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The Role of Laboratory Testing in Differentiating Type 1 Diabetes from Type 2 Diabetes in Patients Undergoing Bariatric Surgery

Scott J. Pilla¹, Nisa M. Maruthur^{1,2}, Michael A. Schweitzer³, Thomas H. Magnuson³, James J. Potter⁴, Jeanne M. Clark^{1,2}, and Clare J. Lee⁵

¹Department of Medicine, Division of General Internal Medicine, The Johns Hopkins University School of Medicine, Baltimore, MD, USA

²Department of Epidemiology, The Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

³Department of Surgery, The Johns Hopkins University School of Medicine, Baltimore, MD, USA

⁴Department of Medicine, Division of Gastroenterology and Hepatology, The Johns Hopkins University School of Medicine, Baltimore, MD, USA

⁵Department of Medicine, Division of Endocrinology, Diabetes and Metabolism, The Johns Hopkins University School of Medicine, Baltimore, MD, USA

Abstract

Background—It may be difficult to distinguish between adults with type 1 diabetes and type 2 diabetes by clinical assessment. In patients undergoing bariatric surgery, it is critical to correctly classify diabetes subtype to prevent adverse perioperative outcomes including diabetic ketoacidosis. This study aimed to determine whether testing for C-peptide and islet cell antibodies during preoperative evaluation for bariatric surgery could improve the classification of type 1 versus type 2 diabetes compared to clinical assessment alone.

Methods—This is a retrospective analysis of the Improving Diabetes through Lifestyle and Surgery trial, which randomized patients with clinically diagnosed type 2 diabetes and BMI 30–40 kg/m² to medical weight loss or bariatric surgery; one participant was discovered to have type 1 diabetes after experiencing postoperative diabetic ketoacidosis. Using blood samples collected prior to study interventions, we measured islet cell antibodies and fasting/meal-stimulated C-peptide in all participants.

Results—The participant with type 1 diabetes was similar to the 11 participants with type 2 diabetes in age at diagnosis, adiposity, and glycemic control but had the lowest C-peptide levels. Among insulin-treated participants, fasting and stimulated C-peptide correlated strongly with the

Correspondence to: Scott J. Pilla.

Compliance with Ethical Standards

Statement of Informed Consent Informed consent was obtained from all individual participants included in the study.

Statement of Human and Animal Rights This study was approved by the Johns Hopkins University School of Medicine Institutional Review Board. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of Interest The authors declare that they have no conflict of interest.

C-peptide area-under-the-curve on mixed meal tolerance testing ($R = 0.86$ and 0.88 , respectively). Three participants, including the one with type 1 diabetes, were islet cell antibody positive.

Conclusions—Clinical characteristics did not correctly identify type 1 diabetes in this study. Preoperative C-peptide testing may improve diabetes classification in patients undergoing bariatric surgery; further research is needed to define the optimal C-peptide thresholds.

Keywords

Bariatric surgery; Type 1 diabetes mellitus; Type 2 diabetes mellitus; Perioperative care; C-peptide; beta-cell

Introduction

Bariatric surgery improves outcomes in patients with type 2 diabetes, including achieving diabetes remission [1]. Thus, there is advocacy to perform bariatric surgery in patients with type 2 diabetes at body mass index (BMI) as low as 30 kg/m^2 [2], and prospective studies have begun to evaluate patients with even lower BMI [3]. Performing bariatric surgery in patients at a lower BMI increases the likelihood that surgical candidates may include patients with type 1 diabetes who have been misdiagnosed as having type 2 diabetes [4].

Typically patients with type 1 diabetes are diagnosed at a young age and have low adiposity compared to patients with type 2 diabetes [5]. However, more than 25% of type 1 diabetes presents in adulthood [6], and the rate of obesity in type 1 diabetes is high and rising [7]. As such, patients with type 1 diabetes can have or develop insulin resistance in addition to absolute insulin deficiency, and features of type 1 and type 2 diabetes can overlap [7]. Additionally, approximately 10% of patients diagnosed with type 2 diabetes are thought to have latent autoimmune diabetes in adults (LADA), a subset of adult-onset diabetes who have an accelerated progression to insulin deficiency as a result of autoimmunity [8]. Such patients may have clinical features of type 2 diabetes, particularly with regard to age at onset and BMI, yet have absolute insulin deficiency [8]. Therefore, the clinical features of type 1 diabetes may not identify all patients who have absolute insulin deficiency.

