Gut, 1969, 10, 637-642

Lean body mass, gastric acid, and peptic ulcer

J. H. BARON

From the Department of Surgery, Royal Postgraduate Medical School, Hammersmith Hospital, London

SUMMARY Peak acid outputs in normal subjects and patients with duodenal and gastric ulcer were significantly (and similarly) correlated with body weight and calculated lean body mass.

Expression of measurements of peak acid output as a function of body weight or lean body mass lessened but did not abolish the significance of the situation that men with no dyspepsia or gastric ulcer secreted more acid than women; the significant sex difference in duodenal ulcer was, however, abolished.

Data for peak acid output have been tabulated, not only as m-equiv/hr but also as μ-equiv/kg body weight/hr and μ-equiv/kg lean body mass/hr. On the basis of the present data no change is suggested in the current expression of peak acid output as m-equiv/hr since expression of acid output as a function of body weight or lean body mass improves neither the variability nor the diagnostic discrimination of measurement of peak acid output.

There have been many attempts to relate gastric secretion to different measurements of body build. The simplest hypothesis is that maximum acid output (Kay, 1953) as a function of the parietal cell mass of the stomach (Card and Marks, 1960) is a function of body weight, and significant correlations have been found between maximum acid output and body weight in animals, such as the rat (Shay, Sun, and Gruenstein, 1954) and the dog (Baron, unpublished data), as well as the human child (Ghai, Singh, Walia, and Gadekar, 1965) and infant (Rodbro, Krasilnikoff, and Christiansen, 1967), with no differences between the sexes.

Available data for the human adult are conflicting. Cox (1952) found 'no consistent relationship between stomach size and age or body size'. In normal adult men a significant correlation between maximum acid output and body weight was obtained by Marks (1961), but not by Baron (1964), nor by Vakil and Mulekar (1965), nor by Goyal, Gupta, and Chuttani (1966), nor (for submaximal secretion) by Booth, Hunt, Miles, and Murray (1957), nor in the data of Lander and Maclagan (1934) (see Baron, 1964).

In normal adult women a significant correlation between maximum acid output and body weight was obtained by Baron (1964) and by Vakil and Mulekar (1965), but in neither men nor women with gastric or duodenal ulcer were there such significant correlations (Baron, 1964).

Marks (1961) considered that the 'significant positive correlation found between maximum acid output and body weight in controls helps to explain a portion of the difference between the mean maximum acid output values in male and female control subjects'. Card has suggested 'that the smaller acid output (and parietal cell mass) of women may be simply due to their lower body weight or smaller lean body mass' (Baron, 1964). It has hitherto been difficult to accept the hypothesis for body weight because of the conflicting data described above, and difficult to test the hypothesis for lean body mass because of difficulties in accurately measuring this function of body size.

Lean body mass can now be calculated from height (H, cm) and weight (W, kg) by the formulae of Hume (1966):

MEN

Lean body mass = 0·32810 W + 0·33929 H − 29·5336

WOMEN

Lean body mass = 0·29569 W + 0·41813 H − 43·2933

Hume and Melrose (1967) in a preliminary communication have obtained significant correlations between maximum acid output and lean body mass in normal subjects. The present communication re-examines my personal data as well as those of other investigators both for body weight and also for lean body mass by the Hume formulae. Calculations have been made to test the various hypotheses, to study the effects of age and sex, and also to assess whether the variability and diagnostic discrimination of measurements of peak acid output would be improved by the expression of acid output on a body weight or lean body mass basis.

TABLE I

WEIGHT AND LEAN BODY MASS OF SUBJECTS WITHOUT DYSPEPSIA, WITH DUODENAL ULCER, AND WITH GASTRIC ULCER, AND THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN SEXES AND OF PATIENTS WITH ULCER FROM NORMAL SUBJECTS

	Weight (kg)					*Lean Body Mass (kg)*				
	n	*Mean*	*SE*	*P*[1]	*M/F Ratio*	*n*	*Mean*	*SE*	*P*	*M/F Ratio*
Normal subjects										
Men	20	67·90	2·02	<0·002	1·6	20	51·70	1·16	<0·001	1·23
Women	20	58·40	1·83			20	42·05	1·20		
Duodenal ulcer										
Men	50	68·46	1·63	<0·05	1·12	48	51·65	0·71	<0·001	1·21
Women	20	61·30	2·95			18	42·67	1·53		
Gastric ulcer										
Men	20	62·85	2·02	<0·001	1·27	20	49·60	1·16	<0·001	1·31
Women	20	49·55	1·97			20	53·29	1·26		

[1]Significance, P, of difference from normal of

Duodenal ulcer:	Men	>0·8	>0·9
	Women	>0·4	>0·7
Gastric ulcer:	Men	>0·1	>0·2
	Women	<0·001	<0·01

POPULATIONS STUDIED

Four populations have been studied and are denoted by the abbreviations, B, P, LM, and I.

In population B the peak acid output had been measured with an augmented histamine test in 20 male and 20 female subjects without dyspepsia, 20 male and 20 female patients with gastric ulcer, and 50 male and 20 female patients with duodenal ulcer (Baron, 1963a and b). The heights of two men and two women with duodenal ulcer were not recorded so that calculations of lean body mass were made in only 48 men and 18 women with duodenal ulcer.

In population P Dr C. V. Perrier, of the Clinique Universitaire Thérapeutique, Hôpital Cantonal, Geneva, had measured peak acid output with an augmented histamine test (Baron, 1963a) in 20 normal men and 52 men with duodenal ulcer. The heights of two normal men and four men with duodenal ulcer were not recorded so that calculations of lean body mass were made in only 18 normal men and 48 men with duodenal ulcer.

In population LM the 'free acid' output in the hour following the injection of 0·01 mg/kg histamine acid phosphate had been measured in 91 male medical students without dyspepsia (Lander and Maclagan, 1934).

In population I the acid output in the hour following the injection of 0·01 mg/kg histamine acid phosphate had been measured in 18 normal men, in 14 men with gastric ulcer, and in 13 men with duodenal ulcer by Ihre (1938).

RESULTS

BODY BUILD The men of Baron (1963a and b) were significantly heavier than the women and had significantly larger lean body mass. Neither the body weight nor the lean body mass of patients with duodenal ulcer or of men with gastric ulcer differed significantly from normal. Women with gastric ulcer were not only significantly lighter than normal women, but also had a lower lean body mass (Table I).

CORRELATIONS OF ACID WITH BODY BUILD In normal subjects (Tables II and III) significant correlations of gastric acid with body weight were found with I men, P men, and B women; a correlation of doubtful significance was obtained by combining B and P

TABLE II

CORRELATIONS OF PEAK ACID OUTPUT WITH BODY WEIGHT AND LEAN MASS IN NORMAL SUBJECTS

		Body Weight			*Lean Body Mass*		
Sex	*Group*	*n*	*r*	*P*	*n*	*r*	*P*
Men	B	20	0·11	0·32	20	0·33	0·078
Men	P	20	0·46	0·021	18	0·57	0·072
Men	B + P	40	0·23	0·074	38	0·38	0·0085
Women	B	20	0·45	0·023	20	0·41	0·038
Men + women	B	40	0·37	0·009	40	0·49	0·006
Men + women + men	B, P	60	0·40	0·0007	58	0·55	0·000004

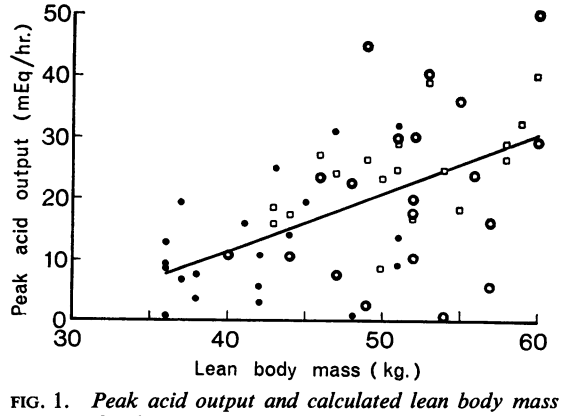

FIG. 1. *Peak acid output and calculated lean body mass in normal subjects.* ○ = B *men,* □ = P *men,* ● = B *women,* $r = 0{\cdot}5481$, $P = 0{\cdot}000004$, $y = 0{\cdot}95x - 26{\cdot}3$

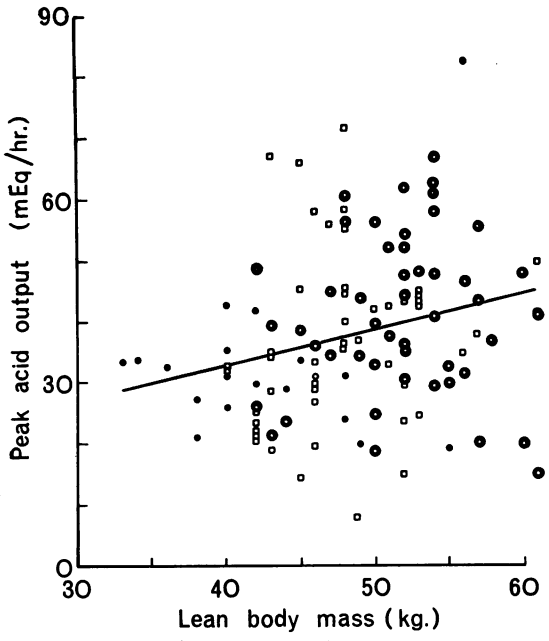

FIG. 2. *Peak acid output and calculated lean body mass in patients with duodenal ulcer.* ○ = *B men,* □ = *P men,* ● = *B women, r = 0·2623, P = 0·002, y = 0·59x + 9·30*

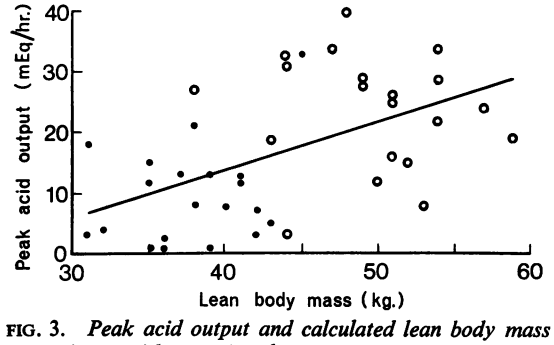

FIG. 3. *Peak acid output and calculated lean body mass in patients with gastric ulcer.* ○ = *B men,* ● = *B women, r = 0·5212, P = 0·0003, y = 0·78x − 17·5*

men, and significant correlations were found by combining B men and women, and also by adding to them P men (a total of 60). In duodenal ulcer patients (Table IV) there were significant correlations between acid output and body weight in I men and in P men; the combined B and P men showed a significant correlation, as did the combined B men and women, and also the combination of B men and women with the P men (a total of 122). In gastric ulcer patients there were significant correlations between acid output and body weight with I men (Table III) and the combined B men and women with gastric ulcer (a total of 40) (Table IV).

TABLE III

CORRELATIONS OF SUBMAXIMAL ACID OUTPUT WITH BODY WEIGHT AND LEAN BODY MASS

			Body Weight			*Lean Body Mass*		
Diagnosis	*Sex*	*Group*	*n*	*r*	*P*	*n*	*r*	*P*
Normal	Men	LM	91	−0·06	0·28	91	−0·04	0·36
Normal	Men	I	18	0·76	0·00014	18	0·75	0·00018
Duodenal ulcer	Men	I	13	0·41	0·083	13	0·24	0·20
Gastric ulcer	Men	I	14	0·65	0·006	14	0·65	0·006

The correlations between peak acid output and lean body mass were essentially similar to those with body weight in normal subjects (Table II, Fig. 1), in patients with duodenal ulcer (Table IV, Fig. 2), and gastric ulcer (Table IV, Fig. 3), as well as in studies of submaximal acid output (Table III).

ACID OUTPUT AND BODY BUILD The data of peak acid output of the normal subjects and peptic ulcer patients of Baron (1963a and b) are provided in Table V in the original m-equiv/hr, as well as μ-equiv/kg body weight/hr, and μ-equiv/kg lean body mass/hr for the convenience of those who use or wish to use such weight-corrected acid data.

SEX AND ACID OUTPUT Normal men secreted one-and-three-quarter times as much acid as women

TABLE IV

CORRELATIONS OF PEAK ACID OUTPUT WITH BODY WEIGHT AND LEAN BODY MASS IN PATIENTS WITH PEPTIC ULCER

			Body Weight			*Lean Body Mass*		
Ulcer	*Sex*	*Group*	*n*	*r*	*P*	*n*	*r*	*P*
Duodenal	Men	B	50	0·10	0·25	48	0·06	0·35
Duodenal	Men	P	52	0·34	0·0066	48	0·28	0·029
Duodenal	Men	B + P	102	0·22	0·0124	96	0·20	0·0248
Duodenal	Women	B	20	0·23	0·17	18	0·26	0·15
Duodenal	Men + women	B	70	0·21	0·0436	66	0·25	0·0203
Duodenal	Men + women + men	B, P	122	0·24	0·0034	114	0·26	0·0024
Gastric	Men	B	20	0·29	0·10	20	−0·12	0·31
Gastric	Women	B	20	−0·05	0·42	20	0·26	0·13
Gastric	Men + women	B	40	0·42	0·003	40	0·52	0·0003

TABLE V

PEAK ACID OUTPUT IN NORMAL SUBJECTS AND PATIENTS WITH DUODENAL AND GASTRIC ULCER RELATED TO SEX DIFFERENCES AND MALE/FEMALE RATIOS

Diagnosis		*Expression of Peak Acid Output*													
		m-equiv/hr					*μ-equiv/kg Body Weight/hr*					*μ-equiv/kg Lean Body Mass/hr*				
		n	*Mean*	*SE*	*P*	*M/F*	*n*	*Mean*	*SE*	*P*	*M/F*	*n*	*Mean*	*SE*	*P*	*M/F*
Normals																
All ages	Men	20	21·6	3·1	0·016	1·76	20	317·0	47·3	0·06	1·54	20	413·4	57·7	0·09	1·48
	Women	20	12·3	2·0			20	205·5	31·4			20	287·0	43·9		
⩾ 30	Men	16	18·7	3·2	0·006	2·34	16	282·6	52·9	0·02	2·05	16	366·2	63·2	0·02	1·88
	Women	15	8·0	1·2			15	138·1	20·3			15	195·1	30·1		
< 30	Men	4	33·4	5·9	0·25	1·32	4	455·0	83·3	0·57	1·12	4	602·0	104·4	0·72	1·07
	Women	5	25·3	2·5			5	407·6	26·5			5	562·8	41·4		
Duodenal ulcer																
	Men	50	42·0	1·9	0·005	1·31	50	608·2	29·0	0·19	1·13	48	793·5	37·1	0·80	1·02
	Women	20	32·0	3·0			20	537·6	44·4			18	775·2	64·5		
Gastric ulcer																
	Men	20	22·6	2·2	0·001	2·35	20	391·3	40·0	0·004	1·73	20	483·3	47·1	0·008	1·64
	Women	20	9·6	1·7			20	225·6	35·9			20	296·3	48·0		

TABLE VI

CORRELATIONS OF PEAK ACID OUTPUT WITH AGE IN NORMAL SUBJECTS AND PATIENTS WITH DUODENAL AND GASTRIC ULCER

			Peak Acid Output			*Peak Acid Output/kg Body Weight*			*Peak Acid Output/kg Lean Body Mass*		
Group	*Diagnosis*	*Sex*	*n*	*r*	*P*	*n*	*r*	*P*	*n*	*r*	*P*
B	Normal	Men	20	−0·30	>0·1	20	−0.25	>0·1	20	−0·27	>0·1
B	Normal	Women	20	−0·71	<0·001	20	−0·73	<0·001	20	−0·71	<0·001
B	Normal	Men + women	40	–	–	40	−0·40	<0·01	40	−0·44	<0·01
B	Duodenal ulcer	Men	50	+0·09	>0·3	50	0·06	>0·3	48	0·07	>0·3
B	Duodenal ulcer	Women	20	−0·14	>0·2	20	−0·20	>0·2	18	−0·14	>0·2
B	Duodenal ulcer	Men + women	70	–	–	70	−0·001	>0·5	66	0·13	>0·1
B	Gastric ulcer	Men	20	−0·07	>0·3	20	0·03	>0·4	20	0·009	>0·4
B	Gastric ulcer	Women	20	−0·27	>0·1	20	−0·28	>0·1	20	−0·30	>0·1

TABLE VII

PROPORTIONS OF DUODENAL ULCER PATIENTS WITH PEAK ACID OUTPUTS ABOVE THE UPPER LIMIT OF NORMAL

	Peak Acid Output			*Peak Acid Output/kg Body Weight*			*Peak Acid Output/kg Lean Body Mass*		
	n	*Upper Limit of Normal*[1] *(m-equiv/hr)*	*Duodenal Ulcer > Upper Limit of Normal*	*n*	*Upper Limit of Normal (μ-equiv/kg/hr)*	*Duodenal Ulcer > Upper Limit of Normal*	*n*	*Upper Limit of Normal (μ-equiv/kg/hr)*	*Duodenal Ulcer > Upper Limit of Normal*
Men	50	49·2	15/50 (30%)	50	740	13/50 (26%)	48	930	14/48 (29%)
Men ⩾ 30	43	44·0	22/43 (51%)	43	705	13/14 (30%)	41	872	16/41 (39%)
Women	20	30·2	10/20 (50%)	20	486	11/20 (55%)	18	680	11/18 (61%)
Women ⩾ 30	17	17·4	17/17 (100%)	17	295	15/17 (88%)	15	429	13/15 (87%)
Men + women				70	633	25/70 (36%)	66	821	28/66 (42%)

[1]Mean + 2SD

(Table V) and when the data were expressed as a function of body weight or lean body mass the ratio fell to about one-and-a-half times and the difference between the sexes became less significant. There was no significant sex difference in those under 30 years. However, normal men of 30 years or over secreted more than twice as much as women, and this ratio was slightly reduced by the expression of the acid output as a function of body weight or lean body mass, but the sex difference remained significant. In patients with duodenal ulcer the significant sex difference was no longer significant if the data were expressed as a function of weight or lean body mass, but in gastric ulcer the sex differences still remained significant after such treatment of the data.

AGE AND ACID OUTPUT In normal subjects, but not in patients with peptic ulcer, peak acid output decreased with age (Table VI) and this correlation was significant in normal women. Expression of acid output as a function of body weight or lean body mass did not appreciably alter these results.

ACID OUTPUT AND PEPTIC ULCER The hypersecretion of duodenal ulcer patients and the essentially

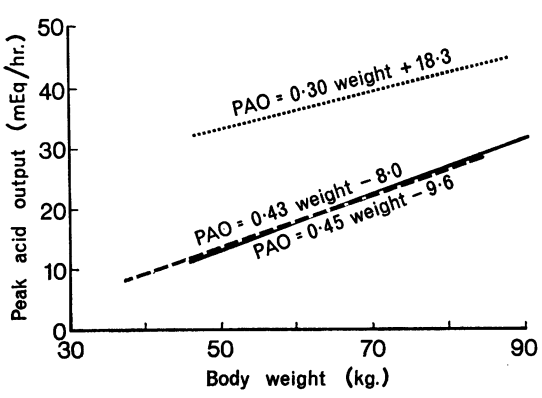

FIG. 4.

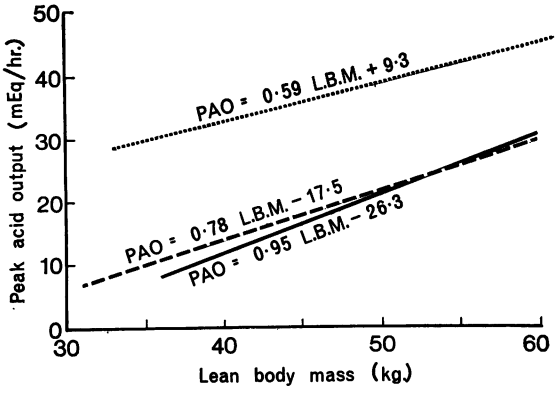

FIG. 5.

FIG. 4. *Regression lines of peak acid output with body weight in normal subjects* (———) *and patients with gastric ulcer* (— — —) *and duodenal ulcer* (· · · · · ·)

FIG. 5. *Regression lines of peak acid output with calculated lean body mass in normal subjects* (———) *and patients with gastric ulcer* (— — —) *and duodenal ulcer* (· · · · · ·).

normal secretion of gastric ulcer patients were consistent throughout the ranges of body weight (Fig. 4) and lean body mass (Fig. 5). The proportions of duodenal ulcer patients with peak acid output above the upper limit of normal were lessened by the expression of the results as a function of body weight or lean body mass (Table VII).

VARIABILITY OF MEASUREMENTS OF PEAK ACID OUTPUT The variability of peak acid output was not appreciably altered if the results were expressed as a function of body weight or lean body mass instead of in absolute quantities (Table VIII).

TABLE VIII

VARIABILITY OF MEASUREMENT OF PEAK ACID OUTPUT AS EXPRESSED IN ABSOLUTE QUANTITIES OR AS FUNCTION OF BODY WEIGHT OR LEAN BODY MASS

Diagnosis	*Coefficient of Variation (SD/Mean × 100)*		
	m-equiv/hr	*μ-equiv/kg Body Weight/hr*	*μ-equiv/kg Lean Body Mass/hr*
Normal men all ages	65	67	63
⩾30	68	75	69
<30	35	37	35
Normal women all ages	74	68	68
⩾30	59	57	60
<30	22	15	16
Duodenal ulcer			
Men	32	34	32
Women	42	37	35
Gastric ulcer			
Men	44	46	43
Women	82	71	72

DISCUSSION

Expression of peak acid output results as a function of body weight or lean body mass does not alter the findings of the previous study (Baron, 1964) that the body build of patients with duodenal ulcer is not different from normal and that women with gastric ulcer are lighter than normal women (Table I). However, my previous conclusions (Baron, 1964) are altered by increasing the number of subjects by the combination of the data with another series (P) and by combining the sexes. (1) Convincing correlations between peak acid output and body weight (and lean body mass) are found in normal subjects, as originally suggested for body weight by Marks (1961) and for lean body mass by Melrose and Hume (1967); (2) convincing correlations are also now obtained for peak acid output and body weight (and lean body mass) in patients with gastric and duodenal ulcer; (3) the correlation coefficients of peak acid output with these two different expressions of body size are similar, and formal analysis reveals no significant difference between them.

The sex differences in peak acid output are lessened by expression of results in terms of body weight and lean body mass, supporting the suggestion by Marks (1961) that 'the significant positive correlation found between maximum acid output and body weight in controls helps to explain a portion of the difference between the mean maximum acid output values in male and female subjects'. However, only a small portion of the difference can be explained on this basis, and even on a weight or lean body mass basis the peak acid output of normal men over 30 years is double that of, and significantly different from, normal women. Similarly, Crean (1963) could only lessen and not make insignificant the sex difference of acid output in 99 normal subjects (Card and Sircus, 1963) by expressing the results as a function

of body weight. There is still no clear explanation for this sex difference in the normal adult human and this sex difference has not been found in children nor in any other animal which has been studied.

The significant sex difference in the patients of Baron (1963b) with duodenal ulcer (though not gastric ulcer) is abolished by the expression of the peak acid output as a function of body weight and lean body mass. However, Crean (1963) could only lessen and not make insignificant the sex difference of acid output in 200 patients with duodenal ulcer (Card and Sircus, 1963) by expressing the results as a function of body weight. One can speculate that the significant difference in normal subjects and patients with gastric ulcer may be due not to the men secreting more acid than the women, but paradoxically to the women secreting less acid than the men because of a higher incidence of gastritis and hyposecretion in women, especially those with gastric ulcer. Such gastritis and hyposecretion are less common in duodenal ulcer, and no significant difference is found in these patients after correction for weight and lean body mass. There seems no reason to alter a previous suggestion that 'the sex difference in normal subjects is . . . largely due to the falling off in acid output in older women' (Baron, 1963a) since the decline of peak acid output with age in normal subjects, especially women, is not altered by expression of the results for acid in terms of body weight or lean body mass (Table VI).

Both basal and peak acid outputs are conventionally expressed as m-equiv/hr (Baron, 1963c), but in view of the correlations of acid output with body weight and lean body mass it is possible that acid output should be expressed per kilogram body weight or lean body mass; pancreatic secretion is often expressed per kilogram body weight. Such data are provided in Table V as an example, but there is little justification for recommending a general change to expressing acid output results on a body weight or lean body mass basis since the present data suggest that there would be neither an increase in the diagnostic discrimination between normal subjects and duodenal ulcer patients (Table VII) nor a decrease in the variability of measurements of peak acid output in any diagnostic group (Table VIII).

The support of the Wellcome Trust is gratefully acknowledged. I wish to thank Dr Lee Lander, Professor Maclagan, and Dr C. V. Perrier for allowing me to study their unpublished data.

REFERENCES

Baron, J. H. (1963a). Studies of basal and peak acid output with an augmented histamine test. *Gut*, **4**, 136-144.

—— (1963b). An assessment of the augmented histamine test in the diagnosis of peptic ulcer. *Ibid.*, **4**, 243-253.

—— (1963c). Measurement and nomenclature of gastric acid. *Gastroenterology*, **45**, 118-121.

—— (1964). Peptic ulcer, gastric secretion and body build. *Gut*, **5**, 83-85.

Booth, M., Hunt, J. N., Miles, J. M., and Murray, F. A. (1957). Comparison of gastric emptying and secretion in men and women with reference to prevalence of duodenal ulcer in each sex. *Lancet*, **1**, 657-659.

Card, W. I., and Marks, I. N. (1960). The relationship between the acid output of the stomach following 'maximal' histamine stimulation and the parietal cell mass. *Clin. Sci.*, **19**, 147-163.

——, and Sircus, W. (1963). Unpublished data quoted by Crean (1963).

Cox. A. J., Jr (1952). Stomach size and its relation to chronic peptic ulcer. *Arch. Path.*, **54**, 407-422.

Crean, G. P. (1963). The endocrine system and the stomach. *Vitam. and Horm.*, **21**, 215-280.

Ghai, O. P., Singh, M., Walia, B. N. S., and Gadekar, N. G. (1965). An assessment of gastric acid secretory response with 'maximal' augmented histamine stimulation in children with peptic ulcer. *Arch. Dis. Child.*, **40**, 77-79.

Goyal, R. K., Gupta, P. S., and Chuttani, H. K. (1966). Gastric acid secretion in Indians with particular reference to the ratio of basal to maximal acid output. *Gut*, **7**, 619-623.

Hume, R. (1966). Prediction of lean body mass from height and weight. *J. clin. Path.*, **19**, 389-391.

——, and Melrose, A. G. (1967). Relation between maximal acid output of stomach and lean body mass. *Brit. med. J.*, **2**, 30-31.

Ihre, B. (1938). Human gastric secretion. *Acta. med. scand*, suppl. **95**.

Kay, A. W. (1953). Effect of large doses of histamine on gastric secretion of HCl. *Brit. med. J.*, **2**, 77-80.

Lander, F. P. L., and Maclagan, N. F. (1934). One hundred histamine test-meals on normal students. *Lancet*, **2**, 1210-1213.

Marks, I. N. (1961). The augmented histamine test. *Gastroenterology*, **41**, 599-603.

Rodbro, P., Krasilnikoff, P. A., and Christiansen, P. M. (1967). Parietal cell secretory function in early childhood. *Scand. J. Gastroent.*, **2**, 209-213.

Shay, H., Sun, D. C. H., and Gruenstein, M. (1954). A quantitative method for measuring spontaneous gastric secretion in the rat. *Gastroenterology*, **26**, 906-913.

Vakil, B. J., and Mulekar, A. M. (1965). Studies with the maximal histamine test. *Gut*, **6**, 364-371.