The muscular activity of the stomach in ulcer cases

by

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In previous papers (1953, 1954, 1959) the author has studied the activity of the stomach musculature and its influence on the general shape of the stomach and on the mucosal foldings in cases of ulcer with different localizations. Roentgen examination has shown that characteristic and different changes occur in cases of ulcer in the corpus and in cases with the ulcer situated at the incisura angularis. After the publication of these papers several physiologic investigations have been made, demonstrating different qualities of the musculature in the two parts of the stomach on either side of the incisura angularis. Electrogastrograms have been produced with improved technique and examinations have been made with this method after surgical segmentation of the stomach. Other experimental investigations have shown the influence of the extrinsic nerves on the motor activity of the stomach.

Before discussing the roentgenologic observations illustrated by a few typical pictures of ulcer cases, some information is required about relevant physiological investigations.

The activity of the muscles of the stomach emanates from inherent cell activity initiated in pacemaker regions which seem to vary somewhat in localization from moment to moment. To a certain extent this myogenic activity can be said to be the original basis of the tonus, although it is strongly modified by exogenic nervous, chemical and mechanical influences and local nervplexa. As a principle, the tonus of smooth muscles is equivalent to the tetanic contraction of a skeletal muscle, i.e. it seems to be built up as a summation of single twitches. A difference between the two types of muscle activity is the extreme slowness of the smooth muscle contractions, which allows maintenance of a steady contraction by a much smaller number of single twitches per unit of time (Bozler 1948). The tonic contraction can thus be kept up with a small energy expenditure (Bülbring 1953). The musculature has a so-called synzytical type viz. permitting a more or less pronounced spreading of the excitation by way of intermuscular bridges and local nervplexa (Bozler 1948).

Accordingly, the tonus of a stomach cannot be estimated by its size (for instance from a roentgen picture), as the tension of the muscle elements can be adapted to various states of contraction even when the size of the stomach is the same. On the other hand, an increase of the tonus sets in, if the stomach contracts still more, just for the duration of this additional contraction.

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The nomenclature of the different parts of the stomach is not entirely standardized. In this paper the concepts longitudinal and transverse stomach are used as these parts differ strikingly as to anatomic structure and function. The longitudinal stomach consists of the fornix (or fundus) and the corpus, extending downwards to the level of the incisura angularis (or angulus). The transverse stomach beneath the incisura angularis consists of the sinus (or antrum) and the canalis (Forssell 1913).

As is well known the muscular coat of the longitudinal stomach consists of three layers, an outer layer with longitudinal fibres, a middle one with circular fibres and an inner layer with longitudinal and oblique fibres forming a muscle band to a great deal detachable from the other musculature. In the transverse stomach there are only two layers, the outer layer with longitudinal and the inner layer with circular fibres. More details about the anatomic structure will be given below in connection with the roentgen findings.

Basic experimental investigations of the stomach musculature have been published by Alvarez (1916, 1923, 1948). He found on excised muscle strips different responses to electrical and mechanical stimuli on either side of the level of the incisura angularis, and observed on electrogastrograms on cat that a different type of muscular activity might appear in the longitudinal and the transverse stomach. During the last decades the technique for making electrogastrograms has improved. In suppressing low as well as high frequency components by means of a phase-lock tracing philter disturbing influences from the adjacent organs are neutralized. Electrodes have been applied in different ways. Some have been implanted in the stomach wall, suction electrodes have been introduced through a nasogastric tube and exterior cutaneous electrodes have been used successfully on man.

Hinder and Kelly (1977) have performed electrogastrograms on human beings, during laparotomies, with electrodes fixed on different levels in the musculature of the stomach (figure 1).

The electrogastrogram in fig. 1 shows a short usually triphasic initial period followed by an isopotential period together constituting the pacemaker potential (also called slow wave, basic electrical rhythm, initial potential). These have the same frequency in man about 3/min.—from the corpus down to the pylorus, but the amplitude is greater in the transverse part of the stomach and the propagation velocity increases with caudad propagation. The upper part of the longitudinal stomach is a silent region. The pacemaker potentials do not directly release the peristaltic waves but “appear to provide an electrical framework through which stimuli can act to modify gastric motility” (Kelly et al. 1969). The pacemaker potential is myogenic in origin and generated in the longitudinal muscle layer.

The peristaltic wave is directly connected with another form of electrical potential, the action potential (also called spike potential, fast potential, second potential), visible as bursts of fast spikes of unequal amplitude (Monges et al. 1971). The action potential is superimposed intermittently on the initial period of the pacemaker potential, is myogenic in origin but is not propagated and not omnipresent (Bass 1965). The peristaltic contractions of the circular musculature seem to be phased by impulses in the longitudinal cells (Daniel et al. 1963, Papasowa et al. 1968). The activity from the
Fig. 1. Pacesetter potentials are found in mid and distal corpus and in antrum but not in fundus and proximal corpus. (After Hinder and Kelly)

Hinder et al. (1977) have confirmed in man by transection in the lower part of the corpus that the frequency of the pacesetter potential remains unchanged in the proximal segment but decreases distally to the transection.

Accordingly, the muscular activity origin-

Fig. 2. Recordings of the electrical activity in the stomach after two complete sections: The diagram indicates the location of the sections and the position of the electrodes. The proximal segment maintains a regular normal rate. The middle and distal segments have slower rates with large rate variations. (After Weber and Kohatsu 1970).
ates from a pacemaker located on the greater curvature side in the midpart of the corpus (Weber et al. 1970, Kelly et al. 1971). Sarna et al. (1972) characterize this location as the site of the highest intrinsic frequency of impulses. In a normal stomach this pacemaker dominates and synchronizes the electric activity in the longitudinal and transverse parts of the stomach. However, if the sinus part of the stomach for some reason is disengaged from the influence of this dominating pacemaker in the corpus a slower rhythmic motivity is generated in the transverse stomach, probably depending on another specific pacemaker for this part.

It is well known that the autonomic nervous system plays an important role for the function of the stomach. A somewhat schematic survey of the literature will be given here, reporting facts relevant to the roentgenologic observations.

Changes of the tonus in the muscular coat are registered by adapting mechano-receptors or tension-receptors situated in the stomach area (Paintal 1954, Iggo 1957). The impulses from them are conducted through afferent and efferent fibres in both the vagal and splanchnic nerves, releasing inter-acting reflexes, the vagal reflex transmitted in the brain stem, the splanchnic one in the spinal cord. These gastro-gastric reflexes may be mediated by intramural myenteric nerve-plexa in the stomach wall. They are influenced by subcortical and cortical centra.

A schematic picture of the influence of the extrinsic nerves on the stomach musculature has been published by Abrahamsson (1973), Fig. 3.

The efferent fibres of the vagus have two qualities with different thresholds of excitability (Martinsson et al. 1963, Jansson et al. 1965). Stimulation at lower intensity gives an excitatory effect on the stomach musculature transmitted through thicker nerve fibres and modulated by cholinergica. If, on the other hand, the stimulation of the vagus has a higher intensity affecting the high threshold fibres, a relaxation occurs that is limited to the corpus-fundus part. This non-cholinergic, nonadrenergic relaxation may be considerable and essential for the function of the stomach as a reservoir organ (Martinsson 1965, Jansson 1969, Jahnberg et al. 1977). The relaxation can act also through receptors activated after distension of the oesophagus and pharynx (Abrahamsson et al. 1969).

A relaxation of the corpus-fundus part can be produced also by a selective reflex released from the antrum. In cases of nausea and vomiting this relaxation is striking and followed by a contraction of the antrum (Abrahamsson 1973).

The vagus, consequently, has a double
function, an excitatory cholinergic effect on the stomach and a relaxation reflex affecting its corpus-fundus part.

The splanic reflex consists of an adrenergic inhibitory action released via ganglion coeliacum with suppressive effect on the cholinergic excitatory vagal activity.

As a background for the roentgenological observations of the muscular activity of the stomach a summing up of the physiologic notes above seems to be appropriate.

A dominating pacemaker in the corpus regulates the activity in the normal stomach. As shown on electrogastrograms on animal and man under certain circumstances a dissociation may occur between the longitudinal and the transverse parts giving the latter a lower frequency of its own. Besides, the function of the stomach is to a great extent influenced by the autonomic nerves. As we have seen the corpus-fundus part can be relaxed by the vagus reflex more or less independantly of the antrum, showing a different activity between the two parts of the stomach. It is obvious that the stomach consists of two parts with different characteristics on each side of the angulus.

The size and shape of the stomach can vary within wide limits depending on the activity of its muscular coat. Moreover, in the individual case the shape may be influenced by the patient's physical constitution, his position, the space of the abdominal cavity, the firmness of the abdominal wall. In a normal stomach the different parts and also the different muscular layers are functionally well coordinated into a uniform pattern of motor activity.

In cases of ulcer, on the other hand, roentgenologic examination shows reactions of the muscular coat different in the longitudinal and transverse parts of the stomach owing to their physiologic and anatomic characteristics.

Fig. 4 and Fig. 5 illustrate the shape and folding of the longitudinal stomach typical for ulcers in this region.

The pictures 4 and 5 illustrate ulcers in the corpus in different stages of development showing the same characteristics. The contraction is more or less pronounced. The increased folding of the great curvature, the toothlike serration (or Zähnelung) is limited to the longitudinal stomach ending at its lower margin with a sharp demarcation at the transition to the transverse stomach. This picture generally found in cases with an ulcer in the lon-
Fig. 5. A small ulcer in the lower part of the corpus with a corresponding contraction in this region on the greater curvature side. A second small ulcer is situated below the cardia with a decreased width of the lumen also on this level. An increased folding, a serration, is seen along the whole longitudinal stomach. Operation revealed an ulcer approximately at the incisura angularis and histologic examination an ulcer with interruption of the muscularis (After Lilja 1954).

gitudinal stomach seems to presuppose an anatomical structure with corresponding extension.

Basic investigations of the stomach anatomy have been made by v. Aufschnaiter (1894), Cunningham (1908) and Forssell (1913). It has been mentioned before that the longitudinal stomach has three muscle layers. The outer layer has longitudinal fibres spreading over the anterior and posterior surfaces. Along the lesser curvature these fibres are reinforced, forming the medial longitudinal band or the so-called "Schweizerkravatte", which divides before reaching the incisura angularis into two branches leaving between them an area with very sparse longitudinal fibres, therefore in the literature called membrana angularis. The middle muscular layer consists of circular fibres encircling the stomach. The inner oblique layer, the sling bundle, also called the suspensory sling, exists only in the longitudinal stomach without any equivalent in the transverse stomach nor in the whole digestive tract. It has a histologic structure different from the rest of the stomach musculature (Forssell 1913). This layer is located on the anterior and posterior sides of the stomach extending downwards to the level of the incisura angularis. It consists of longitudinal strands next to the lesser curvature, here forming a strong special muscular band, detachable from the circular layer and from the mucosa as well. "In all degrees of contraction it remains a differ-

Fig. 6. The extent of the inner muscular layer (After Forssell).
entiated muscle" (Forssell 1913). More laterally the bundles from this inner layer layer deviate archlike with a more transverse course in the direction of the greater curvature, here merging into the circular layer and into the submucosa, being possible to trace as far as the greater curvature.

The inside of the stomach showing the extent of the inner muscular layer is illustrated by fig. 6.

That the inner muscular layer has a capacity to contract more or less independently of the other musculature has been shown by Cunningham (1908), illustrated by an anatomical preparation reproduced here (Fig. 7).

According to Cunningham "the part which the oblique fibres played in determining this stomach form was rendered evident". A contraction in the lower part of the corpus on the greater curvature side, an isthmus or "Engpass", has been observed in human stomachs, surviving a short time after death, by Aschoff (1918), Volkmann (1920), Gruber (1921).

An experimental clinical observation is made by Barclay (1936). He had the opportunity, during operation, to stimulate electrically the upper part of the lesser curvature. The result was a contraction of the inner muscle layer independently of other musculature. Barclay states: "These experiments, therefore, confirm to a very large extent the hypothesis that the oblique band can act entirely independently of the circular and longitudinal coats."

Ever since Forssell's investigations in 1913 it has been known that the inner oblique layer has a structure diverging from that of other stomach musculature. Beck et al. (1971) excised, from guinea pigs, strips from this layer and found here a special pattern of reaction: "The unusual property of the sling muscle is its inexcitability to electrical stimulation when its nerve supply is blocked. Probably related to this property is the sling's lack of spontaneous activity and its failure to propagate spikes." According to these observations the sling bundle has on guinea pig a special function due to the autonomic nerves. These observations stimulate the interest for further experimental investigations. In this connection it may be mentioned that the author of this paper in publications in 1954 and 1959 presupposed a special function of the inner oblique layer owing to the roentgenologic observations of the shape and folding of the stomach in cases of ulcer.

The roentgenologic observations in cases of ulcer in the longitudinal stomach show a more or less pronounced contraction of the this part of the stomach, sometimes as an inward bulging or a local spasm in the lower part of the corpus. In addition, there is a serration of the greater curvature, always ending downwards at the transition to the transverse stomach. The anatomical extent
of the inner oblique layer or the suspensory sling, with a capacity to contract independently, corresponds to the area of the serration of the greater curvature. These coinciding anatomic and roentgenologic observations are independent of accidental circumstances and have a mutual dependence, indicating that the observed contraction of the longitudinal stomach and the serration of the greater curvature are roentgenological signs that the inner muscle layer is more contracted than the adjacent muscle layers. The occurrence of the serration in ulcer cases has only rare exceptions (cases of very superficial mucosal ulcers). The excitatory effect of the ulcer usually spreads over the whole greater curvature but may be more marked at the level of the ulcer. A contraction of the muscle layers to a different degree may be denoted as a dyskinesia. It may be discussed if the vessels penetrating the muscular coat strangulate the blood supply to the mucosa. This question seems not to have been examined.

A reduced size of the longitudinal stomach is clearly visible in cases with big and deep ulcers, and a marked contraction sometimes is seen even in cases with a small niche. According to the different sites of the ulcers a certain differentiation occurs in such a way that some bundles of the inner layer are more strongly affected. If the ulcer is located on the long medial muscle bundles a more or less pronounced inward bulging may be seen in the lower part of the greater curvature. In another case the contraction may affect more locally the laterally deviating muscle bundles at the level of the ulcer, the well-known local spasm. The origin of the so-called cascade-stomach with a backward tipping of the upper part of the longitudinal stomach may be caused by reduction of space in the abdominal cavity, e.g. by a colon meteorism, an expansive process or a disturbance of the diafragma. But the cascade-stomach is often caused by an ulcer on the posterior side with a stronger contraction of the posterior wall than of the anterior one. Ulcers have been found in the longitudinal stomach in 25 cases of 40 with cascade-stomach (Naumann 1953).

The serration, however, can be observed without a demonstrable ulcer niche, but if the serration is found there is reason to look carefully for an ulcer at the lesser curvature or, in a cascade-stomach, on the posterior wall of the stomach. Often the serration remains after the ulcer has healed. Not seldom, however, a serration can be seen even without the presence of any demonstrable ulcer in the longitudinal stomach, and it is comparatively common in cases with duodenal ulcer. It may possibly be a pre-ulcer condition. We have then only to state the presence of a dyskinesia of the musculature. If there is no serration of the greater curvature, the occurrence of an ulcer in the longitudinal stomach is improbable.

Already Schwarz (1916) and Schütze (1917-18) drew attention to a serration, a Zähnelung, of the greater curvature, looking upon it as a manifestation of a hypertonus of the musculature arising mainly in cases of gastro-duodenal ulcers but sometimes also in other pathologic conditions, e.g. in cholecystitis. Since then the interest in this serration has not been particularly great. The condition seems to have been explained as belonging the so-called hypertrophic gastritis, as a symptom of an irritable stomach or simply and perhaps usually as an anatomic variation. During many years the roentgen method has been used.
for diagnosing gastritis, but especially after taking biopsies from the mucosa an obvious discrepancy has been shown between the roentgenologic and histologic findings. A roentgen picture of a marked folding of the greater curvature does not permit any conclusion concerning a histologic gastritis.

The significance of the serration has been noticed by Kenzler, Frik (1961). They confirm the author's opinion that the serration is independant of gastritis and probably related to a lasting contraction of the inner oblique layer. According to these authors a pronounced serration occurred in 75% out of 200 cases of gastro-intestinal disease in the upper part of the abdomen and is very seldom missing in cases of ulcer.

The transverse stomach has another motive reaction in cases of ulcer. With the exception of the well-known contraction of the canalis by a prepyloric ulcer, local contractions are rare as well as regional contractions, described by Zehbe (1928), Sandström (1944).

If an ulcer is located at the incisura angularis, a characteristic change of the shape of the stomach occurs, provided that the ulcer is sufficiently big and deep. A sack-like dilatation on the greater curvature side of the sinus is pertinent to this condition and has been said to resemble a tobacco-pouch, remaining even after healing of the ulcer (Presser 1937, Warmoes 1950). The greater curvature of the transverse stomach is smooth, without the toothlike serration that characterizes the picture of an ulcer in the longitudinal stomach. Moreover, a disturbance of the peristalsis of the transverse stomach often is seen at fluoroscopy with shallow and irregular waves and between these single deep waves progressing to the pylorus. In some cases changes may be seen

Fig. 8. A rather big ulcer is seen at the incisura angularis with a wide slack sinus without any serration of the greater curvature. The corpus has a typical serration with a sharp lower limit. (After Lilja 1953).

Fig. 9. The same patient as in Fig. 8, a month later, after treatment. The ulcer has almost disappeared but the sack-like dilatation of the sinus remains.

After a recurrence of the ulcer one year later operation was made. Microscopic examination showed an ulcer with fibrous connective tissue. (After Lilja 1953).
in the activity of the canalis. Besides, a serration of the corpus usually occurs with a distinct limit at the transition to the sinus. Owing to the contraction of the corpus the wide sinus will be still more marked.

The author (1953) found a wide and slack sinus in 18 out of 22 operated cases of big ulcers at the incisura angularis with interruption of the muscular wall under the ulcer.

As there is no suspensory sling in the transverse stomach there are only two muscle layers here: an outer layer with longitudinal fibres essentially collected to the ligamenta ventriculi on the anterior and posterior surfaces, and an inner layer with circular fibres radiating fanwise from the minor curvature to the more extensive greater curvature. In the canalis there is a differentiation of the circular fibres forming a muscle knot on the minor curvature side with two loops to the greater curvature, this being a special arrangement for the function of the canalis (Torgersen 1942).

We have seen a difference in the behaviour of the two parts of the stomach in cases of ulcer. In the longitudinal stomach there is a muscular contraction, if the ulcer is located here, with a serration of its greater curvature. In the transverse stomach, on the other hand, a wide and slack sinus, like a tobacco-pouch, is found in cases of deep ulcers at the incisura angularis, often combined with changes of the peristalsis in this part of the stomach. This difference may be put in relation to the muscular structure and the physiologic activity of the two parts of the stomach.

The contraction of the longitudinal stomach is probably influenced by all muscle layers. However, the suspensory sling with its strong bundles of longitudinal as well as oblique fibres, its unique structure and function is of special importance for pursing up the longitudinal stomach in cases of ulcer. In this way the longitudinal stomach is well equipped to accommodate the muscular activity after the changing volume and weight of the contents.

In the transverse stomach the muscular reaction of an ulcer at the incisura angularis is quite different. A deep ulcer here located in membrana angularis beneath the strong supporting bands in the longitudinal stomach interrupts more or less the musculature. As there is no supporting suspensory sling in the transverse stomach the stability of the sinus is impaired by the ulcer and the roentgen picture shows a wide sinus without any serration of the greater curvature. Since the wide sinus usually is combined with a contracted lower part of the corpus the transition between the two parts is still more marked on the greater curvature side.

The disturbance of the peristalsis of the transverse stomach with shallow and irregular waves is often seen in cases of big ulcers at the incisura angularis. This observation can be related to the experiences made from electrogastrograms that the transverse stomach under special conditions may have a pattern of activity different from that in the longitudinal part, a frequency of its own. Many authors have presupposed the existence of a second pacemaker for the transverse stomach, which is able to take over the regulation of the activity. A big ulcer at the incisura angularis may cause an interruption of the influence from the dominating pacemaker for the whole stomach located in the corpus.

Thus the roentgenologic observations show remarkable differences of the muscular
activity in cases of ulcer in the longitudinal stomach and ulcer at the incisura angularis: a contraction with the typical serration of the greater curvature in the former and a wide sinus and often an impairment of the peristalsis in the latter. The author has correlated these roentgenologic findings with anatomic and physiologic facts.

Summary

The author has compared the roentgenologic findings of the stomach with the structure and function of its tunica muscularis. Physiologists, previously, have observed that the stomach as to the muscular activity consists of two parts with different characteristics on each side of the angulus. The muscular activity in a normal stomach is well coordinated from the cardia down to the pylorus. The roentgenologic studies, however, have been concentrated on the appearance of the muscular activity in cases with ulcer in each part, in the longitudinal stomach and at the incisura angularis, giving principally different roentgenologic pictures of the shape and mucosal folding. In this way it has been possible to observe the activity of the strong bundles of the suspensory sling in the longitudinal stomach, limited to this part and unique in the whole digestive tract.

In recent years physiologic investigations have added valuable information about the muscular function of the stomach, briefly reported in this paper. Electrogastrograms have confirmed that the function, normally synchronized, under certain conditions can show a dissociation of the two parts. Experimental investigations have shown that the autonomic nervous system has an important function for the stomach as a reser-

voir-organ. Beside the earlier known mode of activity of this system, the vagus is mediating a reflex without any known transmitter substance, this vagal reflex also indicating a different activity between the two parts of the stomach.

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