Effect of Diet and Exercise on Postprandial Blood Glucose Levels

Capstone Project

MGT 8823: Data Analysis for Continuous Improvement (SUMMER 2021)

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Business Case

Background: Research has shown that for diabetics, particularly Type 2, controlling the daily carbohydrate intake with regular exercise can result in reduction of blood glucose levels. The new guidelines issued by American Diabetes Association[1] recommends that postprandial (~2 hours after a meal) glucose levels to be less than 180 mg/dL (milligrams/deciliter). Extensive clinical trials indicate that exercise (30 mins/day at 50-70% max heart rate, max HR) and regulating carbohydrate intake (250-275 g for a 2000-2200 calories a day) is a key factor for maintaining healthy glucose levels.

As a diabetic with co-morbidities (hypertension, high cholesterol) whose blood glucose levels are primarily controlled by prescription medications, I have been advised by my physician to closely monitor my diet and exercise to reduce postprandial blood glucose level to ≤ 160 mg/dL from my current average of > 190 mg/dL. This is important to reduce my medication dependence, improve natural regulation of blood glucose levels and my long-term health by reducing the probability of cardiovascular diseases.

1. https://clinical.diabetesjournals.org/content/39/1/14
2. https://www.cdc.gov/diabetes/managing/eat-well/diabetes-and-carbohydrates.html

Define: Problem & Goal

Problem: My average postprandial blood glucose level was > 190 mg/dL as of May 31, 2021, with an unmonitored diet and exercise regimen.

Goal: To reduce my average postprandial blood glucose level to ≤ 160 mg/dL by July 12, 2021, at the end of a 6-week study (beginning from June 1, 2021) of monitoring my diet and exercise.

Operational Definition

Blood glucose levels are measured by a commercial glucose meter called 'One-touch Ultra'. The measurement is carried out ~2 hours after my last meal of the day (always dinner). The meter was calibrated biweekly using a standard solution that is provided with the meter strips.

The amount of carbohydrates (g) in my meals & snacks and (throughout the day) is calculated from standardized values for an Indian Vegetarian diet.[1] The average amount of carbohydrates in restaurant meals (Mexican, Chinese, Thai etc.) are approximated by the typical portions. I also monitored the alcohol consumed during the day standardized by 1 drink (12 oz beer, 5% v/v) and Fruits/Vegetables servings and the total was included in the carbohydrates consumed.

The amount of daily exercise implies the total amount of time my heart rate was 50-70% of max heart rate recommended for my age. This translates to 88-122 bpm and monitored via a Samsung Watch app or via in-built sensors on a treadmill/elliptical trainers. A baseline time of 10 mins is added to actual exercise since I live in a 3-story house with multiple trips up and down.

The 6 weeks of monitoring into two halves (06/01/2021 – 06/20/2021 & 06/21/2021 – 07/12/2021) to demarcate a 'before' & 'after' when I became further disciplined with at least 45 minutes of exercise per day and reduced carbohydrate intake.

The daily medication schedule was also recorded.

