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Accelerated Gastric Emptying in Hypertensive Subjects

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The phenomenon of accelerated gastric emptying has been previously reported in two conditions that are considered to be part of the insulin-resistance syndrome: namely, noninsulin-dependent diabetes (NIDDM) and increased body mass index (BMI). No previous studies have assessed the rate of gastric emptying in patients with essential hypertension, another disease considered to be part of the insulin-resistance syndrome. **Methods:** Scintigraphic gastric emptying studies were performed on nine hypertensive subjects and on nine sex-, age-, ethnicity and BMI-matched controls. **Results:** Subjects with hypertension had significantly more rapid gastric half-emptying times (gastric T_{50}) (40.0 ± 6.9 min versus 56.6 ± 3.7 min, $p = 0.02$) than controls. There was an inverse relationship between average glucose during the first 30 min and 60 min of the oral glucose tolerance test with the gastric half-emptying time (Spearman rank correlation coefficient $r_s = -0.64$, $p = 0.0045$ and $r_s = -0.48$, $p = 0.0428$, respectively). **Conclusion:** The occurrence of accelerated gastric emptying in hypertensive subjects, in addition to that previously reported in subjects with NIDDM or increased BMI, suggests the possibility that accelerated gastric emptying may be a common finding in insulin resistant states.

Key Words: hypertension; gastric emptying; insulin-resistance syndrome

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Essential hypertension commonly occurs in patients who also have obesity, noninsulin-dependent diabetes mellitus (NIDDM) and atherosclerotic cardiovascular disease. Because insulin resistance is a common factor associated with each of these disease entities, the association between them has been termed insulin-resistance syndrome (IRS) (1-4). Although the mechanism for the close relationship of these medical conditions is controversial, the statistical association of these conditions with insulin resistance is well accepted (4). In addition to insulin resistance, subjects with essential hypertension have been shown to have elevated postprandial glucose and insulin levels after administration of an oral glucose load (5-7).

Previous studies by our group have described an accelerated rate of gastric emptying in subjects with two medical conditions associated with insulin resistance, namely, NIDDM and increased body mass index (BMI) (8,9). Determining the rate of gastric emptying in hypertensive patients is important because a rapid rate of emptying has been clearly associated with elevation of postprandial glucose values (9,10). Subjects with elevated postprandial blood glucose levels following an oral

glucose load have a significantly greater risk of dying of coronary heart disease compared to subjects with normal postprandial glucose values (6,7).

No previous studies have been performed to assess the rate of gastric emptying in patients with essential hypertension. This study was performed to assess their rate of gastric emptying compared to matched controls and to determine if the elevated postprandial blood glucose and insulin levels observed in hypertensive subjects were related to an accelerated rate of gastric emptying.

METHODS

Subjects

This study was approved by the Institutional Review Board at the University of Texas Health Science Center at San Antonio. All subjects gave written informed consent after the nature of the procedure was explained. Local newspaper ads and fliers posted around the University of Texas Health Science Center at San Antonio were used (with the Institutional Review Board's approval) to solicit volunteers. All volunteers for the study were accepted in consecutive order. Those subjects with known diabetes mellitus were excluded from the study. All subjects, hypertensives and controls, were given a 75-g oral glucose tolerance test. Subjects who were diagnosed as having diabetes, as per the 1995 American Diabetes Association's Clinical Practice Recommendations (11,12), were excluded from the study. Subjects with known gastrointestinal disorders or recent surgery were also excluded from the study.

Gastric emptying studies were performed on nine hypertensive subjects and on nine subjects without hypertension as verified by three blood pressure measurements on three different days. The hypertensive subjects were matched with a nonhypertensive subject of the same sex, age, ethnicity and BMI. Of the 18 subjects, 12 were men and 6 were women. All of the women were premenopausal. Six of the subjects were Mexican-American, 2 were Asian-Indian and 10 were non-Hispanic white. The characteristics of the hypertensive subjects and the matched controls are shown in Table 1. None of our hypertensive or control subjects had a history of heart or renal disease or were taking any type of medication other than their prescribed anti-hypertensive medication. The length of time our hypertensive subjects had been diagnosed ranged from 1 to 24 yr.

The amount and type of antihypertensive medication varied greatly in our subjects. One of our hypertensive subjects was taking an angiotensin-converting enzyme (ACE) inhibitor, a calcium channel blocker and a vasodilator/diuretic for his hypertension. Another subject was taking an ACE inhibitor plus a calcium

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TABLE 1
Characteristics of Subjects by Hypertension Status

Variable	Hypertensive subjects			Control subjects			Significance
	No.	Mean	s.e.	No.	Mean	s.e.	
Age (yr)	9	44.6	2.7	9	44.1	2.2	0.6884
BMI (kg/m ²)	9	26.6	1.2	9	25.8	1.1	0.1763
Weight (kg)	9	80.7	5.0	9	77.7	5.3	0.2354
75 g OGTT							
Glucose 2 hr (mg/dl)	9	106.8	13.1	9	106.3	8.8	0.9818
Glucose 2 hr (mmol/liter)	9	5.93	0.73	9	5.91	0.49	0.9818

BMI = body mass index; OGTT = oral glucose tolerance test

channel blocker. Three of our hypertensive subjects were taking ACE inhibitors alone; two, calcium channel blockers alone; one, a diuretic alone; and one, a vasodilator/diuretic. All patients took their medication once a day, in the morning. The morning of the study the medication was withheld until completion of the study so that the patients had been off their medication for 24 hr prior to beginning the study. Patients were not taken off medications for a longer period of time due to the potential medical risks associated with elevation of blood pressure.

Gastric Emptying Studies

All testing was begun at 7:30 a.m., after an overnight fast, and lasted until approximately 10:30 a.m. An 18-gauge angiocatheter was placed in the subject's antecubital fossa for blood access. Two baseline blood samples were drawn just prior to the administration of the glucose meal and then single samples were drawn at 15-min intervals up to and including 120 min. Following the placement of the angiocatheter, a glucose solution (50 g glucose in 450 ml of water) containing approximately 200 μCi ^{99m}Tc-sulfur colloid (^{99m}Tc-SC) was given to the subject to drink in its entirety within a 5-min period. Immediately after the subject had finished drinking the glucose solution, the subject was asked to stand in front of the gamma camera where consecutive 1-min images were obtained in the anterior and posterior projections while the subject was standing. At 15-min intervals, repeat consecutive 1-min images were obtained. This study was continued for 120 min. Between standing image acquisitions, the subject was allowed to sit in a chair at a 90° angle.

Images were acquired with a gamma camera using a low-energy, all-purpose collimator with a 20% energy window setting centered at 140 keV. The camera was connected to a Medasys Pinnacle Computer (Ann Arbor, MI). Regions of interest were drawn around the stomach for all images acquired. The baseline images were drawn around all the activity to visualize both the stomach and the intestine. The percent activity remaining in the stomach was calculated as the stomach counts/total counts on the initial image. The geometric means of the anterior and posterior images were calculated as previously described (13). The total geometric mean counts at each 15-min interval were converted to a percentage of the maximal geometric mean counts recorded during the study. The gastric half-emptying time (T_{50}) was calculated by linear interpolation using the nearest time point with radioactive counts above 50% of the glucose solution remaining in the stomach and the nearest point below 50% remaining in the stomach.

Blood Analysis

Blood was assayed for glucose and insulin. Blood for glucose analysis was collected in vacutainer tubes containing potassium oxalate and sodium fluoride.

Blood for insulin analysis was collected in red-top glass tubes (containing no preservative) and a radioimmunoassay (RIA) for insulin was performed. Blood for the insulin assay was centrifuged and the serum was poured off into plastic tubes and then immedi-

ately frozen until the time of assay. The assay for insulin was performed using the Diagnostic Products Corp. (Los Angeles, CA) RIA procedure. The RIA intra-assay variation for the insulin assay was 2%; 4% for the inter-assay variation. The sensitivity of the insulin assay is 7 pmole/liter.

Statistical Analysis

For analysis of the gastric emptying, glucose and insulin levels, a paired sample t-test was used comparing the nine hypertensive subjects with age-, BMI-, ethnicity- and sex-matched controls. Results are expressed as mean \pm standard error of the mean (s.e.m.). If we could not satisfy the assumptions of the paired t-test, we used the nonparametric Wilcoxon signed-rank test (14). We used the Spearman rank correlation coefficient (14) to examine the association of gastric half-emptying time with blood glucose and insulin levels.

RESULTS

Gastric Emptying

The percent solution remaining in the stomach at each time point is shown in Figure 1. The gastric emptying of the hypertensive subjects was approximately 40% more rapid than that of the controls (Table 2). The T_{50} of the hypertensive subjects was 40.0 ± 6.9 min versus 56.6 ± 3.7 min for the control subjects ($p = 0.02$). The percent of glucose solution remaining in the stomach was significantly less for the hyper-

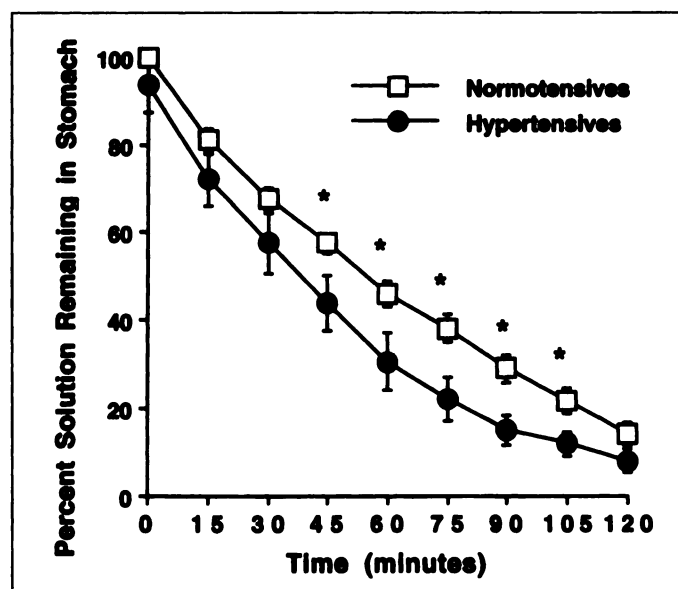


FIGURE 1. Average percent glucose solution remaining in the stomach over a 2-hr period following ingestion of a 50-g oral glucose solution in hypertensive and normotensive subjects ($n = 9$, $*p < 0.05$).

TABLE 2
Gastric Half-Emptying Time, Average Glucose, Average Peak Glucose, Average Time to Peak Glucose and Average Insulin by Hypertension Status

Variable	Hypertensives			Controls			Significance
	No.	Mean	s.e.	No.	Mean	s.e.	
Gastric half-emptying time (min)	9	40.0	6.9	9	56.6	3.7	0.0200
Fasting glucose (mmol/liter)	9	5.4	0.1	9	5.2	0.1	0.2687
Average glucose (mmol/liter)	9	7.4	0.5	8	6.4	0.5	0.1693
Glucose excursion (mmol/liter)	9	4.5	0.7	8	3.0	0.4	0.1138
Glucose range (mmol/liter)	9	5.2	0.7	9	3.6	0.4	0.0541
Peak glucose (mmol/liter)	9	9.9	0.8	9	8.2	0.5	0.0977*
Time of peak glucose (min)	9	43.3	3.9	9	31.7	4.6	0.1108
Fasting insulin (pmole/liter)	9	60.7	5.3	9	57.7	6.4	0.6545
Average insulin (pmole/liter)	9	294.7	90.9	8	269.4	45.9	0.9453*
Insulin excursion (pmole/liter)	9	490.5	142.0	9	344.4	62.2	0.3008*
Peak insulin (pmole/liter)	9	551.2	145.7	9	402.2	62.2	0.3594*
Time of peak insulin (min)	9	45.0	3.5	9	40.0	5.0	0.4379

*Wilcoxon signed-rank test.

Excursion = baseline value to peak value; range = lowest value to highest value.

tensive subjects at 45, 60, 75, 90 and 105 min of the study. One hypertensive subject emptied the contents of his stomach so quickly that a substantial amount of the solution had emptied even before the first camera image was acquired.

Glucose and Insulin

The fasting blood glucose and the average glucose over the 2 hr were not significantly different between hypertensive and control subjects (Table 2), although the average glucose level for the hypertensive subjects was higher at each observation time than for the control subjects (Fig. 2). The peak glucose concentration was slightly higher in the hypertensive subjects and the average range (difference between maximum and minimum glucose) was larger among the hypertensive subjects. Although hypertensive subjects emptied their stomachs faster than the control subjects, a longer time was required for the glucose level to reach its peak in hypertensive subjects. Four of nine hypertensive subjects emptied half of their stomach contents before their peak glucose value, while all control subjects emptied half their stomach contents after their peak glucose (p = 0.1250). There were no significant differences between the

hypertensive and control subjects in fasting or average insulin (Table 2 and Fig. 3).

Relationship of Glucose and Insulin to Gastric Half-Emptying Time

There was an inverse relationship between average glucose during the first 30 min and the first 60 min of the oral glucose tolerance test with the gastric half-emptying time ($r_s = -0.64$, $p = 0.0045$ and $r_s = -0.48$, $p = 0.0428$, respectively). That is, the shorter the gastric half-emptying time, the higher the glucose level. Insulin level was not significantly related to gastric half-emptying time.

DISCUSSION

Gastric emptying rates have been associated with postprandial glucose elevations not only in this study, but in other studies (9,10). Postprandial glucose elevations may be a more common phenomenon among hypertensive subjects than hyperinsulinemia. A recent longitudinal study has concluded that the association of glucose tolerance with hypertension was stronger than the association of hyperinsulinemia with hypertension (7).

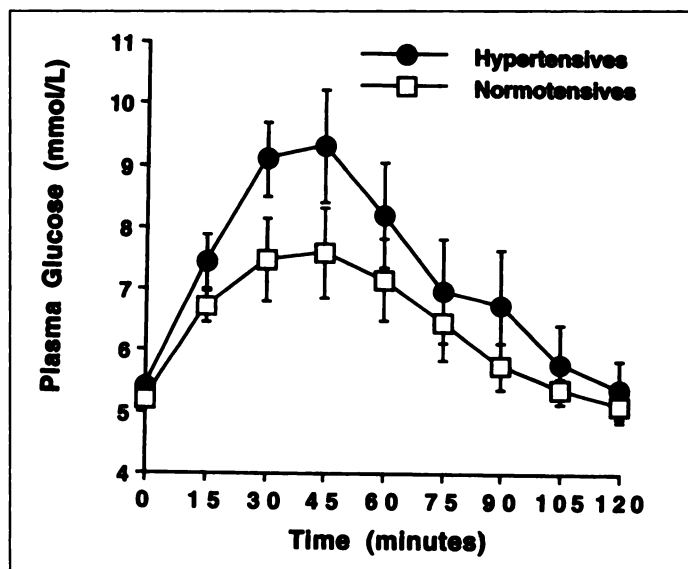


FIGURE 2. Average plasma glucose values following ingestion of a 50-g oral glucose solution in hypertensive and normotensive subjects (n = 9).

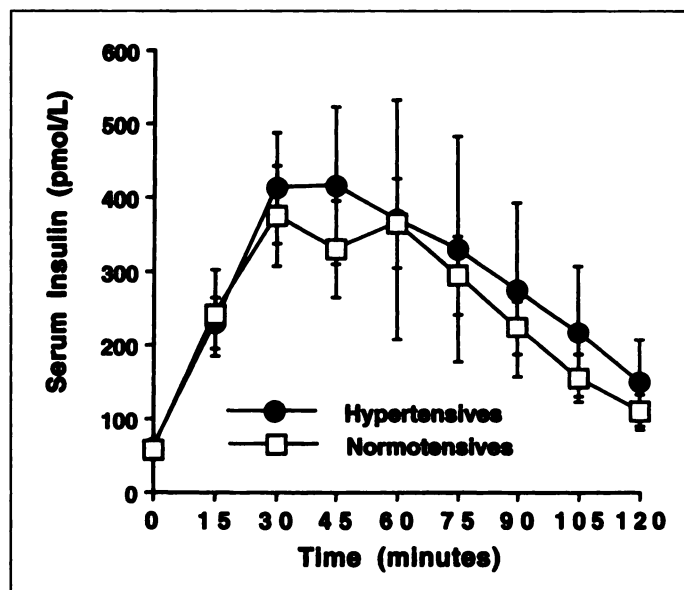


FIGURE 3. Average serum insulin values following ingestion of a 50-g oral glucose solution in hypertensive and normotensive subjects (n = 9).

In another study, subjects who had a 1-hr postprandial blood glucose level of >6.66 mmol/liter following a 1-g/kg body weight oral glucose challenge, had a 1.7 times higher risk of having hypertension after 18 yr compared to subjects with a 1-hr postprandial glucose level of <5.15 mmol/liter (15). The hypertensive subjects in our study, following ingestion of a 50-g oral glucose solution, had a mean 1-hr glucose value of 8.2 mmol/liter. A glucose abnormality, therefore, seems apparent in these hypertensive subjects even though their insulin levels are similar to the controls.

A recent review article in the *New England Journal of Medicine* (5) discusses the importance of postprandial glucose elevations and its association with hypertension. Both Pyörälä et al. (6) and Vaccaro et al. (7) found that hypertensive subjects with elevated postprandial blood glucose levels following an oral glucose load have a significantly greater risk of dying of coronary heart disease.

The rate of gastric emptying in subjects in this study correlates with their average postprandial blood glucose at 30 min ($r_s = -0.64$, $p < 0.05$) and at 1 hr ($r_s = -0.48$, $p < 0.05$). Although this would suggest that accelerated gastric emptying contributes to the postprandial elevation of glucose consistently observed in hypertensive subjects (16–18), the source of the increased glucose in the circulation may not originate solely from gastrointestinal absorbed glucose. In diabetic subjects with rapid gastric emptying Frank et al. (19) found that the glucose appearing in the circulation originated not only from gastrointestinal absorbed glucose but also from increased hepatic glucose output. A pharmacologically induced reduction in the rate of gastric emptying has been shown to reduce the postprandial blood glucose excursion by 25%–35% in both normal and diabetic subjects (20–22).

The hypertensive subjects in this study emptied glucose from their stomachs at a rate of 2.5 kcal/min based on the gastric half-emptying time while the control subjects emptied at a rate of 1.76 kcal/min. The rapid rate of gastric emptying observed in the hypertensive subjects is faster than the gastric emptying rate of 1.5–2 kcal/min previously reported for glucose solutions given to normal subjects (8,9,20,23,24).

The finding of accelerated gastric emptying in subjects with hypertension in this study is consistent with our previous findings of accelerated gastric emptying in two other conditions that are considered part of IRS: namely, NIDDM and increased BMI. Accelerated gastric emptying in patients with NIDDM has now been reported by other investigators (19,25). It has also been confirmed in several rat models of both NIDDM and insulin-dependent diabetes (26–28).

Although most of the literature suggests a more rapid gastric emptying in obesity (9,29,30), there is conflicting information in this area (31,32). Hunt et al. (33) was the first to demonstrate that obesity is a predisposing factor to rapid gastric emptying. Wright et al. (34) also found rapid gastric emptying in obese patients with a solid meal but not with liquids. Horowitz et al. (31) found a slower rate of gastric emptying in obesity as did Sasaki et al. (32). It is likely that the differences observed by the investigators may be related to the specific meals administered to the patients and to the various methods used to evaluate the rate of gastric emptying. Since the number of patients in these studies has been relatively small, more studies are needed to better determine the effect of obesity on gastric emptying.

Although not statistically significant, the average BMI for our hypertensive subjects was slightly greater than the average BMI for our normotensive controls (Table 1). If the matching is ignored, and the gastric half-emptying time is adjusted for sex, ethnicity, age and BMI using analysis of covariance, less than 1

min of the difference in gastric half-emptying time between hypertensive and normotensive subjects is accounted for by the difference in BMI (15.7 min difference between the hypertensive and normotensive subjects after adjustment for BMI; 16.5 min difference unadjusted for BMI). The slight difference in BMI between our hypertensive and normotensive subjects clearly does not account for the difference observed in gastric half-emptying time between the two groups.

In this study, a glucose solution with a relatively low osmolality (0.62 mol/liter) containing only 50 g of glucose in 450 ml of water was used to determine the rate of gastric emptying. The lower osmolar glucose solution has an osmolality that is similar to commonly consumed soda beverages and fruit drinks (0.5–0.7 mol/liter) (35). The low osmolality of our glucose solution is in contrast to the usual oral glucose tolerance beverage which contains 75 g glucose in 300 ml of water and has a much higher osmolality (1.38 mol/liter). Solutions with high osmolality (>0.80 mol/liter) are associated with a nonspecific slowing of gastric emptying that is not related to the carbohydrate content or feedback from intestinal glucoceptors (24,36). For these reason we believe the 0.62 M 50-g glucose solution represents a physiologic concentration that is representative of daily beverage consumption. The rapid gastric emptying seen in hypertensive subjects might not have been as prominent if a standard glucose solution (i.e., a high osmolar glucose tolerance beverage) had been used. Use of the low osmolar glucose solution is reproducible in terms of calories administered to the patient and eliminates variability in meal energy content and differences in chewing associated with a solid meal, yet it still assesses the gastric emptying of a calorie-containing beverage (24).

The most likely explanation for the accelerated gastric emptying is that hypertensive subjects have decreased feedback control to the stomach from glucoceptors in the duodenum or from those located in the central nervous system. A similar mechanism has been hypothesized to explain the accelerated gastric emptying in patients with NIDDM (8). It is also possible that medication effects could be responsible for the rapid gastric emptying of hypertensive subjects, but all patients withheld their medication for 24 hr before their gastric emptying study. Still another possible explanation may be that hypertensive subjects, who are known to have an increased vascular “tone,” also have increased visceral gastric “tone,” which results in rapid gastric emptying due to decreased gastric compliance.

CONCLUSION

The occurrence of accelerated gastric emptying in subjects with hypertension, in addition to that previously reported in subjects with NIDDM and increased BMI, suggests the possibility that accelerated gastric emptying occurs commonly in insulin-resistant states.

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Photopenia in Chronic Vertebral Osteomyelitis with Technetium-99m-Antigranulocyte Antibody (BW 250/183)

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Photon-deficient areas in $^{99m}\text{Tc}/^{111}\text{In}$ white blood cell (WBC) images for diagnosing vertebral osteomyelitis have been published often. This study retrospectively evaluated whether the use of ^{99m}Tc -labeled monoclonal antigranulocyte antibodies (BW 250/183) is superior to WBC and whether it offers higher specificity. **Methods:** The study included 81 patients (46 men, 35 women; mean age 55 ± 2 yr; from 1989 to 1995) with clinically suspected vertebral osteomyelitis who underwent scintigraphic imaging after intravenous injection of 555 MBq ^{99m}Tc -labeled monoclonal antigranulocyte antibodies. Forty patients suffered from osteomyelitis (20 men, 20 women; mean age 56 ± 6 yr), 6 patients had metastases, 28 patients had spondylosis and disk herniation and 5 patients vertebral compression fractures. Diagnosis was not histologically verified in 2 patients. Planar imaging was performed at 4 and 24 hr postinjection. Histology of osteomyelitis was available in 30 patients, clinical follow-up in 10 patients. Visual uptake scores and quantitative

uptake scores of the suspected areas were calculated. The results were compared to a semiquantitative histological score (high, medium, low grade) as well as to the scintigraphic scores. **Results:** Scintigraphy showed photopenia in all patients with histologically proven vertebral osteomyelitis, independent of the grade of infection. A quantitative evaluation of 4 and 24 hr postinjection demonstrated a 58% increase of the uptake score in cases of histologically proven high-grade infections. This increase was seen predominantly in the thoracic spine but not in lumbar spine. All nonosseous paravertebral abscesses ($n = 2$) showed positive images and an increasing uptake over 24 hr. **Conclusion:** Paravertebral soft tissue infections can be differentiated excellently, whereas vertebral osteomyelitis, vertebral tumors or fractures can be localized, but no differentiation is possible.

Key Words: vertebral osteomyelitis; technetium-99m antigranulocyte antibodies; photopenic lesion; quantitative uptake

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Nuclear medicine imaging is able to provide information on changes in pathophysiological and pathobiochemical processes