a picture puzzle. Advances are made on the border line between the known and the unknown. The known portion often presents only perplexing hints of where the next piece from the unknown can be added. The first task of the investigator is to study carefully what has already been learned. He must familiarize himself with the portion of the picture where the parts have previously been fitted. Then he observes and considers scattered events which might be related to those already in place. Perhaps he incidentally gathers together a group of facts which match, but which cannot yet be joined to the established pattern. Ideas occur to him that a peculiar phenomenon or a group of phenomena might be "explained." "Explaining" is the process of reconciling the new and the old, fitting one into the other. In order to do that he tests his ideas; he experiments. And if the tests prove that the ideas are correct—that what has already been learned and what is nearly learned are harmonious—the body of knowledge is increased. Just in so far as the investigator is scrupulously careful to make his fittings exact, the picture grows. Parts of the growing edge may be neglected for years. They may receive attention eventually in some distant land. But as each one cautiously adds his bit, he matches it in such a way that later bits, when joined, fall in their proper niches.

Among the permanent satisfactions in the life of the investigator is the thought that he is helping to build the ultimate structure of truth. And the medical investigator, furthermore, cherishes the hope that his discoveries may be used in the beneficent services of his profession. Such were the motives which quickened the energies of Dr. William Beaumont. In the preface to his Book he expressed the wish that he might be permitted to cast his "mite into the treasury of knowledge, and to be the means, either directly or indirectly, of subserving the cause of truth, and ameliorating the condition of suffering humanity." That wish was granted. In the century which has passed since his labors ended, investigators in various lands and at various times have turned to the records which he left, have been stimulated by the suggestions which he offered and have extended his pioneer achievements. Both directly and indirectly Beaumont contributed many "mites" to the treasury of knowledge and understanding.

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