Correct classification of diabetes prior to bariatric surgery is critical as patients with absolute insulin deficiency require close inpatient monitoring and continued administration of insulin in the postoperative period [9]. High rates of hypoglycemia and diabetic ketoacidosis occur in patients with type 1 diabetes after bariatric surgery [10–13]. Despite these important considerations for perioperative care, there is no consensus on how patients with diabetes should be evaluated preoperatively to avoid misclassification [2].

It has been proposed that all patients with diabetes should be screened prior to bariatric surgery with a C-peptide level and islet cell antibody tests [14, 15]. C-peptide reflects endogenous insulin secretion by pancreatic β -cells which can be measured fasting or with a stimulation test, which is considered to be more accurate [16]. Islet cell antibodies are auto-antibodies directed at the pancreas found in $>95\%$ of patients with type 1 diabetes at diagnosis and are usually persistent [17, 18]. Studies of bariatric surgery in patients with type 1 diabetes have required the presence of islet cell antibodies or a low C-peptide level

for inclusion [11, 12, 19, 20]. In contrast, bariatric surgery trials enrolling patients with type 2 diabetes use varying criteria to exclude patients with type 1 diabetes [21–25] with two major studies using clinical assessment alone [21, 22].

Here, we present data from the Improving Diabetes through Lifestyle and Surgery (IDeaLS) clinical trial relevant to preoperative diabetes classification. IDeaLS randomized patients with clinically diagnosed type 2 diabetes to medical weight loss, laparoscopic adjustable gastric banding (LAGB), or laparoscopic Roux-en-Y gastric bypass (LRYGB). One participant, referred to as Patient X, was initially thought to have type 2 diabetes by clinical assessment but was discovered to have type 1 diabetes after being readmitted with diabetic ketoacidosis within 72 h of uncomplicated LRYGB. On subsequent evaluation, Patient X was found to have positive islet cell antibodies, a low fasting C-peptide level, and a persistent insulin requirement after LRYGB.

We performed a secondary analysis of participants in the IDeaLS trial to determine whether preoperative testing for pancreatic β -cell function and islet cell antibodies could have prevented diabetes misclassification in our study and could inform protocols to prevent adverse perioperative outcomes in patients undergoing bariatric surgery.

Methods

Participants

The IDeaLS trial enrolled ambulatory adults from July 2013 to June 2014. Inclusion criteria were type 2 diabetes determined by clinical assessment by trial staff, BMI 30–40 kg/m², hemoglobin A1c (HbA1c) 6.5–10%, and insured by a single health insurer. Exclusion criteria included prior bariatric surgery, significant recent weight loss, severe kidney disease, active cancer, HIV, substance abuse, and use of thiazolidinediones. Fifteen participants were enrolled, and three withdrew prior to initial evaluation; this analysis includes the 12 remaining participants.

Study Interventions

The primary objective of IDeaLS was to evaluate the differential effects of surgical and medical weight loss interventions on type 2 diabetes. Participants were randomized to medical weight loss, LAGB, or LRYGB. All surgical procedures were performed at a single academic medical center using standardized protocols [26]. Follow-up continued until participants had lost 10% of initial body weight or for 9 months.

Study Measures

Weight, height, waist circumference, and blood pressure were measured by trained staff using standard protocols. Percent body fat was determined by dual energy x-ray absorptiometry (DXA) using the Lunar Prodigy densitometer. All C-peptide measurements were derived from C-peptide mixed meal tolerance testing (MMT) which was performed as part of the IDeaLS trial prior to study interventions. Additionally, for this study, we retrospectively tested preoperative stored blood for islet cell antibodies. C-peptide was measured in plasma using the Milliplex MAP Human Metabolic Hormone Magnetic Bead

Panel Kit (EMD Millipore, Billerica, MA). The mean minimum detectible concentration was 27 pg/ml and the intra- and inter-assay coefficients of variation were <10 and <15%, respectively. MMT was conducted after an overnight fast, with antihyperglycemic medications held except long-acting insulins which were reduced by 50%; after drinking two cans of Ensure Plus (474 mL), C-peptide was measured at 10 time points over 5 h. Islet cell antibodies tested were glutamic acid decarboxylase 65 antibody (GADA), insulinoma antigen-2 antibody (IA2A), and zinc transporter 8 antibody (ZnT8A). GADA and IA2A were measured by radiobinding assays using the NIDDK standardized protocol at the Northwest Lipid Research Laboratories in Seattle, Washington [27]. ZnT8A was measured by radioimmunoassay at the Barbara Davis Center for Diabetes in Aurora, Colorado [28].

Analysis

Non-parametric summary statistics were used to describe participant characteristics given the small sample size. Stimulated C-peptide was the value at 90-min elapsed time on MMT to align with other studies [16]. C-peptide area under the curve (AUC) was calculated using the trapezoidal method, then converted to mean C-peptide by dividing by time. The homeostatic model assessment calculator V2.2.4 was used to estimate β -cell function (HOMA-B) and insulin resistance (HOMA-IR) from fasting C-peptide and fasting glucose values collected concurrently [29, 30]. Analyses were performed using STATA version 14 (StataCorp LP, College Station, TX).

Results

Median follow up for the 12 study participants was 7.9, 2.3, and 1.8 months in the medical weight loss arm, LAGB arm, and LRYGB arms, respectively. Only Patient X experienced diabetic ketoacidosis or developed signs suggestive of type 1 diabetes during follow-up, so the remaining 11 participants were considered to have been correctly classified as having type 2 diabetes.

Table 1 shows baseline characteristics of the study population. Among the 11 participants with type 2 diabetes, all were female, the median age was 52 years, and the median BMI was 37.3 kg/m². Participants with type 2 diabetes were diagnosed with diabetes at a median age of 42 years, and three were using insulin. Patient X was 59 years old and was diagnosed with diabetes 6 years prior. Her BMI (31.3 kg/m²) was the second lowest of all participants, and her body fat percentage (55%) was the highest. Her fasting glucose and HbA1c were within the range of other participants. Her diabetes medications were metformin, liraglutide, and basal and prandial insulin totaling 25 units daily.

Table 2 shows the results of baseline testing of glucose homeostasis and islet cell antibodies. Participants with type 2 diabetes had a median fasting C-peptide of 1.70 ng/mL and a median stimulated C-peptide of 3.85 ng/mL. Patient X had the lowest C-peptide values of any participant: her fasting and stimulated C-peptide values were approximately one half and one third that of the next lowest participant, respectively. Patient X had the lowest pancreatic β -cell function and the lowest insulin resistance of any participant by HOMA analysis. In addition, Patient X had a C-peptide response to MMT that was qualitatively different from that of other participants, exhibiting very little augmentation of C-peptide

with no clear peak (Fig. 1). Patient X was positive for all three islet cell antibodies: GADA, IA2A, and Znt8A. Among participants with type 2 diabetes, two were positive for GADA; none were positive for other antibodies.

Pancreatic β -cell function measured by mean C-peptide area-under-the-curve from MMT was compared to measures requiring only a single blood draw: fasting C-peptide, stimulated C-peptide, and HOMA-B (Fig. 2). HOMA-B had the highest linear correlation with mean C-peptide ($R = 0.85$). Restricting to participants using insulin, stimulated C-peptide had the highest linear correlation with mean C-peptide ($R = 0.88$); fasting C-peptide and HOMA-B had correlation coefficients of 0.86 and 0.66, respectively.

Discussion

Diabetes classification prior to bariatric surgery is a high-stakes evaluation, as misclassifying a patient who has type 1 diabetes could result in significant adverse perioperative outcomes. In this study, we found that clinical assessment alone misclassified a patient with type 1 diabetes, and that laboratory testing for pancreatic β -cell function could have aided in determining this patient's diabetes subtype.

Pancreatic β -cell function testing has been proposed to be used for diabetes classification prior to bariatric surgery [14, 15]; here, we evaluated several methods. MMT for C-peptide provided detailed data that clearly distinguished Patient X as having lower β -cell function than other participants. However, MMT is not always feasible due to high cost and requirement for multiple blood draws. We compared the mean C-peptide on MMT, a gold standard measure of β -cell function [16], to tests that require only a single blood draw: fasting C-peptide, stimulated C-peptide, and HOMA-B. The performance of these tests in insulin-treated patients is the most relevant, as patients who are not using insulin are unlikely to have type 1 diabetes. Among insulin-treated participants, stimulated C-peptide had the highest correlation with mean C-peptide. Fasting C-peptide performed slightly less well in our study, though it may be falsely low in insulin-treated patients which could require confirmatory testing [16]. HOMA-B had the worst performance and has not been validated in insulin-treated patients [30]. Overall, either fasting or stimulated C-peptide may be a useful and efficient measure of β -cell function prior to bariatric surgery.

A challenge with the use of C-peptide testing is that the optimal threshold to distinguish type 1 diabetes from type 2 diabetes has varied by population [16]. Data from patients with insulin-treated diabetes suggest that those with fasting C-peptide <0.75 ng/mL or stimulated C-peptide <1.80 ng/mL likely have type 1 diabetes [16]. In our study, these thresholds would have correctly classified Patient X but would have incorrectly classified three of 11 participants with type 2 diabetes. A recent trial of LRYGB for type 2 diabetes excluded those with stimulated C-peptide ≥ 1.0 ng/mL and documented one complication of diabetic ketoacidosis among 60 participants undergoing surgery [25]; this threshold would have correctly classified all participants in our study. Of note, C-peptide assays are not universally standardized at this time [16].

We also tested for the presence of three islet cell antibodies (GADA, IA2A, and Znt8A) for diabetes classification. While Patient X was positive for all three antibodies, two participants with type 2 diabetes were also GADA positive. In prior studies, approximately 6–10% of adults diagnosed with type 2 diabetes were GADA positive, and these patients had higher HbA1c, lower C-peptide, and a greater need for insulin longitudinally [8, 31, 32]. Given that islet cell antibody positivity is not highly specific to type 1 diabetes, it is not clear that islet cell antibody testing will add value to β -cell function testing for preoperative diabetes classification. However, it is possible that islet cell antibody positivity may have implications for the effects of bariatric surgery on diabetes outcomes. In patients with type 2 diabetes, lower preoperative C-peptide levels have been associated with a less favorable response to bariatric surgery in respect to glycemic control [33]. Further research is needed to determine whether the presence of islet cell antibodies impacts the efficacy of bariatric surgery.

This study was limited by a small sample size, with only one participant having type 1 diabetes. However, these data highlight the capacity for misclassifying diabetes by clinical assessment alone, supporting the use of objective testing prior to bariatric surgery in all patients on insulin. Routine testing of pancreatic β -cell function in future bariatric surgery trials could provide data to determine the C-peptide threshold that best identifies patients with absolute insulin deficiency. This study supports the use of a stimulated C-peptide threshold of 1.0 ng/mL.

In conclusion, it is important to correctly determine diabetes subtype prior to bariatric surgery to avoid perioperative complications and to identify individuals whose diabetes is unlikely to remit postoperatively. Pancreatic β -cell function testing, which may be done using fasting or stimulated C-peptide, can help to increase the accuracy of preoperative diabetes classification.

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Fig. 1.
Results of C-peptide mixed meal tolerance testing in Patient X (type 1 diabetes) and other participants with type 2 diabetes using insulin ($n = 3$)

Fig. 2.

Scatterplots of mean C-peptide from mixed meal tolerance testing versus pancreatic function tests requiring only a single blood draw, with linear regression lines. Mean C-peptide (the gold standard) was calculated from C-peptide 5-h mixed meal tolerance test as the area-under-the-curve divided by time, and compared to fasting C-peptide (**a**), stimulated C-peptide (level at 90 min on mixed meal tolerance test) (**b**), and HOMA % β -cell function (**c**). *Black lines* are results of linear regression for all participants; *red dashed lines* are results of linear regression for insulin users; *blue dash-dot lines* are results of linear regression for

insulin non-users. The correlation coefficient (R) is shown for each linear regression function. *HOMA* homeostatic model assessment

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Table 1

Baseline characteristics of Patient X (type 1 diabetes) and other participants (type 2 diabetes)

Characteristic ^a	Patient X	Participants with type 2 diabetes
Number of participants, <i>n</i>	1	11
Age (years)	59	52 (32–62)
Female sex	Yes	11 (100)
Race		
White	Yes	2 (18.2)
Black	No	9 (81.8)
Weight (kg)	80.0	99.9 (85.9–112.3)
BMI (kg/m ²)	31.3	37.3 (31.0–40.5)
Waist circumference (cm)	80.0	114.3 (103.5–131.0)
Body fat by DXA (%)	55	45 (38–50)
Fasting glucose (mg/dL)	175	146 (92–256)
Hemoglobin A1c (%)	9.4	8.0 (6.3–10.0)
Age at diabetes diagnosis (years)	53	42 (27–57)
Diabetes duration (years)	6	6 (1–16)
Use of insulin—any type	Yes	3 (27.3)
Use of insulin—long acting	Yes	2 (18.2)
Use of insulin—rapid acting	Yes	3 (27.3)

BMI body mass index, *DXA* dual energy x-ray absorptiometry^aValues expressed as median (range) or *n* (%) of column)

Table 2

Results of glucose homeostasis and islet cell antibody testing of Patient X (type 1 diabetes) and other participants (type 2 diabetes), stratified by insulin use

Characteristic ^a	Patient X	Participants with type 2 diabetes	Type 2 diabetes—insulin users	Type 2 diabetes—insulin non-users
Number of participants, <i>n</i>	1	11	3	8
Fasting C-peptide (ng/mL)	0.37	1.70 (0.69–3.08)	1.74 (0.69–2.15)	1.70 (1.10–3.08)
Stimulated C-peptide (ng/mL) ^b	0.38	3.85 (1.25–7.09)	1.81 (1.59–4.74)	3.86 (1.25–7.09)
Peak C-peptide (ng/mL) ^c	0.43	4.80 (2.34–18.29)	3.99 (2.34–4.80)	6.37 (2.56–18.29)
Mean C-peptide (ng/mL) ^d	0.41	3.85 (1.69–7.59)	2.82 (1.69–3.85)	4.29 (2.12–7.59)
HOMA % beta cell function	10.5	30.3 (21.4–129.0)	28.1 (21.4–30.3)	51.0 (25.4–129.0)
HOMA insulin resistance	0.3	1.6 (0.6–2.4)	1.6 (0.6–2.4)	1.6 (0.8–2.4)
GADA positive	Yes	2 (18.2)	1 (33.3)	1 (12.5)
IA2A positive	Yes	0	0	0
ZnT8A positive	Yes	0	0	0

HOMA homeostatic model assessment, *GADA* glutamic acid decarboxylase 65 antibody, *IA2A* insulinoma antigen-2 antibody, *ZnT8A* zinc transporter 8 antibody

^aValues expressed as median (range) or *n* (% of column)

^bValue at 90 min from C-peptide 5-h mixed meal tolerance test

^cHighest value from C-peptide 5-h mixed meal tolerance test

^dCalculated from C-peptide 5-h mixed meal tolerance test as the area under the curve (trapezoidal method) divided by time