1. https://www.myfitnesspal.com/nutrition-facts-calories/indian-food

Data Collection – Notes

	Date	Level (mg/dl)	Carbs (g)	F/V (No.)	Alcohol (No.)	Ex (WT) (Min)	Ex (Cardio) (min)	Ex (HR) (min)	Medication (binary)	Toast 14	Idli 8	Dosa 12	Pongal 29	Rice 45	Lentils 36	Roti 15	Yogurt 6	F/V 5	Side 30	Dessert 25	Mexican 100	Indian 200	Thai 150	Chinese 100	Misc 100
Before	06/01/2021	187	456	3	2	0	10	10	1	3	5	0	0	3	2	0	2	3	3	0	0	0	0	0	0.5
Before	06/02/2021	182	457	4	3	0	10	10	0	3	0	3	0	3	2	0	2	4	3	0	0	0	0	0	0.5
Before	06/03/2021	193	436	4	2	0	10	10	1	0	0	0	3	3	2	0	2	4	2	0	0	0	0	0	0.5
Before	06/04/2021	191	391	4	2	0	10	10	1	3	0	0	0	3	2	4	2	4	0	0	0	0	0	0	0.5
Before	06/05/2021	188	444	3	4	30	10	40	1	0	5	0	0	3	2	4	2	3	2	0	0	0	0	0	0.5
Before	**06/06/2021**	184	451	3	4	0	10	10	1	3	0	0	0	0	2	0	2	3	2	0	0	0	1	0	1
Before	**06/07/2021**	191	521	4	1	0	10	10	0	0	0	0	3	0	2	0	2	4	1	0	0	1	0	0	1
Before	06/08/2021	197	472	5	1	20	10	30	0	0	0	0	2	3	2	4	2	5	2	0	0	0	0	0	0.5
Before	06/09/2021	181	345	5	3	20	20	40	1	0	0	3	0	2	2	0	2	5	2	0	0	0	0	0	0.5
Before	06/10/2021	183	382	5	3	0	20	20	1	0	0	0	2	3	2	0	2	5	1	0	0	0	0	0	0.5
Before	06/11/2021	187	328	4	1	0	30	30	1	0	0	0	0	3	1	3	2	4	1	0	0	0	0	0	0.5
Before	**06/12/2021**	192	451	3	3	45	10	55	1	0	4	0	0	2	2	0	2	3	1	0	0	0	0	1	1
Before	**06/13/2021**	184	319	3	2	0	10	10	1	0	0	3	0	2	1	0	2	3	1	0	0	0	0	0	1
Before	06/14/2021	178	324	4	1	0	20	20	1	2	0	0	2	2	1	0	2	4	1	0	0	0	0	0	0.5
Before	06/15/2021	182	319	4	2	0	30	30	1	0	0	0	0	2	2	3	2	4	1	0	0	0	0	0	0.5
Before	06/16/2021	167	316	5	2	20	20	40	1	2	0	0	0	3	1	0	2	5	1	0	0	0	0	0	0.5
Before	06/17/2021	179	320	5	1	30	10	40	1	0	4	0	0	3	1	0	2	5	1	0	0	0	0	0	0.5
Before	06/18/2021	185	360	5	1	15	15	30	1	0	0	3	0	3	2	0	2	5	1	0	0	0	0	0	0.5
Before	**06/19/2021**	190	432	3	4	15	10	25	1	0	0	0	0	1	0	4	2	3	0	2	0	0	1	0	1
Before	**06/20/2021**	192	380	5	4	0	30	30	0	0	0	0	3	2	1	0	2	5	1	0	0	0	0	0	1
After	06/21/2021	174	327	3	1	30	20	50	1	2	0	0	0	2	2	0	2	3	2	0	0	0	0	0	0.5
After	06/22/2021	170	301	3	1	30	20	50	1	0	4	0	0	2	2	0	2	3	1	0	0	0	0	0	0.5
After	06/23/2021	168	274	4	2	0	30	30	1	0	0	3	0	2	1	0	2	4	1	0	0	0	0	0	0.5
After	06/24/2021	177	343	4	1	0	30	30	1	0	0	0	0	3	1	4	2	4	1	0	0	0	0	0	0.5
After	06/25/2021	167	283	3	2	30	20	50	1	2	0	0	2	2	0	0	2	3	1	0	0	0	0	0	0.5
After	**06/26/2021**	177	456	3	2	45	10	55	0	2	0	0	0	2	1	0	2	3	0	1	0	1	0	0	0.5
After	**06/27/2021**	170	330	3	3	0	40	40	0	2	0	0	0	3	0	4	2	3	1	0	0	0	0	0	0.5
After	06/28/2021	165	255	3	1	30	30	60	1	0	0	0	2	2	0	0	2	3	1	0	0	0	0	0	0.5
After	06/29/2021	157	278	4	1	20	20	40	1	0	5	0	0	2	1	0	2	4	1	0	0	0	0	0	0.5
After	06/30/2021	154	238	4	1	30	20	50	1	0	0	3	0	2	0	0	2	4	1	0	0	0	0	0	0.5
After	07/01/2021	146	317	4	3	0	10	10	1	2	0	0	0	1	2	4	2	4	1	0	0	0	0	0	0.5
After	07/02/2021	162	319	4	2	45	20	65	1	0	0	0	0	3	2	0	2	4	1	0	0	0	0	0	0.5
After	**07/03/2021**	190	410	2	7	0	20	20	0	0	0	0	0	0	0	0	0	2	0	2	1	0	1	0	1
After	**07/04/2021**	194	460	2	8	0	20	20	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	1	1
After	**07/05/2021**	179	360	2	7	20	20	40	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	1	1
After	07/06/2021	165	303	5	1	45	10	55	1	0	3	0	0	2	2	0	2	5	1	0	0	0	0	0	0.5
After	07/07/2021	163	361	5	1	0	40	40	1	2	0	2	0	2	2	0	2	5	2	0	0	0	0	0	0.5
After	07/08/2021	157	337	5	1	0	40	40	1	0	0	0	2	2	2	0	2	5	1	0	0	0	0	0	0.5
After	07/09/2021	146	324	5	1	20	30	50	1	0	0	0	0	2	2	3	2	5	1	0	0	0	0	0	0.5
After	**07/10/2021**	136	303	5	2	45	30	75	1	0	0	0	0	2	1	4	2	5	1	0	0	0	0	0	0.5
After	**07/11/2021**	138	301	5	2	0	45	45	1	0	0	0	2	2	1	0	2	5	1	0	0	0	0	0	0.5
After	07/12/2021	135	331	5	1	30	30	60	1	2	3	0	0	2	2	0	2	5	1	0	0	0	0	0	0.5

- A snapshot of the excel sheet with the carbohydrate calculations and measured blood glucose levels. I also monitored if I was regular with my medication schedule (missed on two out-of-town weekend trips). Blood sugar levels were recorded in a freely available excel template.[1]
- There was an obvious concern about my increased alcohol & food consumption over the weekend and if it deserved additional analysis as subgroups and hence the highlighted portion.
- The rationale for before & after subgrouping was simple, taking stock at halfway. This will be further discussed in the upcoming slides.

1. https://www.vertex42.com/ExcelTemplates/blood-sugar-chart.html

Measure: Graphical Summary

Hypotheses Testing for Normality:

H_0: Data follow a normal distribution.
H_1: Data do not follow a normal distribution.

