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A FURTHER EXPERIMENTAL CONTRIBUTION TO THE KNOWLEDGE OF THE MECHANISM OF DEGLUTITION.

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It is now about seventeen years since Kronecker and myself* advanced the view that in the act of deglutition liquids and semi-solids are not carried down the œsophagus by the slow process of peristalsis, but are thrown down with great rapidity by the energetic contractions of the mylo-hyoid muscles especially. We supported this view, first, by experimental proofs obtained by the graphic method. A rubber balloon which was placed in the œsophagus recorded on a rotating drum two impressions during each single act of deglutition; a short one at the very beginning of the act, and a longer one which appeared the later the deeper the balloon was located within the œsophagus. There could be no doubt that the second impression was brought about by the peristaltic contractions of the œsophagus, while we had abundant reasons to interpret the first impression as coming from the rapid passing of the liquid.

But to obtain a still more striking proof of the rapidity with which the swallowed mass is usually shot down, another experiment was

* Meltzer, Ueber die Vorgänge beim Schlucken. Du Bois-Reymond's *Archiv*, 1880, 446.

made. A stomach tube was introduced into the œsophagus, the lower end with the side openings remaining a few centimetres above the cardia. Inside the tube opposite the side openings a small roll of blue litmus paper was placed with a long thread attached to it, the outer end of the thread projecting from the outside opening of the tube. When the litmus paper was rapidly withdrawn from the tube about half a second after swallowing lemonade, it was found to have turned red. This could only mean that half a second after the beginning of the act of deglutition the acid liquid was in a deep portion of the œsophagus, while the peristalsis, as we knew from our other experiments, could not reach this spot before six seconds.

Although our experiments thus far proved only that the liquid thrown down reaches the lowest segment of the œsophagus quickly, we assumed that it passes at once into the stomach. We were supported in this assumption by our observation that in the rabbit the cardia becomes momentarily relaxed at the very beginning of the deglutition, which would seem to facilitate the entrance of the swallowed mass into the stomach. Later on, however, we modified this view, when I* discovered that in the vast majority of normal individuals, about seven seconds after the beginning of a single act of swallowing, a murmur is to be heard in the region of the cardia, which has the character of a sound produced by liquid and air squeezed through a narrow aperture, while in a minority of individuals at about the beginning of the deglutition a murmur appears in the same region with a character reminding one of a sound caused by pouring or squirting liquid. I have named the former the "squeezing murmur" (*Durchpressgeräusch*) and the latter rare sound the "squirting murmur" (*Durchspritzgeräusch*). We† then took the stand that the mass thrown down is detained in the œsophagus above the cardia until the contraction of the lower section of the œsophagus begins, which occurs according to our experiments about six or seven seconds after the beginning of deglutition and with which the squeezing murmur coin-

* Meltzer, Ueber Schluckgeräusche, *Centralbl. f. d. med. Wissenschaft.*, 1883, No. 1.

† Kronecker and Meltzer, Der Schluckmechanismus u. s. w. Du Bois-Reymond's *Archiv*, 1883, Supplementband.

cides in time. We explained the origin of the sound by assuming that the contraction of the lowest section of the œsophagus squeezes the detained swallowed mass through the tonically contracted cardia, thus producing irregular vibrations which the auscultating ear perceives as a squeezing murmur. The squirting murmur occurs, we assume, in persons whose cardia for some reason or other is relaxed and in whom the swallowed mass is squirted directly into the stomach without any delay.

