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Studies on Roentogenographic Characteristics of the Stomach and Duodenum around the Pylorus 1. Normal Cases

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ABSTRACT . To examine the "jet effect" which has been implicated by the up-suspending and down-suspending experiments of the Mann-Williamson ulcer to be involved in ulcer formation, the gastroduodenal angle (GD angle) was established using the upright right anterior oblique view of an ordinary gastric X-ray inspection. The relationship between the GD angle and the morphology of the stomach and duodenum was studied in 88 healthy subjects.

The mean GD angle was 105.7° in males and 96.5° in females. With an increase in the GD angle, the Ba (Width of gastric angle section)/Bc (Width of gastric body section) ratio decreased, suggesting an acceleration of the tension of the gastric walls, while the duodenal loop area and the duodenal loop height increased. In addition, the number of duodenal longitudinal folds (Lf) tended to increase, suggesting acceleration of duodenal motility. The mean loop area was 15.2 cm^2 in males and 9.2 cm^2 in females. Antral peristalsis (AP) correlated positively with the Ba/Bc ratio and inversely with the GD angle.

In cases where the Lf number was more than two, i. e., accelerated cases, we found greater loop area and height, which suggested a correlation between them. An increase in the GD angle and AP as well as a decrease in the Ba/Bc ratio was also noted. This suggested gastric emptying based on the acceleration of gastric motility. It was suggested that in proximal duodenal anomaly (PDA) and distal duodenal anomaly (DDA), the motility of the stomach and duodenum differed.

Key words : Roentogenographic characteristics — Gastroduodenum — Motility

Roentogenographic characteristics in relation to the onset and progress of peptic ulcer were determined by Shinohara[1] in a series of studies mainly concerning the motility of gastric walls. Tsukamoto[2] pointed out that the torsion anomaly of the duodenal loop might be an important factor in the pathogenesis of peptic ulcers.

Our present study focuses on whether or not the "jet effect", which has been implicated in ulcer formation by the up-suspending and down-suspending experiments[3-8] for the Mann-Williamson ulcer, which made a historic contribution to the understanding of the onset of peptic ulcers, could be elucidated.

It is known that in cases of gastric ulcer in the initial stage, the stomach is hypotonic, and peristalsis is weakened, while in cases of duodenal ulcer in

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the initial stage, the stomach is hypertonic, and in most cases peristalsis is accelerated. Quantitative and systematic analysis of these phenomena have not so far been performed, except in some fragmentary experiments. For this reason the authors, following the results of Shinohara and Tsukamoto, attempted to describe the morphological characteristics of the stomach, particularly the gastroduodenal correlation surrounding the pylorus, as observed in gastric X-rays.

Since the "jet effect" occurs as a result of the antral contents being ejected into the duodenal cap through the pylorus in the normal stomach, it can theoretically be expressed by the angle of inclination of the pyloric tube. The authors determined this angle, the GD angle, under fixed conditions, and examined the relationship between this angle and the morphology of the stomach and duodenum and their motility.

SUBJECTS AND METHODS

Subjects : Eighty-eight healthy subjects who visited our department for gastric X-ray inspections from March to October 1982 were used for our study. Those who complained of symptoms in the upper digestive tract were included, but not if ulcers were detected on X-ray inspections or if then was a previous history of ulcers. Excluded were those cases where diseases other than upper digestive tract ailments existed, such as cholelithiasis or pancreatitis. Cases where a clear contrast of the duodenal loop was not obtainable or where a lot of gas entered the duodenal loop were also excluded.

Methods : 1. *Procedures for taking X-rays of the upper digestive tract*

Subjects were given foaming tablets (Gastroluft, 12 tablets) and fasted until mornig when 250 ml 100% w/v Baritogen Sol (barium sulfate 100% suspension solution) was administered orally. An ordinary gastric X-ray inspection followed.

After taking the frontal view in the upright position, the passage of barium through the duodenum was observed from the upright right anterior oblique view in which the pyloric ring can be noted immediately before compression. A picture was taken from a position from where almost all the duodenal loop could be seen, taking care to avoid overlapping of the duodenal loop and the gastric antrum as much as possible. No antispasmodics were administered on this occasion. X-ray photographs were taken with a Type DT-SK camera at 200 mA, 0.25 sec. and 80-90 KVP (PHOTO).

2. *Measurements*

We used pictures from the right anterior oblique and frontal views in the upright position when the duodenal loop was almost completely filled with barium. Duodenal anomalies were sought in all pictures (Fig. 1).

2-1. *The angle of the upright right anterior oblique*

The front of the abdominal CT picture at the second lumbar vertebrae was made 0°, and the right side 90°, and the angle formed by them was divided into 6 parts from "a" through to "f" : a ; 0°-15°, b ; 15°-30°, c ; 30°-45°, d ; 45°-60°, e ; 60°-75° and f ; 75°-90° (Fig. 2). The division into which the plane of the right anterior oblique view fell was decided by the position of the starting point of the left transverse process to the second lumbar

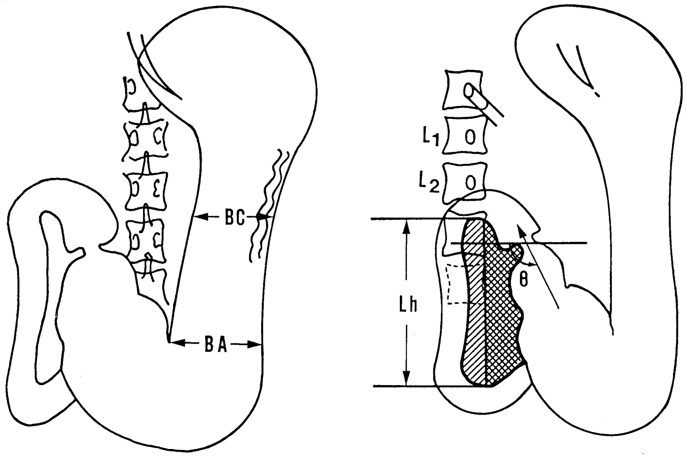

Fig. 1. Site measured by X-ray film of the stomach

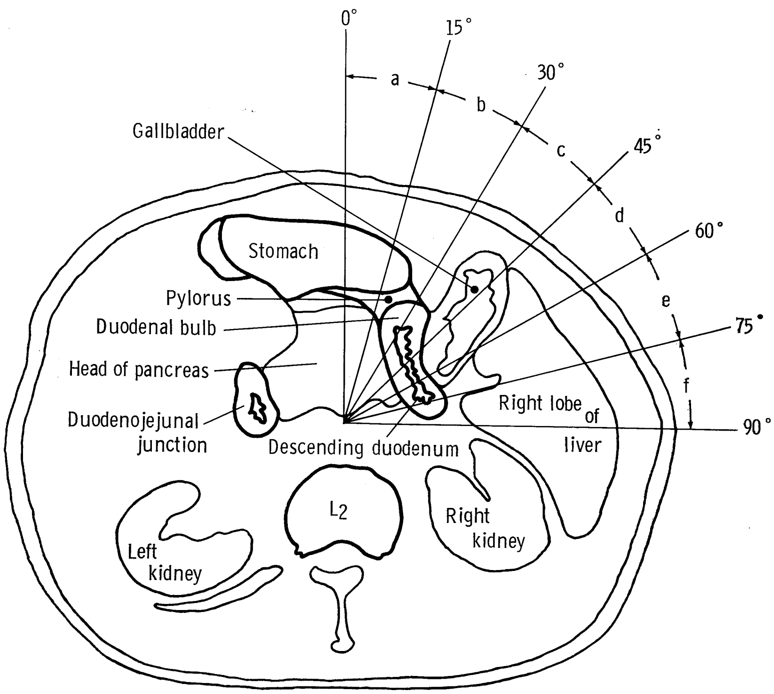

Fig. 2. Angle of upright right anterior oblique view of abdominal CT picture at second vertebrae

vertebrae.

2–2. *GD angle*

From the upright right anterior obliqe view, the corresponding tangents ps and rq on the inside of the greater and lesser curvatures of the gastric antrum and duodenal cap were determined and then lines connecting p and q and r and s were drawn. The angle formed by the line AD connecting the mid-points of pq and rs (A and D) and a horizontal line was the GD angle. When the pyloric ring was closed, however, the line AD was the line connecting A, the point of contact, and the mid-point D of the line GL connecting the points G and L 2 cm from A on the inside of the greater and lesser curvatures in the antrum (Fig. 3).

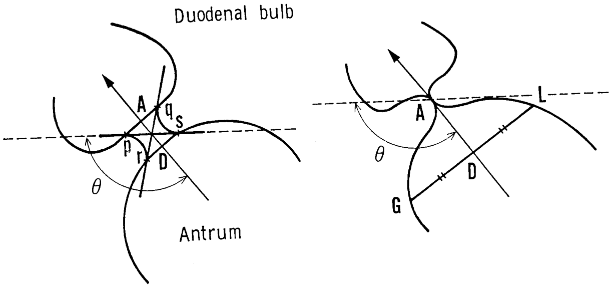

Fig. 3. Gastrodudenal angle (GD angle)

2–3. *Antral peristalsis* (*AP*)

Contractions shown roentogenographically in both the antral greater and lesser curvatures from two directions, the upright frontal and right anterior oblique views, were considered to be based on antral peristalsis, and were expressed by the number of peristaltic waves.

2–4. *Width of the gastric angle section/width of the gastric body section* (*Ba/Bc ratio*)

In accordance with Shinohara's method,[1] the Ba/Bc ratio was represented by the ratio of the width of the gastric angle section to the width of the gastric body section, in the upright frontal view.

2–5. *Duodenal loop area* (*or loop area*)

The inside of the duodenal loop and the area partly encircled by the antral greater curvature in the upright right anterior oblique view was calculated and expressed in square centimeters. The area can be calculated more accurately by envisaging the front of the duodenal loop, since it varies individually. With the upright frontal view alone we were unable to observe the morphology of the pyloric antral greater and lesser curvatures, so that evaluation of gastric peristalsis was not easy to make. In addition, the morphology of the stomach, especially the influence of the gastric antrum on the loop area, could not be ignored. Therefore, the highest point of the inside of the duodenal loop was divided perpendicularly into two areas, the loop-side area and stomach-side area.

The X-ray charts were evaluated by a digitizer (Apple Graphic Tablet), and the area was calculated using a personal computer (Apple II). The error of the Apple Graphic Tablet determined with the area of a chart about 1mm, 10.00 cm^2, and the error was 2–3%.

2–6. *Maximal vertical internal diameter of the duodenal loop* (*or loop height*)

The maximal vertical internal diameter of the duodenal loop at the upright

right anterior oblique was expressed in centimeters.

2-7. *Duodenal longitudinal folds (or Lf)*

The longitudinal folds observed in parallel with the longitudinal axis over the entire length of the duodenal loop were called Lf, and the number and location of folds were studied.

2-8, *Malrotation of the duodenum (or MD)*

On the basis of Thommersen's standards,[9] proximal duodenal anomaly (PDA) and distal duodenal anomaly (DDA) were examined.

RESULTS

1) *Distribution of age and sex, and the incidence of MD*

Eighty-eight normal subjects, consisting of 47 males and 41 females, with ages ranging from 15 to 80 (mean of 47.3 years) were studied. There were 17 cases of MD (19.3%). The number of subjects with MD in the age group up to 40 was 11 (64.7%), and the overall frequency was 33.3% (Fig. 4).

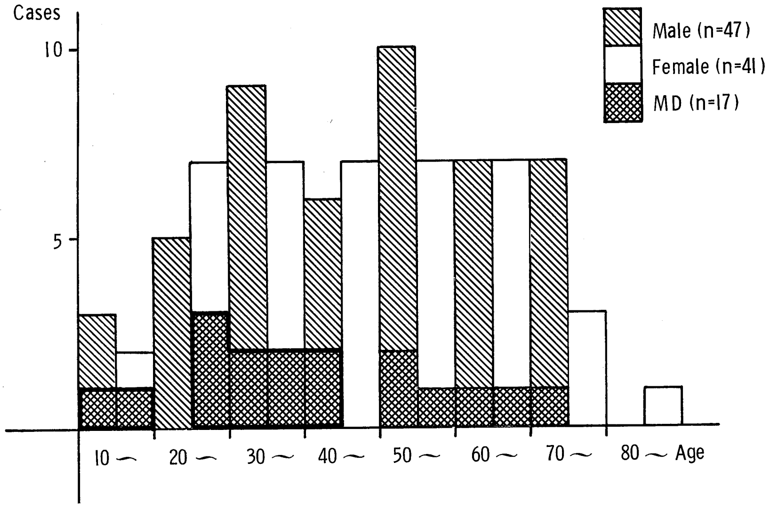

Fig. 4. Age and sex distribution in 88 normal subjects

2) *The angle of the upright right anterior oblique view*

Subjects in whom the GD angle could be determined and the duodenal loop could be seen from the front at the angle of 30° to 45° occupied the highest percentage at 37.5%, followed by 45°-60° and 60°-75°. Those whose GD angle and duodenal loop could be seen in the range from 30° to 75° occupied 88.7% (Table 1).

3) *GD angle*

The mean GD angle in healthy subjects classified by age and sex was calculated (Table 2). Although no definite difference was observed according to age, the mean angle in males proved to be 105.7° (over 100° or all age groups), whereas in females, the mean was 96.6° (below 100° in all age groups, except for those in their sixties). Table 3 shows the distribution of the GD angle at 100° and 120°, and indicates that the angles of 68.3% of the

TABLE 1 Number of subjects whose upright right anterior oblique view fell whithin each angle range

	Male	Female	Total
a : 0～15°		2 (4.9)	2 (2.3)
b : 15～30°	4 (8.5)	3 (7.3)	7 (8.0)
c : 30～45°	16 (34.0)	17 (41.5)	33 (37.5)
d : 45～60°	15 (31.9)	12 (29.3)	27 (30.7)
e : 60～75°	12 (25.5)	6 (14.6)	18 (20.5)
f : 75～90°		1 (2.4)	1 (1.1)
	47 (100)	41 (100)	88 (100)

TABLE 2 Gastroduodenal angle (**GD angle**)* by age and sex in 88 normal subjects

Age	Cases	**Male**	**Female**	Total
～ 19	5 (5.7)	103.7	77.0	93.0
20 ～ 29	12 (13.6)	112.4	92.3	106.6
30 ～ 39	16 (18.2)	104.3	93.7	99.7
40 ～ 49	13 (14.8)	104.0	94.0	98.6
50 ～ 59	17 (19.3)	111.6	87.0	101.7
60 ～ 69	14 (15.9)	111.7	101.4	106.6
70 ～ 79	10 (11.4)	105.9	96.3	103.0
80 ～	1 (1.1)		69.0	69.0
average		105.7	96.6	101.6

* ; °

TABLE 3 Differences in the gastroduodenal angle (GD angle) according to sex in 88 normal subjects

GD angle	**Male**	**Female**	Total
～ 99°	19 (40.4)	28 (68.3)	47 (53.4)
100°～119°	16 (34.1)	9 (22.0)	25 (28.4)
120°～	12 (25.5)	4 (9.7)	16 (18.2)
	47 (100)	41 (100)	88 (100)

females were below 99°.

4) *The loop area*

As shown in Table 4, the mean loop area in males was 15.2cm^2 and in females, 9.2cm^2, the mean in both sexes being 12.4cm^2. With a widening of the GD angle, the stomach-side area clearly widened. The loop-side area also showed a widening tendency, but more conspicuously at 120° and above. No relationship between AP and loop area was noted.

In those cases where the Lf number was more than two, as compared to those where the number was 0 or 1, both the loop-side and stomach-side area were clearly enlarged. The stomach-side area in DDA tended to be smaller than without DDA (Table 5).

TABLE 4 **Loop Area*** by age and sex in 88 normal subjects

Age	**Male**	**Female**	Total
~ 19	12.4	6.4	10.0
20 ~ 29	18.6	8.2	12.6
30 ~ 39	12.3	10.4	11.5
40 ~ 49	19.8	11.0	15.1
50 ~ 59	13.9	7·8	11.4
60 ~ 69	18.7	8.9	13.8
70 ~ 79	11.8	8.2	10.7
80 ~		13.4	13.4
average	15.2	9.2	12.4

* ; cm²

TABLE 5. Relationship between loop area and gastroduodenal configuration (Average values : cm²)

			Loop-side area		Stomach-side area		Total-loop area	
GD angle	~ 99°	n=47	5.5		4.3		9.8	
	100°~119°	n=25	5.9		5.5		11.3	
	120°~	n=16	8.0		12.9		21.4	
AP	0	n=14	5.8		6.5		12.5	
	1	n=48	6.0	6.2	5.9	6.1	11.9	11.8
	2	n=23	6.5		6.4		11.8	
	3	n= 3	4.9		10.6		15.5	
No. of Lf	0	n=19	4.9	5.1	5.3	5.5	10.2	10.7
	1	n=50	5.2		5.6		10.8	
	2	n=13	9.2		9.5		18.7	
	3	n= 5	8.5	9.4	5.9	9.1	14.4	18.5
	4	n= 1	19.4		20.4		36.8	
MD	PDA	n= 8	7.0		7.9		14.8	
	DDA	n= 9	5.3		3.2		8.4	
	(N)	n=71	6.1		6.5		12.6	

TABLE 6 Correlation among GD angle, antral peristalsis (AP), B_A/B_C ratio, loop area, loop height and longitudinal fold

GD angle	**AP**		B_A/B_C	**Loop area (cm²)**	**Loop height (cm)**	**Lf**	
~ 99°	(−) 8 (+) 39	1.2	1.26	9.8	5.2	(0-1) 40 (2-4) 7	1.0
100°~119°	(−) 3 (+) 22	1.2	1.10	11.3	5.6	(0-1) 20 (2-4) 5	1.1
120°~	(−) 3 (+) 13	1.0	10.4	21.4	6.6	(0-1) 9 (2-4) 7	1.4
Mean		1.2	1.17	12.4	5.6		1.1

5) *The relationship between the GD angle and gastroduodenal motility*

When the GD angle was largely, changes in AP were not observable, but the Ba/Bc ratio was reduced, and a tendency towards an increase in the loop area, loop height and Lf number was noted (Table 6).

6) *The relationship between AP and gastroduodenal motility*

Only the Ba/Bc ratio showed a clear correlation which the increase in AP. The GD angle decreased rather than increase. However, no definite trend was noted in duodenal motility (Table 7).

TABLE 7 Correlation among antral peristalsis (AP), GD angle, B_A/B_C ratio and loop area

AP		GD angle (°)		B_A/B_C		Loop area (cm²)		Lf	
0	n=14	106.6		1.35		12.4		(0–1) 13 (2–4) 1	1.0
1	n=48	101.3	100.9	1.16	1.14	11.9	11.8	(0–1) 37 (2–4) 11	1.1
2	n=23	100.0		1.11		11.8		(0–1) 16 (2–4) 7	
3	n= 3	95.0		1.02		15.5		(0–1) 3 (2–4) 0	0.7

7) *The relationship between the Lf number and gastroduodenal motility*

Those where only one Lf was observed occupied the majorty of 56.8%, followed by those where no Lf was found (21.6%). These two groups were considered normal, and those where two or more Lfs were detected were regarded as accelerated cases. With an increase in the Lf number, expansion of the loop area and an increase in the loop height were observed. On the other hand, a tendency for the GD angle and AP to increase and the Ba/Bc ratio to decrease were noted (Table 8).

TABLE 8 Correlation among number of longitudinal fold (Lf), loop area, loop Height, GD angle, antral peristalsis (AP) and B_A/B_C ratio

No of Lf		Loop area (cm²)		Loop height (cm)		GD angle (°)		AP			B_A/B_C	
0	n=19	10.2	10.7	4.9	5.2	101.5	99.3	1.2	1.1	(−)13	1.13	1.18
1	n=50	10.8		5.3		98.5		1.1		(+)46	1.21	
2	n=13	18.7	18.5	6.7	6.9	112.6	109.8	1.3	1.3	(−) 0	0.98	1.00
3	n= 5	14.4		6.7		99.4		1.2			1.06	
4	n= 1	36.8		9.1		125.0		2.0		(+)19	0.97	

8) *MD and gastroduodenal motility*

Because of an unbalanced sex ratio, a definite comparison was not possible, but it was observed that, when PDA existed, a decrease in the GD angle and an increase in the Ba/Bc ratio were found, whilst when DDA existed, a decrease in the GD angle and in the Ba/Bc ratio were recognized, together with a narrowing of the loop area (Table 9).

TABLE 9 Relationship among duodenal malrotation (MD), duodenum and stomach

MD	Sex M	Sex F	Loop area (cm²)	Loop height (cm)	Lf	GD angle (°)	AP	B_A/B_C
PDA n=8	6	2	14.8	5.6	(0-1) 6 (2-4) 2 1.3	95.8	(−) 3 (+) 5 1.1	1.31
DDA n=9	3	6	8.4	5.7	(0-1) 8 (2-4) 1 1.1	93.3	(−) 1 (+) 8 1.1	0.97
(N) n=71	38	33	12.6	5.6	(0-1)55 (2-4)16 1.1	103.3	(−)10 (+)61 1.2	1.18

PDA : Proximal duodenal anomaly
DDA : Distal duodenal anomaly
N : Normal duodenal configuration

9) *Comparison of the sites where Lf appeared in the non-MD group and MD group*

In the non-MD group, those where Lfs were noted in the descending pars, constituted a majority of 57.4%, followed by those where found in the horizontal, ascending and upper pars of duodenum. Although many Lfs were found in cases cf PDA and DDA, the number of accelerated cases where more than two Lfs were found were rather few, and many Lfs were noted near the PDA or DDA lesions (Table 10).

TABLE 10 Site of duodenal longitudinal fold in normal duodenal configuration (N) proximal duodenal anomaly (PDA) and distal duodenal anomaly (DDA)

No. of Lf	N				PDA				DDA			
	Cases	S	D	HA	Cases	S	D	HA	Cases	S	D	HA
0	17	—	—	—	1	—	—	—	1	—	—	—
1	38	3	22	13	5	1	4	0	7		5	2
2	12	3	12	9	1		1	1	0			
3	3	0	4	3	1	1	1	1	1		2	1
4	1	0	2	2	0				0			
Total	71	6	40	27	8	2	6	2	9	0	7	3

S ; Pars superior of duodenum
D ; Pars descendens
HA ; Pars horizontalis & ascendens

DISCUSSION

Although several studies have been conducted on gastroduodenal motility, only a few are useful in clinical practice. The present experiment examined the "jet effect" (propelling force), that is, the hydrodynamic and mechanical force in the up-suspending and down-suspending experiments of the Mann-Williamson ulcer surrounding the pylorus. The GD angle was evaluated, and its meaning as well as its relation to morphological characteristics of the stomach and duodenum described by Shinohara and Tsukamoto,[1,2] were examined in normal subjects having no peptic ulcers.

The GD angle is one of the means whereby the increase and decrease in the "jet effect", indicating hydrodynamic action, can be expressed numerically. The "jet effect" intensified by the chemical force (acidity) of the gastric juice. The increase in this chemical force is concurrently involved with the acceleration of gastric secretion, and the acceleration of gastric secretion is, needless to say, necessarily connected with the intensification of the mechanical force of gastric juices. The most appropriate case in clinical practice allowing us to observe the "jet effect" may be the onset of ulcers in the anastomosed region. It has long been known that the higher the acidity of a intragastric solution, the more delayed is the emptying from the stomach.[6] This increase which is also induced when the extramural nerve and nerve muscle are cut is probably attributable to the local reflex via the intramural nerve cells.[4-6]

The existence of several receptors over the duodenal mucosa has been suggested, and it is a matter of course that the velocity of the transfer of the contents from the stomach to the duodenum is affected by the physical and chemical composition of the contents of the stomach.[5-7,10]

As to the pyloric sphincter, which has been considered to exert much influence on gastric emptying, Schulze-Delrieu[13] reported that when electric stimulus was given to the resected human pyloric muscle, the distal pyloric sphincter looked more like the duodenal ring muscle than the antral ring muscle, and its relaxation response was larger than that of the duodenal muscle. This response indicates that the pyloric sphincter may be more closely associated with duodenal motility, i.e., constriction and relaxation, than with gastric motility, suggesting that it is not merely an intramucosal reflex, like the relaxation of the pyloric sphincter, due to HCl stimulation of the antral mucosa. The fact that when air is sent into the duodenum through an endoscope the pylorus remains open after removing the endoscope, indicates that the motility of the pyloric sphincter may be influenced by duodenal motility.

Miyaoka[7] studied the shape of the stomach and gastric emptying patterns, and stated that in those cases where the perpendicular distance of the gastric angle to the pylorus was less than 5cm, not being influenced by gastric ptosis, as compared with those above 5cm, gastric emptying clearly showed a linear relationship to a log scale, depending on the shape of the stomach. A short perpendicular distance may also be regarded as being associated with an increase in the "jet effect".

The authors considered the GD angle to be a significant indicator of gastroduodenal motility and gastric emptying, and the acceleration of gastric tonus and duodenal motility, but not acceleration of gastric peristalsis, to be suggested by an increase in the GD angle.

Fukuhara[4] reported that in principle a law similar to Poiseulle's Law, $V = r^4p/8\eta l$, can applied to the measurement of the emptying of the gastric contents. In other words, the factors controlling gastric emptying are volume V, peristalsis producing a pressure difference p, tonus which is a factor changing the diameter of the tube, and viscosity η. The most important among these factors are peristalsis and tonus. The authors recognized acceleration of the tonus of the stomach with an increase in AP, while the GD angle decreased. Accordingly, it is possible that the GD angle correlates with gastric tonus, and inversely correlates with gastric peristalsis. It is considered, therefore, that under physiological conditions these mechanisms might work to control gastric emptying. It is presumed that gastric emptying may be easily accelerated by increasing the GD angle and denying the possibility of retropulsion by resecting the pyloric antrum, leading the authors to consider the possibility of controlling gastric emptying by the adjustment of the GD angle and the size of the opening for anastomosis.

It was noted that the GD angle widened with an increase in the number of Lfs, and that gastric emptying was accelerated due to the acceleration of gastric peristalsis and tonus. In addition, a widening of the loop area and an increase in the loop height were also noted on that occasion, suggesting a correlation between duodenal motility and loop area. The increase in the loop area and height were mainly caused by the constriction of the duodenal walls, especially of the ring muscle, and when the constriction was intensified, the intestinal tract was lengthened in the direction of the long axis and became more slender. These finding agree fairly well with those of Borgström who reported an inhibition of the propulsive movement among the three types of duodenal movement : propulsive, retrograde and static. It is, therefore, necessary to study these movements, especially the relationship between the propulsive movement and the number of Lfs.

Brown[12)] studied thea ssociation of digestive hormones using dogs in which the gastric body transplanted. When their duodenum was perfused with an alkaline solution, the trasplanted stomach strongly constricted. It was pointed out by this result that in the duodenal mucosa, there is a substance associated with stimulating gastric peristalsis, i. e., Motilin. The actions of digestive hormones accelerating gastric emptying without intermediary neural control from the inside or outside, must further be clarified.

PDA and DDA were also studied in relation to duodenal malrotation and gastroduodenal motility. It was considered that the narrowing of the loop area in DDA might be due to the deformation of the third portion, and it was presumed that the deformation of the loop due to MD might influence the loop area. However, no correlation with duodenal motility was recognized. Although in PDA the decrease in tonus, and in DDA the acceleration of tonus, of gastric motility were recognized, correlation with duodenal motility was not observed. The sites of Lf were rather near the sites of MD, perhaps because of the intramucosal reflex related to the rise in the inner pressure of the focus and the shortness of the distance between the MD and Lf in the small intestine.

Consequently it was concluded that gastroduodenal motility was different according to the site of MD, which produced a difference in gastric emptying. Thommersen,[9)] however, stated that in PDA gastric emptying was accelerated, while in DDA it was prolonged. This contradiction requires further study.

CONCLUSION

The gastroduodenal angle (GD angle) was established, and its relationship to gastroduodenal motility was examined in normal subjects.

With the widening of the GD angle, tonus of the gastric walls and acceleration of duodenal motility were observed, whereas gastric peristalsis showed no change. Expansion of the loop area in the duodenum, a widening of the

GD angle and acceleration of gastric motility due to the acceleration of duodenal motility were recognized, and resulted in a subsequent acceleration of gastric emptying.

It was suggested that in proximal duodenal anomaly (PDA) and distal duodenal anomaly (DDA), the motility of the stomach and duodenum differed.

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