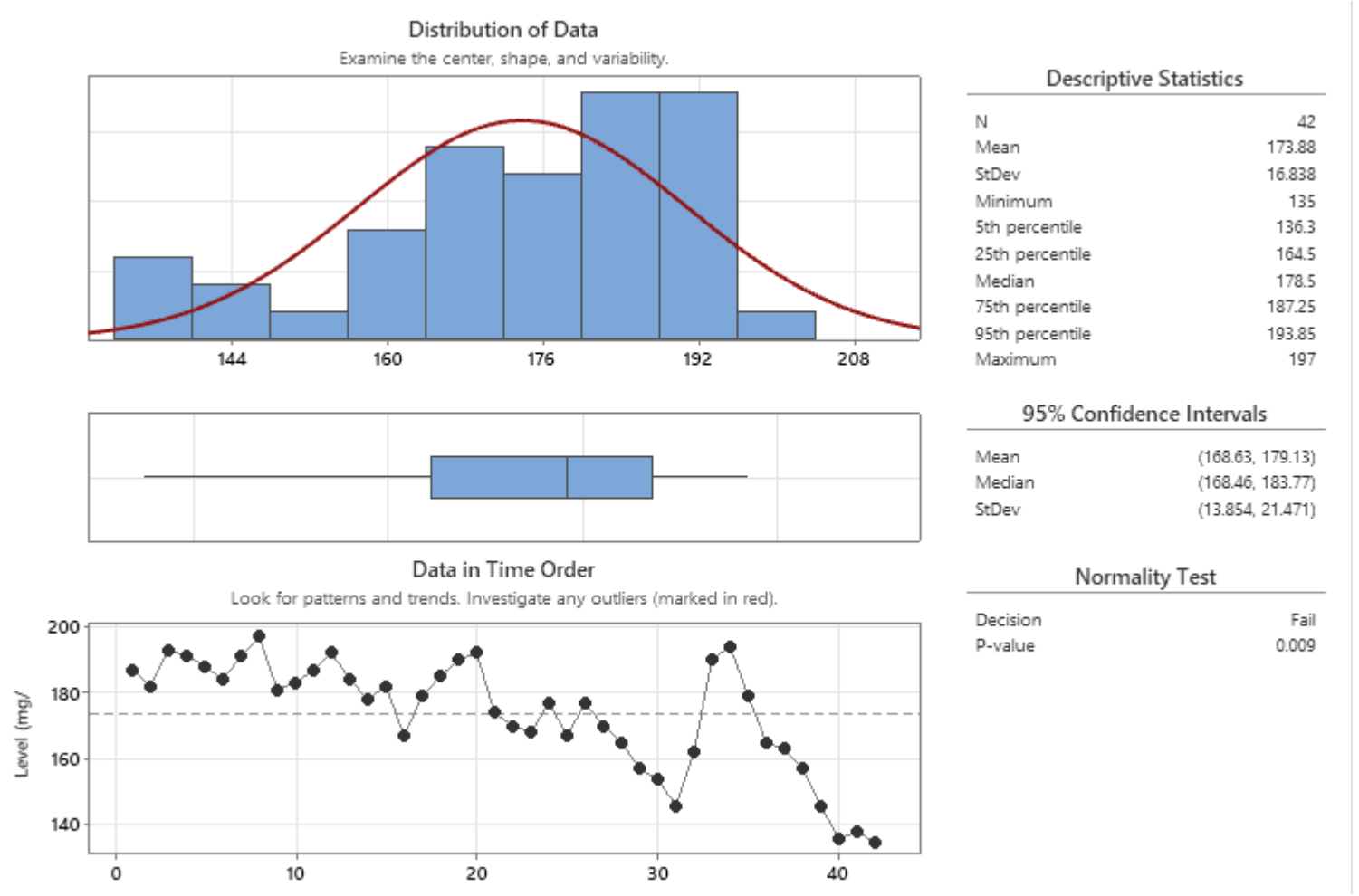
With a *p*-value of 0.009, I reject the null hypothesis for $\alpha = 0.05$, i.e., the blood glucose levels fail the normality test.

Mean: 173.88 mg/dL
Median: 178.5 mg/dL

The histogram shows that the distribution is left skewed.

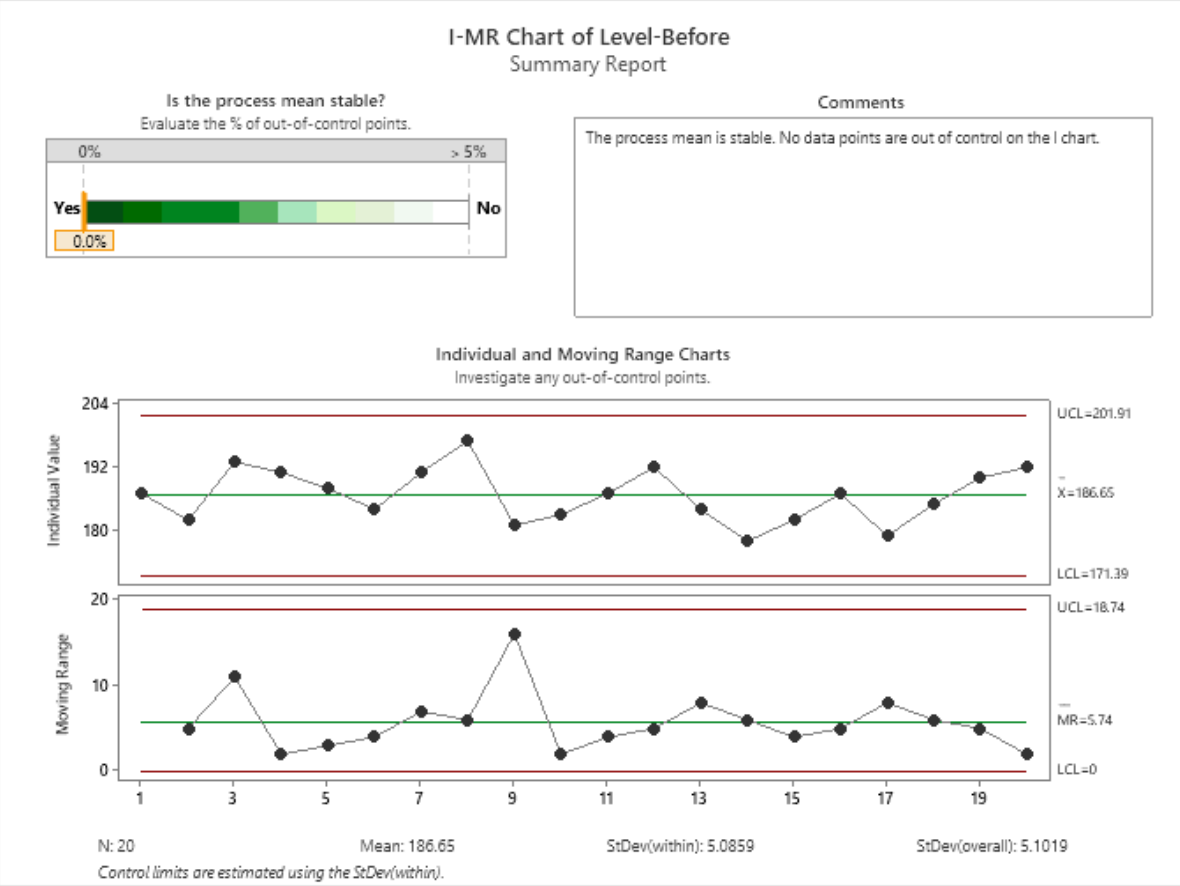
No outliers detected.

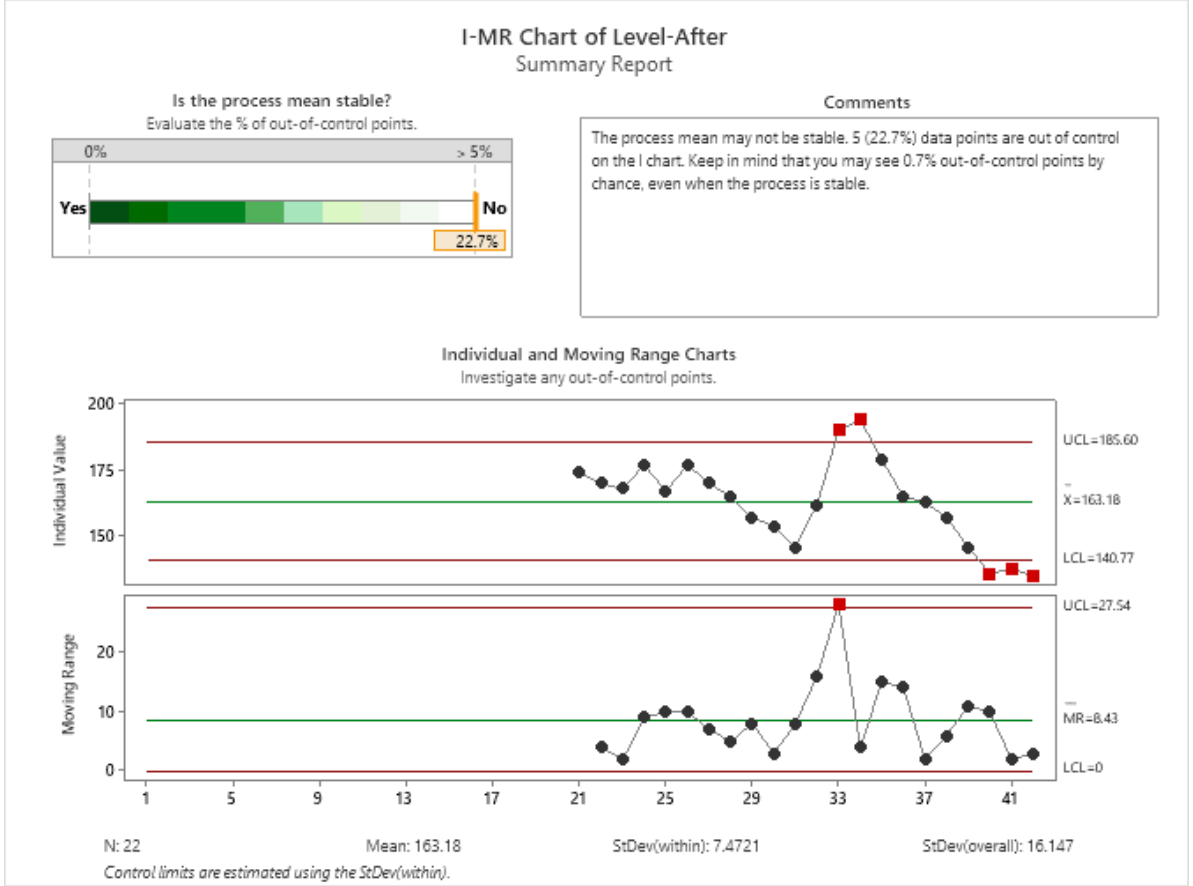
Graphical Summary of Blood Glucose Levels (mg/dL)



The Y metric is 'Blood Sugar Level (mg/dL)' measured from 06/01/2021 to 07/12/2021. It is a continuous variable and a time-series.

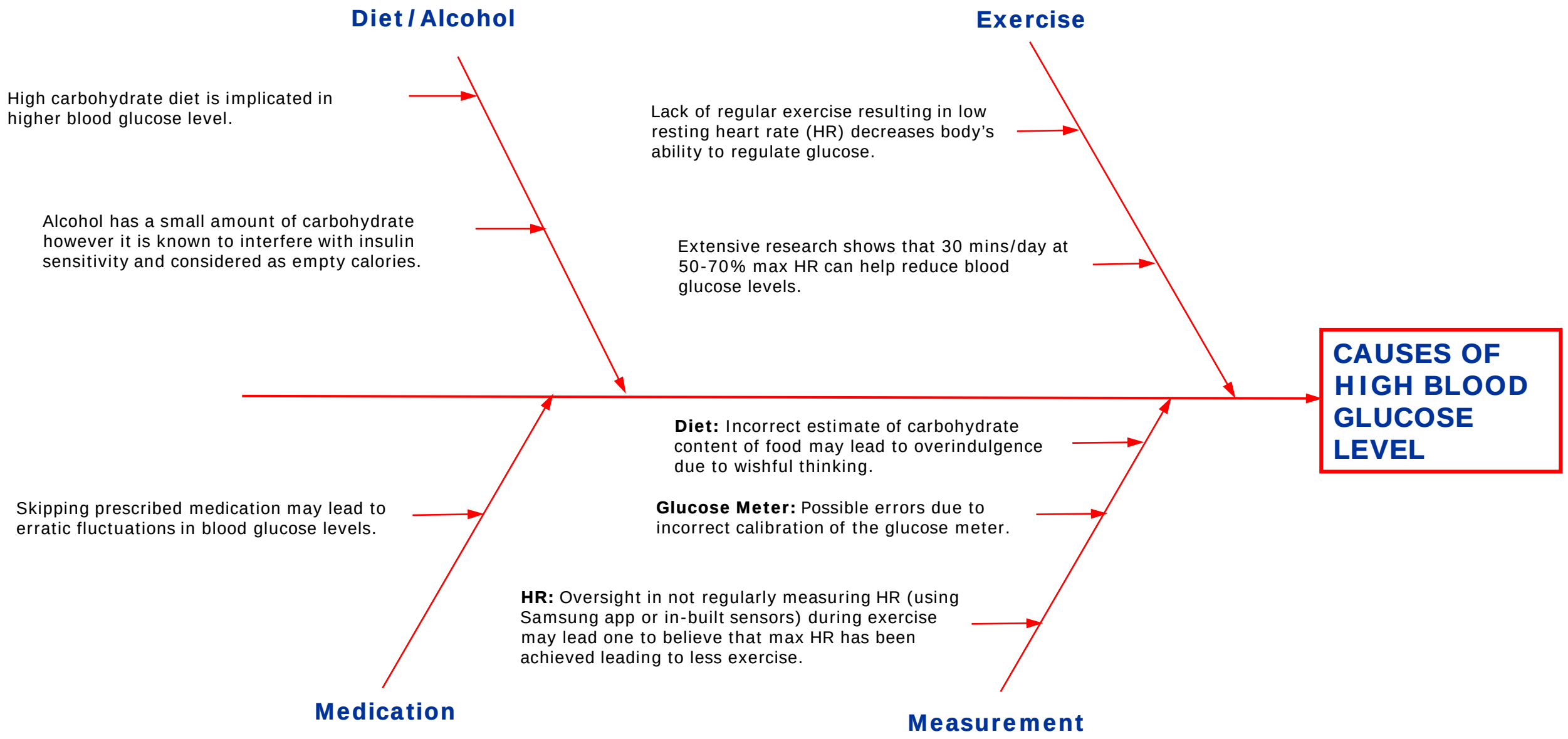
Measure: Control Charts



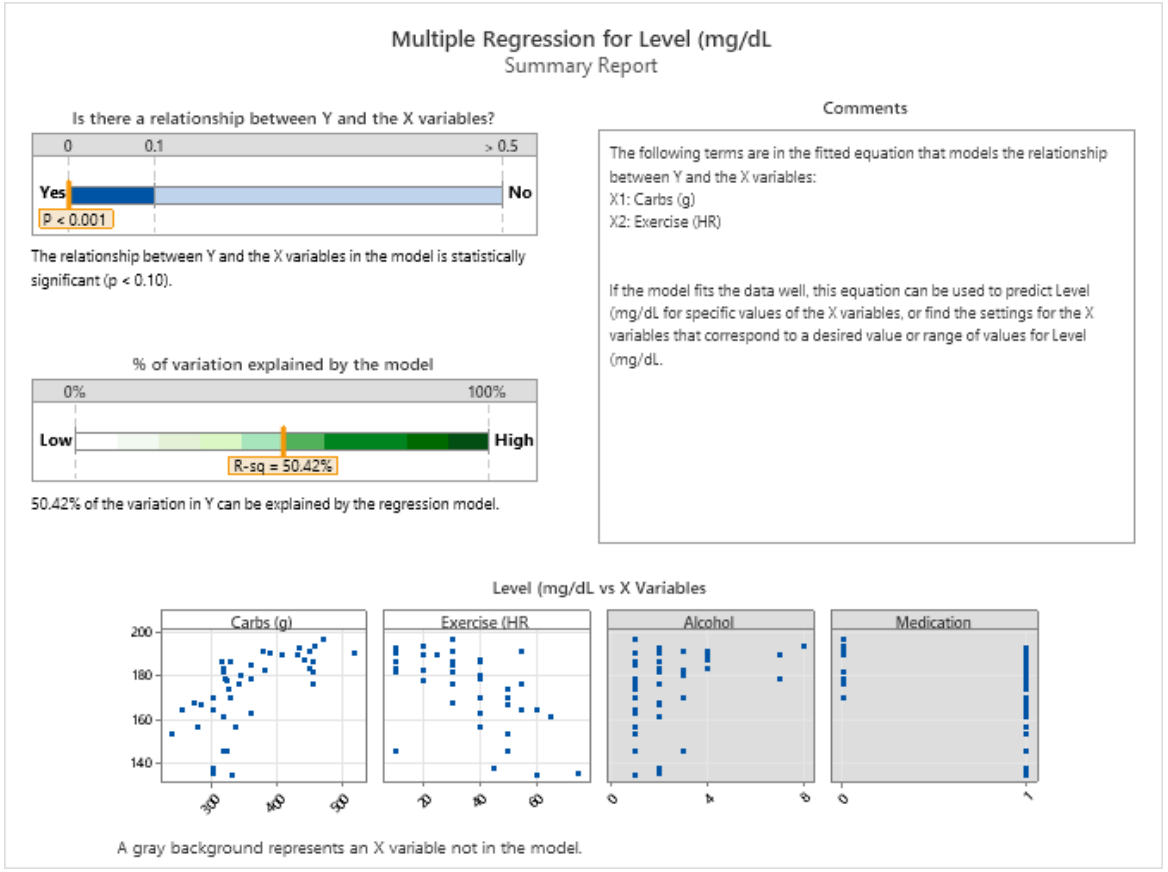


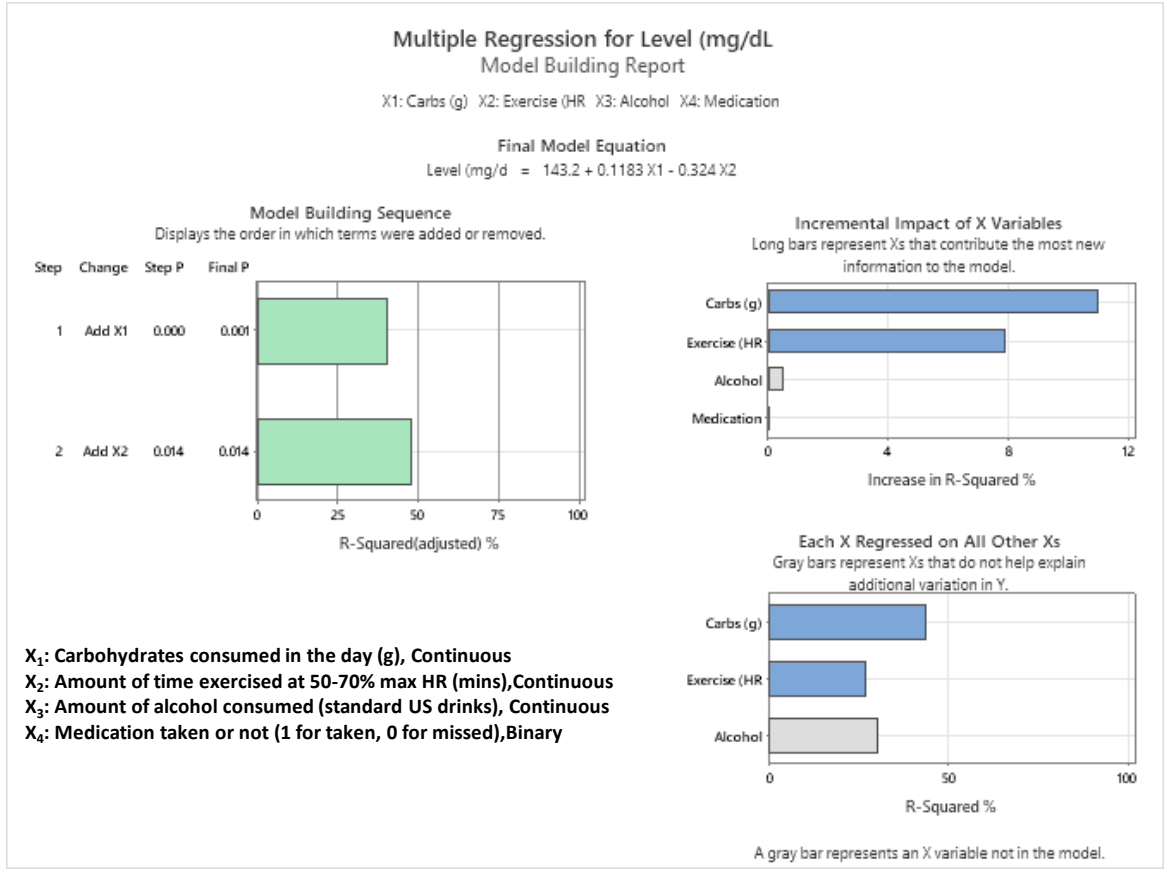
Using the before and after demarcation as noted earlier (halfway through the study), I tried to understand if the process is stable or not. In the first half of the study, the process is stable with a mean blood sugar level is 185.65. However, in the second half of the study, the process is not stable, i.e., on certain weekends, the level was beyond the UCL while towards the end, the levels were below the LCL.

Analyze: Fishbone diagram for Causes of High Blood Glucose Levels



Improve: Regression Model (with no interaction terms) for the full 6-week study





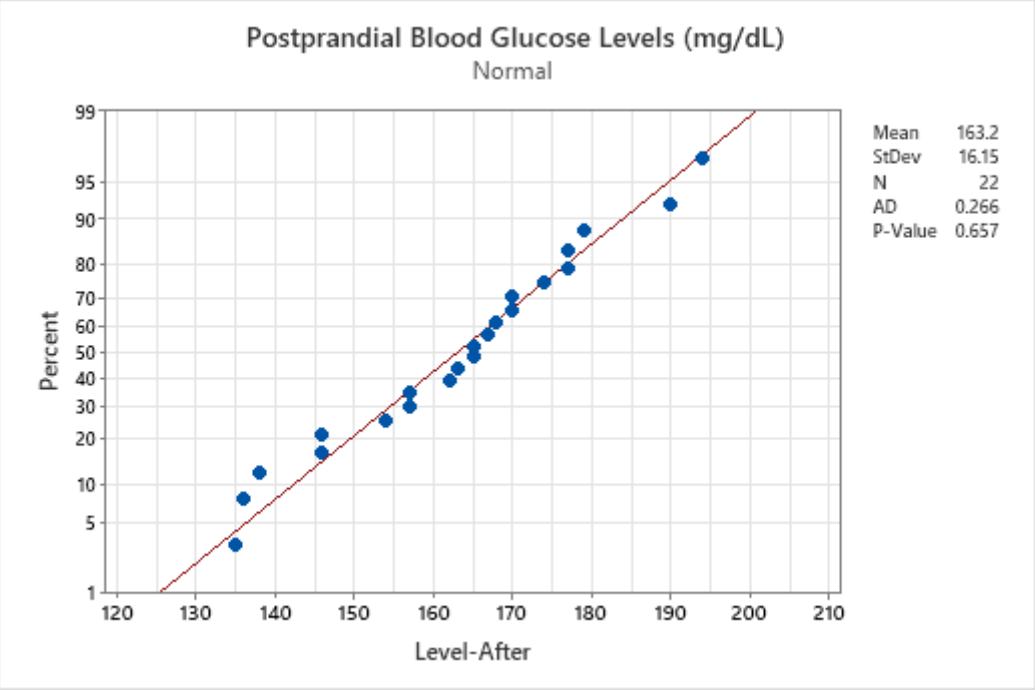
X_1: Carbohydrates consumed in the day (g), Continuous
X_2: Amount of time exercised at 50-70% max HR (mins),Continuous
X_3: Amount of alcohol consumed (standard US drinks), Continuous
X_4: Medication taken or not (1 for taken, 0 for missed),Binary

Final Model: Y (level, mg/dL) = 143.2 + 0.1183*X_1 – 0.324 *X_2 with R^2 = 50.42%. As we expect, **increasing carbohydrate consumption increases the blood sugar level (slope = +0.1183 (mg/dL)/g)** however **exercise has a relatively higher negative effective on blood sugar levels (slope = -0.324 (mg/dL)/min)**.

In this study, skipped medications and alcohol consumption was not a significant variable (Caution: Correlation or lack thereof is not causation). We do note that while alcohol may have other physiological effects, the carb content from alcohol is included in the Carbs(g) variable.

Improve: Hypothesis Testing for Target Mean (160 mg/dL) during the second half

I performed a 1-sample t test for blood sugar levels in the second half of the study (06/21/2021 to 07/12/2021). The truncated portion of the data passes the normality test. With a *p*-value of 0.366 at $\alpha = 0.05$, we fail to reject the null hypothesis that the mean is equal to 160 mg/dL. This is also clear from the 95% CI for the mean bounded by (156.02, 170.34) mg/dL.



One-Sample T: Level-After

Descriptive Statistics

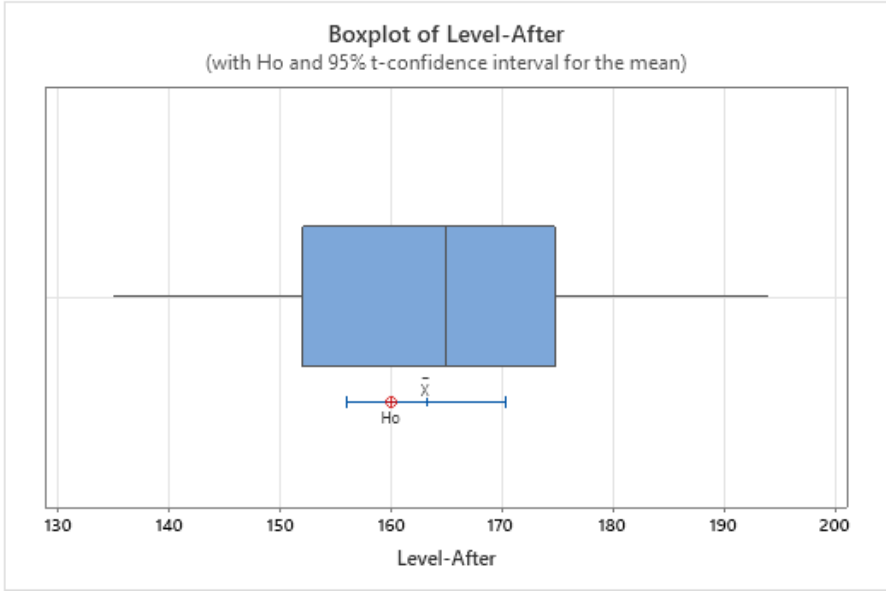
N	Mean	StDev	SE Mean	95% CI for μ
22	163.18	16.15	3.44	(156.02, 170.34)

μ: population mean of Level-After

Test

Null hypothesis $H_0: \mu = 160$
Alternative hypothesis $H_1: \mu \neq 160$

T-Value	P-Value
0.92	0.366



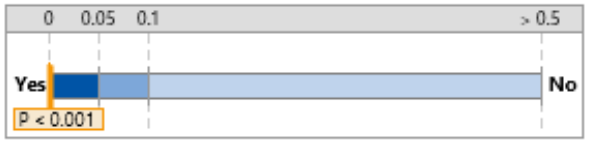
Improve: Hypothesis Testing for Exercise Levels ‘Before’ & ‘After’

2-Sample t Test for the Mean of Excercise (b and Excercise (A

Summary Report

Mean Test

Is Excercise (b less than Excercise (A?



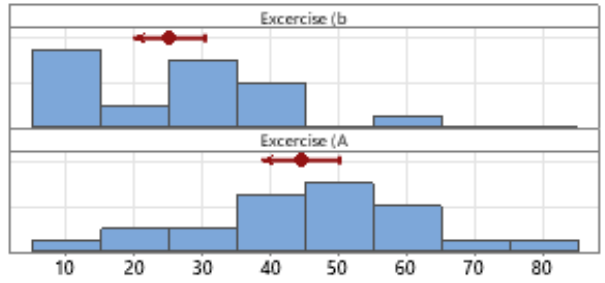
The mean of Excercise (b is significantly less than the mean of Excercise (A (p < 0.05).

95% Upper Bound for the Difference

Is the entire interval below zero?

Distribution of Data

Compare the data and means of the samples.



Individual Samples

Statistics	Excercise (b	Excercise (A
Sample size	20	22
Mean	25	44.318
95% Upper bound	30.29	50.044
Standard deviation	13.669	15.606

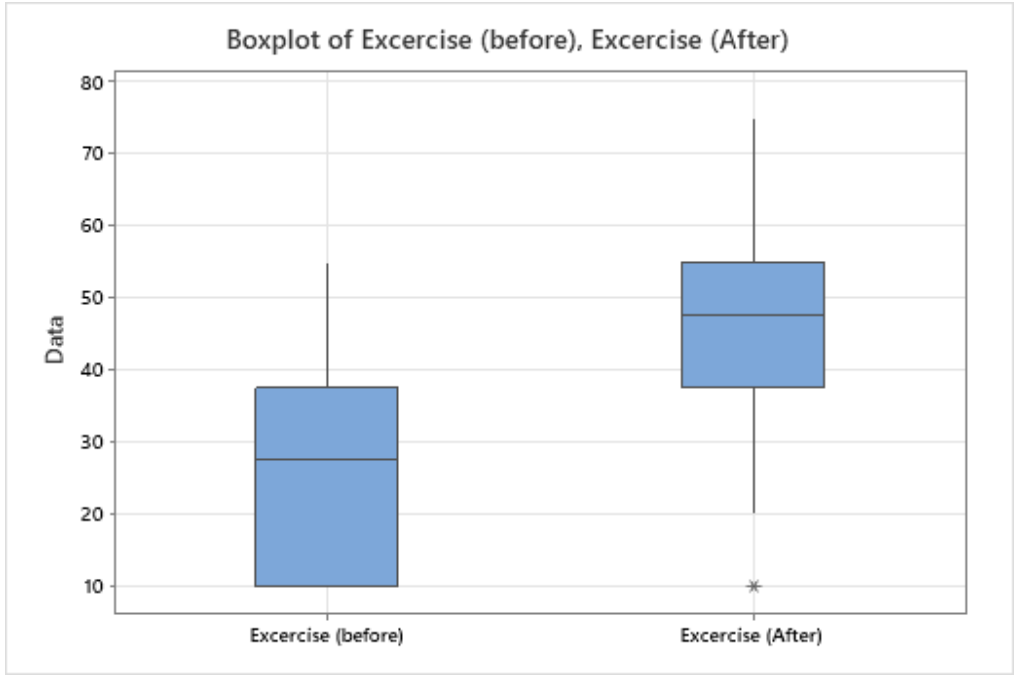
Difference Between Samples

Statistics	*Difference
Difference	-19.318
95% Upper bound	-11.706

*Difference = Excercise (b - Excercise (A

Comments

- Test: You can conclude that the mean of Excercise (b is less than Excercise (A at the 0.05 level of significance.
- CI: Quantifies the uncertainty associated with estimating the difference in means from sample data. You can be 95% confident that the true difference is less than -11.706.
- Distribution of Data: Compare the location and means of samples. Look for unusual data before interpreting the results of the test.



This tests shows that the mean of exercise level in the ‘after’ phase is higher than ‘before’ phase at $\alpha = 0.05$ level significance.

Improve: Hypothesis Testing for Carb Consumption ‘Before’ & ‘After’

Two-Sample T-Test and CI: Carbs (g)-Before, Carbs (g)-After

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Carbs (g)-Before	20	395.2	64.1	14
Carbs (g)-After	22	327.8	56.4	12

Estimation for Difference

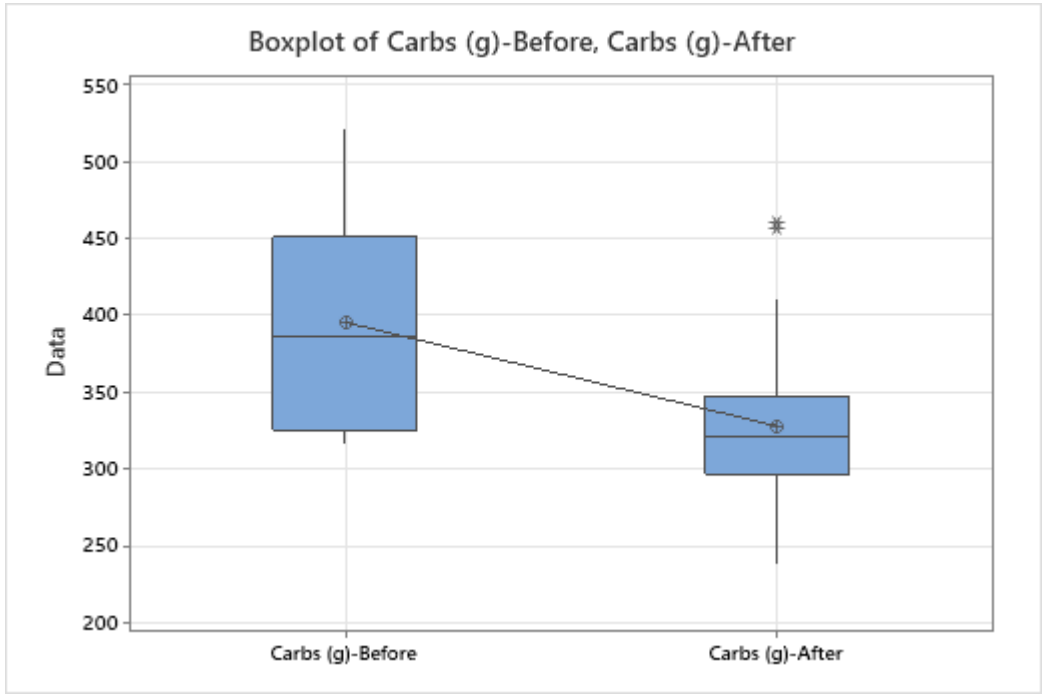
Difference	95% