Postprandial Plasma-glucose and -insulin Responses to Different Complex Carbohydrates

Phyllis A. Crapo, R.D., Gerald Reaven, M.D., and Jerrold Olefsky, M.D., Palo Alto

SUMMARY

We have studied the effects of dextrose, rice, potato, corn, and bread on postprandial plasma glucose and insulin responses in 16 subjects. All carbohydrate loads were calculated to contain 50 gm. of glucose. The data demonstrate (1) that dextrose and potato elicited similar plasma glucose responses whereas rice, corn, and bread elicited lower responses; (2) similarly, dextrose and potato elicited similar and greater plasma insulin responses than rice and corn, with the response to bread being intermediate; (3) when the study group was divided in half, on the basis of each subject's one-hour plasma glucose response to dextrose, the differences in the plasma glucose and insulin responses were greater in the subjects with the highest glucose response to dextrose than in the low responders. In conclusion, there is a range of plasma-glucose and insulin responses to different complex carbohydrates, with rice and corn producing the lowest response curves. Furthermore, these differences are accentuated in patients with reduced glucose tolerance. DIABETES *26*:1178-83, December, 1977.

Epidemiologic studies[1-3] have reported that as nations become more affluent, the nature of the people's carbohydrate consumption changes such that the ratio of complex (starches) to simple carbohydrates decreases. It has been suggested that this change in dietary pattern is responsible for the occurrence of various diseases, such as atherosclerosis,[3-6] diabetes,[4-6] and hyperlipemia.[7-10] One proposed physiologic basis underlying such suggestions is a traditionally held tenet that simple carbohydrates are more readily available for immediate absorption by the gut than are more complex carbohydrates and that they therefore produce a greater and faster rise in postprandial plasma glucose and insulin responses than do the supposedly more gradually digested and absorbed complex carbohydrates.[11-13] Consequently, diets restricted in simple carbohydrates have been recommended in disease states in which control of plasma glucose and/or insulin is felt to be important.[14,15] This concept of carbohydrate digestion and absorption has been challenged, however, in studies by Dahlqvist and Borgstrom[16] and Fogel and Grey.[17] These workers have demonstrated that after test meals, more than enough intraluminal amylase is present to rapidly hydrolyze ingested starch. They concluded that absorption, not intraluminal digestion, was the rate-limiting step in over-all starch assimilation.

On the other hand, we have recently shown[18] that complex carbohydrates resulted in lower glucose and insulin responses than equivalent amounts of glucose or sucrose, indicating that despite adequate amylase, the process of starch digestion proceeds more slowly. We also found that glucose and insulin responses to cooked potato were significantly greater than the glucose and insulin responses to rice. These latter findings suggest that not all starches are treated identically by gastrointestinal digestive and absorptive processes. If there are significant differences in these processes, then grouping all complex carbohydrates together may cause confusion in evaluating epidemiologic and other study findings and may contribute to less effective and less precise dietary intervention.

In order to pursue and expand our previous findings, we have studied the effects of four different kinds of dietary starch (potato, rice, corn, and wheat) on postprandial plasma glucose and insulin responses.

From the Department of Medicine and the General Clinical Research Center, Stanford University Medical Center, and the Palo Alto Veterans Administration Hospital, Palo Alto, California 94305.

Address reprint requests to Phyllis Crapo, R.D., General Clinical Research Center, Room E340, Stanford University Medical Center, Stanford, California 94305.

Accepted for publication August 4, 1977.

MATERIALS AND METHODS

Sixteen normal volunteers, two women and 14 men, were studied. The mean weight of the study group was 165 lb. and the mean relative weight, according to Metropolitan Life Tables, was 0.96, with a range of 0.87 to 1.03. No subject ingested any drug known to affect glucose or insulin metabolism, and all subjects had normal oral glucose tolerance tests according to criteria of the American Diabetes Association.[19] During the course of the study, each subject consumed a weight-maintenance solid-food diet that included at least 200 gm. of carbohydrate each day. Five different carbohydrate sources were studied. The composition of these test carbohydrate loads is outlined in table 1. The carbohydrate content of each of the test substances was independently determined by chemical analysis, and the test doses were calculated so that the glucose load in all of them was 50 gm. All studies were conducted after an overnight fast, and their order was randomized. At 8 a.m., subjects were given one of the substances to consume. Because the dextrose was given in a 500-ml. volume, the subjects consumed 500 ml. of water along with each starch meal in order to eliminate meal volume as a variable. They consumed the entire test load in 15 minutes. Blood samples were drawn for measurement of plasma glucose and insulin at time zero, and at 30, 45, 60, 120, and 180 minutes following the beginning of the period of consumption. There was at least a one-day interval between each study.

Analytic methods. Samples for plasma glucose were collected in EDTA tubes and measured by a Beckman Glucose Analyzer (Beckman Instruments, Fullerton, Ca.) by the glucose oxidase method. Plasma immunoreactive insulin was measured by the method of Desbuquois and Aurbach.[20] Statistical analysis was carried out by the use of the paired *t*-test for dependent means.

TABLE 1

Composition of carbohydrate test loads*

	Carbohydrate	Amount gm.	CHO gm.	Pro. gm.	Fat gm.	Preparation
A.	Glucose	50	50	0	0	Dissolved in water and brought to a total volume of 500 ml. Lemon flavoring added.
B.	Rice†	61, dry	50	4.9	0.8	Boiled, 20-30 minutes
C.	Russet potato	317, raw	50	6.3	1.7	Baked in foil
D.	Diet-pack whole-kernel corn	279, drained solids	50	7.9	1.8	Heated
E.	White, enriched wheat bread	102	50	8.7	2.9	Slices, served plain

*Analysis of the carbohydrate, protein, and fat content of the rice, potato, corn, and bread was performed by Food Products Labs, San Francisco, California, and the resulting data were used in calculating the test loads. †Uncle Ben's Converted Brand rice.

TABLE 2

Mean (±S.E.) glucose and insulin responses during the oral carbohydrate tolerance tests*

		F	30′	45′	60′	120′	180′
		Plasma glucose (mg./100 ml.)					
1.	Dextrose	92 ± 2.0	136 ± 8.1	132 ± 8.6	121 ± 8.0	90 ± 5.5	82 ± 2.9
2.	Potato	89 ± 2.3	133 ± 3.9	138 ± 6.1	125 ± 8.2	92 ± 4.4	88 ± 2.2¶
3.	Bread	90 ± 2.8	119 ± 3.7‡	117 ± 5.6†	113 ± 5.4	96 ± 3.7	92 ± 1.9¶
4.	Rice	95 ± 2.2	122 ± 4.9†	111 ± 6.1§	104 ± 5.1¶	97 ± 2.9	96 ± 2.5§
5.	Corn	90 ± 2.4	128 ± 5.4	120 ± 7.6†	105 ± 8.1¶	93 ± 2.6	92 ± 2.3¶
		Plasma insulin (μU./ml.)					
1.	Dextrose	9 ± 1.2	84 ± 12.1	78 ± 13.3	59 ± 6.7	17 ± 3.2	7 ± 1.3
2.	Potato	7 ± 1.2	64 ± 9.9†	76 ± 10.0	61 ± 8.3	19 ± 4.1	7 ± 1.6
3.	Bread	8 ± 1.2	57 ± 11.0†	51 ± 7.6†	51 ± 5.3	22 ± 4.9	10 ± 2.2
4.	Rice	10 ± 2.0	46 ± 7.3¶	37 ± 5.4¶	29 ± 4.5§	16 ± 1.8	10 ± 1.5
5.	Corn	6 ± 5.8	46 ± 7.7¶	35 ± 4.9¶	24 ± 4.1§	8 ± 1.6§	8 ± 1.6

*Statistical comparisons indicate the significant differences between the dextrose values and the values of the various starches. †Represents p < 0.05. ‡Represents p < 0.01. ¶Represents p < 0.005. §Represents p < 0.001.

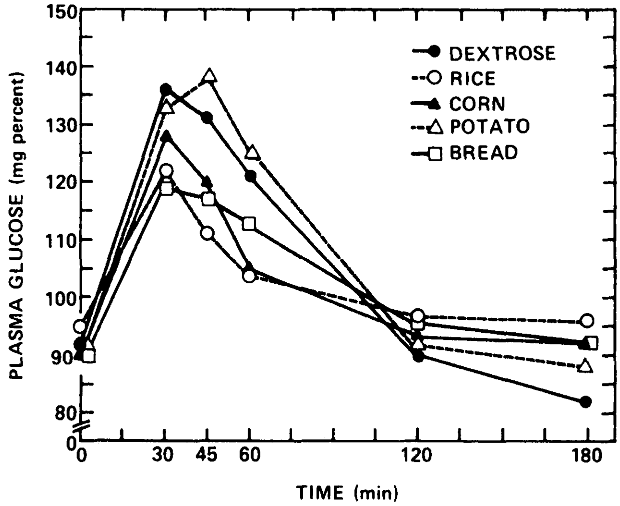

FIG. 1. Mean plasma glucose responses to dextrose, rice, corn, potato, and bread.

RESULTS

The mean (± S.E.) plasma glucose and insulin responses to each of the oral carbohydrate loads at all time points are given in table 2.

In figure 1 it can be seen that the plasma glucose responses to dextrose and potato are significantly higher than the plasma glucose responses to rice and bread until 120 minutes; the glucose response to corn is somewhat intermediate.

The plasma insulin responses to the different carbohydrates are summarized in figure 2. The plasma insulin response curves to dextrose and potato are similar with the exception that the peak insulin response to potato is delayed, being significantly ($p < 0.05$) lower than dextrose at 30 minutes. The plasma insulin responses to both dextrose and potato are significantly higher than the plasma insulin responses to rice and corn until 120 minutes; the insulin response to bread was somewhat intermediate.

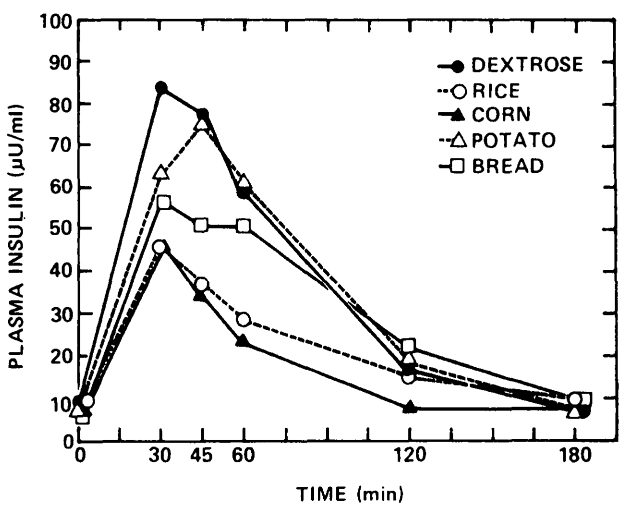

FIG. 2. Mean plasma insulin responses to dextrose, rice, corn, potato, and bread.

The total areas under the glucose response curves (A) and the insulin response curves (B) are summarized in figure 3. Despite the fact that the early glucose peaks to potato and dextrose are higher, the areas under all of the glucose response curves are essentially identical, and this is due to the rapid return to baseline (or below baseline) levels of the glucose response curves to dextrose and potato at 120-180 minutes. The total areas under the insulin response curves, however, are different. Dextrose and potato give the highest insulin responses, bread elicits a slightly lower but not statistically different response, and rice and corn give the lowest responses.

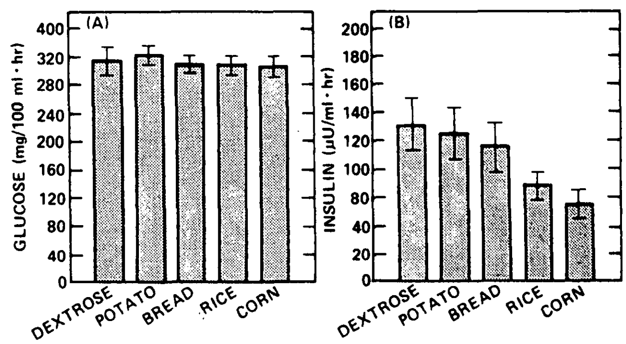

FIG. 3. Total areas under the plasma glucose (A) and plasma insulin (B) response curves for dextrose, potato, bread, rice, and corn. None of the glucose area responses are significantly different. There are no significant differences between the insulin area responses to dextrose, potato, and bread or between the responses to rice and corn. However, the rice and corn responses are significantly different from the dextrose, potato ($p < 0.01$), and bread ($p < 0.05$) responses.

To examine the interaction between a subject's glucose tolerance and his response to the different carbohydrate loads, the study group was divided in half on the basis of each subject's one-hour plasma glucose response to dextrose. The data from the "high responders" (figure 4A) and "low responders" (figure 4B) were then analyzed separately. It can be seen that the differences in plasma glucose response to the various carbohydrates are accentuated in the subjects who were "high responders," as compared with "low responders." If the insulin responses are examined in similar fashion (figure 5), it can be seen that the dif-

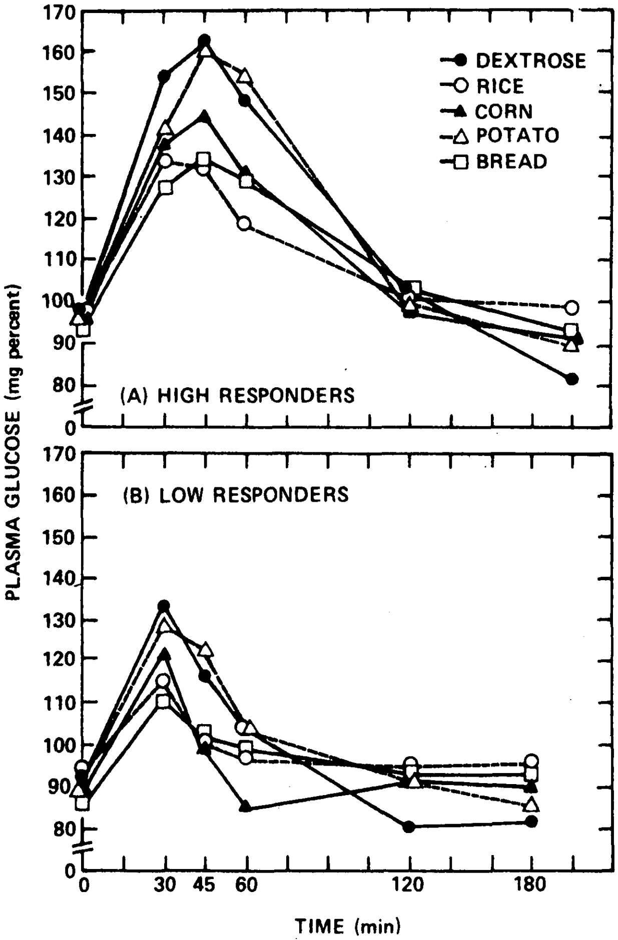

FIG. 4. Mean plasma glucose responses to dextrose, rice, corn, potato, and bread in the high responders (A) and in the low responders (B). It should be noted that none of the high responders had chemical diabetes.

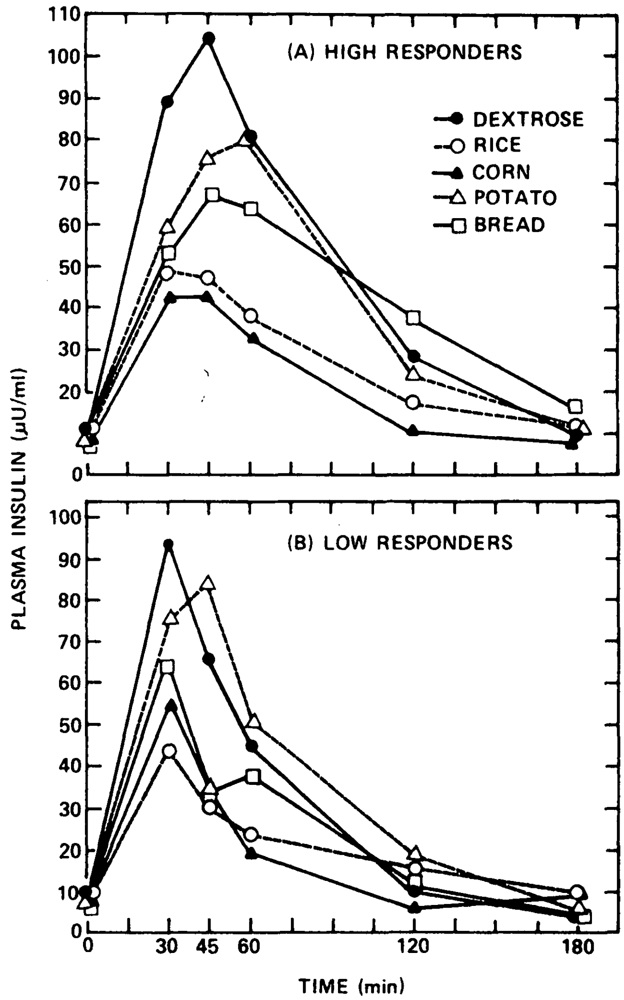

FIG. 5. Mean plasma insulin responses to dextrose, rice, corn, potato, and bread in the high responders (A) and in the low responders (B).

ferences in plasma insulin response to the different carbohydrates are also greater in the "high responders" (5A) than in the "low responders" (5B).

DISCUSSION

We have studied the effects of four different kinds of dietary starch on postprandial plasma glucose and insulin responses. The results show that there is a range of plasma glucose and insulin responses to different starches. The plasma glucose and insulin responses following potato ingestion are similar to the responses following oral dextrose, while rice, corn, and bread have lower responses. These results support the idea proposed in our earlier study[18] that the rate of digestion and absorption is not the same for all orally ingested starch molecules. The mechanism(s) for the differences between starches is not clear, although gastric emptying time, physical availability of starch to hydrolytic enzymes, and differences in the stimulation of gastrointestinal insulinogenic hormones may be factors. The similarity shown in the areas under the glucose response curves for all of the carbohydrate loads may suggest that all of the carbohydrate ingested (regardless of composition) was eventually absorbed. However, in spite of the equality in glucose area, there are significant differences in the insulin responses when expressed as area under the curve. Thus, determinants other than plasma glucose level are modulating the insulin response. In this regard, protein has been shown to stimulate insulin secretion.[21] However, the differences in protein content between the starches is small (see table 1), and it is unlikely that such differences could be responsible for the divergence seen in the insulin responses. Alternatively, it is possible that some other factor(s) within the given foodstuffs has an insulin stimulatory effect. It seems more likely to us that the rates of transit, digestion, and absorption of the carbohydrates are the other important factors in modulating the insulin stimulatory mechanism.

Our results indicate that the subjects with the higher plasma glucose responses to dextrose (most glucose intolerant) have greater differences in their glucose and insulin responses to the oral starch loads than the subjects with the lower glucose responses. Although we did not study patients with diabetes, one can speculate that the differences between the glucose and insulin responses would be even more noticeable in diabetic patients. In this event, a more specific therapeutic recommendation could be made in regard to the quality of carbohydrate to include in the diet in order to minimize glucose and insulin excursions. Further studies in diabetic subjects will be necessary to confirm this speculation.

Since the data demonstrate a range of glucose and insulin responses to different starches, previously held ideas classifying starches as a single group, specifically in regard to glucose and insulin metabolism, must be reassessed. It is clear that the restriction of dietary carbohydrate for the purpose of reducing glucose and insulin excursions is not a simple matter. That is, it may not be sufficient to restrict simple carbohydrates in order to alter the plasma glucose and insulin levels. If it is therapeutically important to lower the postprandial plasma insulin and/or glucose responses, then specifying the type of complex carbohydrate to use in the diet may be an important adjunct in achieving these goals. Clearly, further studies of other foodstuffs would allow even more precise recommendations, and such studies are indeed indicated. Furthermore, epidemiologic data calling attention to the ratio of simple to complex carbohydrates may need to be reëvaluated in light of our evidence that all complex carbohydrates can not be assumed to give equal metabolic responses. If the epidemiologic evaluations can be made on the basis of the predicted glucose and insulin responses to particular carbohydrate sources rather than on the assumption that complex carbohydrates form a homogeneous group, conclusions based on such studies could be more specific.

Lastly, it should be pointed out that we have studied only the acute responses to these carbohydrates, and the relevance of these results to long-term ingestion of the starches cannot be assumed. If the long-term and acute responses are comparable, then there would be some obvious implications of these results. Since hyperinsulinemia can promote hypertriglyceridemia,[22] one could anticipate that if the starch giving the lowest postprandial insulin and glucose responses (rice) was used preferentially over that which gave higher responses (potato), significant improvement in plasma triglyceride levels would occur.

ACKNOWLEDGMENTS

This work was supported in part by National Heart and Lung Institute grant HL08506, grant RR 70 from the Division of Research Resources, National Institutes of Health, and a grant from the American Diabetes Association. We wish to thank Joyce Clark, Evangeline Morrison, Jo Moore, and the nurses on the General Clinical Research Center for their invaluable technical assistance.

REFERENCES

[1]Hollingsworth, D. F., and Greaves, J. P.: Consumption of carbohydrates in the United Kingdom. Am. J. Clin. Nutr. *20*:65-72, 1967.

[2]Yudkin, J.: Man's choice of food. Lancet *1*:645-49, 1956.

[3]Antar, M. A., Ohlson, M. A., and Hodges, R. E.: Changes in retail market food supplies in the United States in the last seventy years in relation to the incidence of coronary heart disease, with special reference to dietary carbohydrates and essential fatty acids. Am. J. Clin. Nutr. *14*:169-78, 1964.

[4]Cohen, A. M., Bavly, S., and Poznanski, R.: Change of diet of Yemenite Jews in relation to diabetes and ischaemic heart-disease. Lancet *2*:1399-401, 1961.

[5]Yudkin, J., and Roddy, J.: Levels of dietary sucrose in patients with occlusive atherosclerotic disease. Lancet *2*:6-8, 1964.

[6]Yudkin, J.: Dietary fat and dietary sugar in relation to ischaemic heart-disease and diabetes. Lancet *2*:4-5, 1964.

[7]Kuo, P. T., and Bassett, D. R.: Dietary sugar in the production of hyperglyceridemia. Ann. Intern. Med. *62*:1199-212, 1965.

[8]Kaufmann, N. A., Poznanski, R., Blondheim, S. H., and Stein, Y.: Changes in serum lipid levels of hyperlipemic patients following the feeding of starch, sucrose, and glucose. Am. J. Clin. Nutr. *18*:261-69, 1966.

[9]Lopez, A., Hodges, R. E., and Krehl, W. A.: Some interesting relationships between dietary carbohydrates and serum cholesterol. Am. J. Clin. Nutr. *18*:149-53, 1966.

[10]Hodges, R. E., and Krehl, W. A.: The role of carbohydrates in lipid metabolism. Am. J. Clin. Nutr. *17*:334-46, 1965.

[11]Allen, F. M.: Experimental studies on diabetes. J. Exp. Med. *31*:395-402, 1920.

[12]Conn, J. W., and Newburgh, L. H.: The glycemic response to isoglucogenic quantities of protein and carbohydrate. J. Clin. Invest. *15*:665-71, 1936.

[13]Swann, D. C., Davidson, P., and Albrink, M. J.: Effect of simple and complex carbohydrates on plasma non-esterified fatty

acids, plasma-sugar, and plasma-insulin during oral carbohydrate tolerance tests. Lancet *1*:60-63, 1966.

[14]Fajans, S. S.: Current unsolved problems in diabetes management. Diabetes *21* (Suppl. 2):678-84, 1972.

[15]Fredrickson, D. S., Levy, R. I., Bonnell, M., and Ernst, N.: Dietary Management of Hyperlipoproteinemia, A Handbook for Physicians and Dietitians. U.S. Dept. of Health, Education, and Welfare, Public Health Service, Washington, D.C., U.S. Govt. Printing Office, 1973.

[16]Dahlqvist, A., and Borgstrom, B.: Digestion and absorption of disaccharides in man. Biochem. J. *81*:411-18, 1961.

[17]Fogel, M. R., and Gray, G. M.: Starch hydrolysis in man: an intraluminal process not requiring membrane digestion. J. Appl. Phys. *35*:263-67, 1973.

[18]Crapo, P. A., Reaven, G., and Olefsky, J.: Plasma glucose and insulin responses to orally administered simple and complex carbohydrates. Diabetes *25*:741-47, 1976.

[19]Committee on Statistics of the American Diabetes Association: Standardization of the oral glucose tolerance test. Diabetes *18*:299-310, 1969.

[20]Desbuquois, B., and Aurbach, G. D.: Use of polyethylene glycol to separate free and antibody-bound peptide hormones in radioimmunoassays. J. Clin. Endocrinol. Metab. *33*:732-38, 1971.

[21]Fajans, S. S., Floyd, J. C., Jr., Knopf, R. F., and Conn, J. W.: Effect of amino acids and proteins on insulin secretion in man. Recent Prog. Horm. Res. *23*:617-62, 1967.

[22]Olefsky, J. M., Farquhar, J. W., and Reaven, G. M.: A reappraisal of the role of insulin in hypertriglyceridemia. Am. J. Med. *57*:551-60, 1974.