Our interpretation of the squeezing murmur has met with objections from several writers. Zenker* has put forward the theory that after the arrival of the swallowed mass at the cardia the air becomes separated from the liquid and remains above it, and the liquid soon oozes down noiselessly into the stomach, while the air follows later with a murmur. Why the air should follow regularly after seven seconds Zenker fails to explain, as he was not aware of the presence of the peristalsis just at this time. The theory of Zenker was accepted by Ewald† and by Quincke,‡ with the additional explanation that the air is carried into the stomach by the peristaltic wave which arrives at the lower end of the œsophagus about seven seconds after the beginning of the act of deglutition, a fact which was established by our experiments. But while Zenker's main objection to our statement was based upon the erroneous supposition that we believed the liquid to be thrown down directly into the stomach at the very beginning of the deglutition, the objection of Ewald and Quincke, on the contrary, was directed against the supposition that the liquid is carried down into the stomach by the peristaltic wave only. Both these writers have made some experiments in support of their view. I shall not enter into a detailed analysis of their statements. It suffices to say that the main object of their experiments was to show that the presence of a squeezing murmur depends upon the passing of air through the cardia and that the passage of liquid alone does not produce any sound. From this supposed fact they drew the conclusion that the

* Zenker, *Berliner klin. Wochenschr.*, 1884, p. 38.
† C. A. Ewald, Du Bois-Reymond's *Archiv*, 1886, p. 376.
‡ Quincke, *Arch. f. exp. Path. u. Pharmakol.*, xxii, p. 385, 1887.

peristalsis carries down into the stomach air only, which causes the squeezing murmur, while the liquid oozes noiselessly through the cardia before the arrival of the peristalsis at the lower end of the œsophagus. But as Quincke himself has established the fact that a murmur is present when air and liquid together are passing through the cardia, and as he insists also that air is swallowed in each act of deglutition, it is evident that their experiments are by no means conclusive for their assumption; they rather permit also the theory that the liquid remains above the cardia until the peristalsis carries liquid and air together through the aperture into the stomach, which, according to Quincke, produces a squeezing murmur. We can fully agree with Quincke that each and every act of deglutition also carries air into the stomach, and we have never insisted that the murmur is due to the passage of the liquid alone through the cardia. We have simply stated that the murmur is coincident with the contraction of the lowest segment of the œsophagus and is apparently due to the passage of the swallowed mass through the cardiac orifice, and I am willing to concede now that the presence of air in the swallowed mass is possibly the main factor in the causation of the characteristic squeezing murmur.

The interpretation of the squeezing sound and its origin are, after all, matters of only secondary importance; the main point of physiological interest is the question: Does the liquid thrown down remain above the cardia until the peristalsis carries it into the stomach, or does it ooze down previously to the arrival of the peristalsis? That it makes a halt above the cardia and is not thrown directly into the stomach just after it is squirted down the œsophagus is disputed by hardly any writer, although there is no other proof for this assumption than the presence of the squeezing murmur with its disputed interpretation.

Briefly recapitulated, the present state of the question is as follows: Our positive experiments have proven only that the fluid is squirted down into a deep part of the œsophagus. We may add here that Hamburger's deglutition murmur, which is to be heard at the back alongside the spinal column at about the beginning of the act of de-

glutition, can be followed down only to the eighth dorsal vertebra, which corresponds to a point in the œsophagus a few centimetres above the cardia. As to the further fate of the swallowed mass we have for the present no other information than the presence of a squeezing murmur at the region of the cardia just at the time of the arrival of the peristalsis. We interpreted this murmur as indicating the passage of the entire swallowed mass, air and liquid, into the stomach; the other three writers mentioned ascribe the murmur to the passage of air alone, while they assume that the liquid enters the stomach before the arrival of the peristalsis. It must be admitted, however, that neither of these views is supported by indisputable experimental proof. It is the object of this paper to offer such experimental observations as will, I believe, fully justify the stand which Kronecker and myself have taken in this question.

The observations were made on dogs and rabbits. The dogs were anæsthetized by ether and the rabbits by chloral. The main difficulty in studying deglutition in dogs lay in the strong interference of the etherization with the reflex act of deglutition. In a future communication I intend to report some observations bearing upon this point. Here, however, I shall only state briefly the method which I found to be most suitable for my purpose. After bringing the dog under thorough anæsthesia both superior laryngeal nerves were tied, tracheotomy performed, the larynx well packed with cotton and artificial respiration begun. Now the anæsthesia was reduced to that degree which permitted the return of the deglutition reflex. The state of apnœa which was brought about by the artificial respiration permits a considerable reduction of the etherization. The acts of deglutition were induced either by injecting liquid (water or milk) into the mouth or pharynx, or by faradic stimulation of the central end of one of the superior laryngeal nerves.

My first effort was directed towards getting a full view of the cardiac opening of the stomach during the act of deglutition. For this purpose the stomach of the dog was exposed, a vertical incision of about two inches made and the contents of the stomach removed. Then a wide tube with a reflecting inner surface, a vaginal speculum,

was introduced and so adjusted as to have the cardiac aperture just at the bottom of the tube. An electric light thrown into the tube facilitated the observation greatly, and the escape from the cardiac orifice of liquid or air or both could be easily scrutinized.

We knew from our former experiments that the time which passes from the beginning of the act of deglutition until the peristaltic wave reaches the cardia amounts in dogs to about four seconds. The present task was simply this: To see whether any of the swallowed liquid comes down through the cardiac orifice either abruptly at about the beginning of the act of deglutition or by slow oozing into the stomach before the peristalsis reaches there; or whether the entire swallowed mass comes down through the cardia into the stomach all at once with the peristaltic wave.

The observations were made in the first place by the graphic method, *i. e.*, one observer caused the marking of a lever upon a revolving tambour just at the beginning of the deglutition, which is easily recognizable by the characteristic sharp ascent of the larynx, while another observer, looking into the tube, marked the first appearance of liquid through the cardiac aperture. Or one observer simply called out the beginning of the deglutition and the other called out the appearance of the liquid, the length of the interval being established by a watch or simply by estimation. I have made a series of these observations on many dogs, and on each dog I made numerous single observations, and I can now state that not in one single instance was any liquid projected through the cardia at the beginning of the deglutition or did any ooze through the cardia into the stomach before the arrival of the peristaltic wave. In all cases the swallowed mass was squeezed through the cardia by the peristaltic wave, about four seconds after the beginning of the act of deglutition. When the deglutition was caused by liquid injected into the pharynx the swallowed mass consisted mainly of liquid containing only a few bubbles of air; when caused by stimulation of the laryngeal nerve the mass consisted mainly of air with only a little fluid.

A similar condition I have discovered also in rabbits. The observation is here quite simple and easy. When the stomach is lifted out

from the abdominal cavity, incised, and some of the contents removed from the region of the cardia, the cardiac aperture is plainly exposed to full view. The time for the arrival of the peristalsis at the stomach is in rabbits quite short, being a little less than two seconds. Nevertheless there could be no doubt of the fact that here, too, the swallowed mass reaches the stomach only with the peristalsis.

This line of observation led me to a search as to the exact location of the point where the swallowed mass is detained before it is carried into the stomach. We have so far said in general terms that it is detained above the cardia. That the mass does not lie immediately above the cardia we could convince ourselves by direct ocular inspection, at least in rabbits. In these animals the part of the œsophagus situated below the diaphragm is easily accessible to full view, especially when, as in the above described observations, the stomach is lifted out of the abdomen. Then we could distinctly see that the swallowed mass never entered the part of the œsophagus below the diaphragm before the arrival of the peristaltic wave.

In dogs I have often introduced the finger through the cardia into the œsophagus, even above the diaphragm, and never could I feel the presence of the swallowed mass before the arrival of the peristalsis. I have also introduced short glass tubes into the œsophagus through the cardiac orifice, thus removing the obstacles possibly caused by the tonic contraction of the cardia; nevertheless the swallowed mass did not enter the stomach before the arrival of the peristalsis.

It could be urged, however, that the finger as well as the glass tube might, as foreign bodies, cause a local contraction of the œsophagus just above them and thus create an artificial bar to the further advance of the swallowed mass. I have therefore tried a method which permits direct inspection of the lower end of the œsophagus during rest and deglutition. A cut was made in the diaphragm near its anterior insertion, through which a speculum was introduced and pushed backward in the direction of the œsophagus. After permitting the lungs to collapse for a while I usually succeeded in adjusting the tube so as to have a good view of the œsophagus just above the diaphragm. The section of the œsophagus which could be seen

in this way was a little more than an inch in length. When the artificial respiration was discontinued and the dog was still in a state of apnœa the observation was easy and distinct. In all these observations the following phenomenon could constantly be demonstrated: The œsophagus was usually in a state of medium contraction and the beginning of the deglutition caused no change in it. A few seconds later the following series of incidents could be seen rapidly to take place: First, the œsophagus was drawn upwards, then strong bulging immediately followed, and right after this a strong transversal contraction swept downward, leaving the œsophagus for a while in a contracted state. During the period of bulging air bubbles could be recognized in the water or the milk. It was clear that in none of the deglutition acts was the swallowed food directly squirted down the œsophagus to as deep a point as the region under inspection, that is, about an inch above the diaphragm.

There now arose a quite embarrassing question. The fact that liquid food is projected down into the œsophagus with rapidity was learned by observations made only on human beings. Hamburger's deglutition murmur, heard alongside the spinal column, which indicates the rapid progress of the swallowed mass, has also been demonstrated up to the present only in human beings. Although Kronecker and myself have made numerous experiments on the œsophagus of dogs and rabbits, we have made them with a view of learning other facts and not for the purpose of ascertaining whether the swallowed mass progresses downward just as rapidly in these animals as we have proven to be the case in human beings. Now we find that in dogs and rabbits the swallowed mass is not squirted down directly into the stomach. We find, furthermore, that in dogs this mass does not reach even the level of the diaphragm. Perhaps, then, in animals the food is not projected down at all, but is carried down slowly by peristalsis.

Though our old tracings obtained from the œsophagus of dogs seemed to contain some material for an answer to this question, I preferred to obtain again direct ocular demonstration of the behavior of the upper part of the œsophagus during the act of deglutition.

For this purpose I have resected in dogs parts of the three upper ribs on the left side. When the artificial respiration was discontinued and the collapsed lung pushed aside by means of retractors, the entire upper part of the thoracic œsophagus was fully exposed to view. There it could be clearly seen that, when the dog was made to swallow by pouring some liquid into his mouth and pharynx, with each deglutition the liquid shot down through the exposed œsophagus long before any peristalsis reached there. The same thing occurred when the deglutition was caused by stimulation of the nerves, *i. e.*, when only air was thrown down in the œsophagus. This observation is in so far a new fact as it had not been and could not have been observed in the human being simply because it is impossible, at least for the majority of normal human beings, voluntarily to swallow air alone without any liquid. I shall here mention a fact which otherwise does not belong in this communication, but which brought out the fact of the swallowed mass being thrown down in the exposed œsophagus of the dog with great distinctness. In the anæsthetized animals it often occurs that the first act of deglutition takes place without being followed by peristalsis. We see in such an abortive deglutition how fluid or air is shot down in the œsophagus and remains there. If a few such abortive deglutitions followed one another in shorter or longer intervals, we saw the œsophagus swell up to quite a large size, looking like a "sausage," until a peristaltic wave set in and carried the entire mass downward all at once.

The appearance of such a considerable accumulation within the œsophagus gave rise to the further question whether it was not caused simply by a mechanical obstacle, *i. e.*, whether the left bronchus was not pressing upon the œsophagus in consequence of the horizontal position of the dog, thereby preventing the swallowed mass from entering the lower part of the œsophagus and reaching the stomach. Were this assumption true, we should still have before us the task to prove that when the animal is in a normal position the food is not directly squirted down into the stomach. The following observations, however, speak positively against such an assumption. In the first place, change of position, which could be easily accomplished, espec-

ially in rabbits, did not change our results; in no position of the animal did the swallowed fluid reach the stomach before the arrival of the peristaltic wave. Secondly, the accumulation of fluid or air within the œsophagus of the dog did not cease even when the left bronchus was lifted by means of a hook from its resting place upon the œsophagus. Furthermore, I have made the following more convincing observation. A piece of the left fifth rib was resected and a speculum was inserted in a manner which permitted the observation of the œsophagus at a point half-way between the diaphragm and the bifurcation of the trachea. I have then seen how sometimes immediately after the beginning of an act of deglutition a bulging appeared at this point of the œsophagus and remained there for some time until a peristaltic wave passed by and carried it downward. The detention of the swallowed mass at this point could not be due to any mechanical obstacle. Finally, after a close observation I have sometimes found that the mass thrown down, if it was small or projected with moderate force, did not reach even the point of the bifurcation.

It deserves to be mentioned that the direct ocular observation of the thoracic œsophagus conveyed to me the impression, first, that in a state of rest the lower part seems to be tonically more contracted than the upper part; and, secondly, that the upper part is distinctly more responsive to the changes of respiration than the lower part of the œsophagus. This latter fact is in conformity with our experience with the human œsophagus. As soon as the balloon was placed in the lowest segment the respiratory oscillations became less distinct.* These observations show that the lower portion of the œsophagus is in a pronounced state of tonic contraction, which may explain the resistance offered to the mass projected downward at the onset of deglutition.

My present observations justify, I believe, the following conclusions:

In animals, as well as in human beings, liquid food is not carried down the œsophagus by the slow progress of the peristaltic wave, but is thrown down rapidly into a deep part of this canal. This applies

* Compare Figs. 17 and 18 in the table of our article, Du Bois-Reymond's *Archiv*, 1883.

likewise to the swallowing of air alone, which is brought about in animals by stimulation of the superior laryngeal nerve.

As to the depth in the œsophagus reached by the immediately projected mass, this depends upon the quantity which is swallowed, upon the force with which it is thrown down, probably also upon the degree of tonicity of the lower portion of the œsophagus, and upon other variable circumstances. In no case did the swallowed liquid immediately reach even the level of the diaphragm, to say nothing of its shooting or oozing through the cardia into the stomach before the arrival of the peristalsis. It is, therefore, an experimentally proven fact that the swallowed mass is detained for some time within the lower part of the œsophagus, and that the position taken by Kronecker and myself concerning this question is correct.

That with each act of deglutition the swallowed mass should remain for a time within the lower portion of the œsophagus must, from a teleological point of view, appear strange indeed and might perhaps be brought into causal connection with the "spontaneous" development of such pathological conditions as dilatation of the œsophagus or the formation of an œsophageal diverticulum.

I shall append here a few brief remarks bearing upon the nature of the squeezing murmur. This murmur can be heard also in the dog, as has already been stated by Quincke.* It can be heard even at a distance when the stomach is well filled with air. This is best accomplished by introducing a tube into the stomach through the duodenum. By blowing up the stomach to different degrees it can be demonstrated that the loudness of the murmur depends largely upon the quantity of air present in the stomach, *i. e.*, the larger the quantity of air, the louder is the murmur, a fact which I pointed out long ago† and which was later confirmed by Quincke. This point is to be borne in mind in examining for this murmur, as it is hardly audible when the stomach contains only very little gas.

When the tube was in the stomach and the cardiac aperture con-

* Loc. cit.

† Meltzer, Zu den Schluckgeräuschen. *Berl. klin. Wochenschr.*, 1884, No. 30.

nected only with the air in the tube, the murmur was mostly very loud and sometimes reminded one of the explosive noise from a brass instrument. The character of the murmur depends apparently not only upon the size but also upon the shape of the vibrating column of air.

When I first described the squeezing murmur I stated that it had its explanation in the irregular vibrations of the tonically contracted cardia, the air within the stomach forming the sounding board. Quincke, however, compared the murmur with the bronchial râles. Without entering into a discussion upon the adequacy of such a comparison I wish here to say that while having the cardia under direct observation, its vibrations, during the formation of the murmur, could directly be seen.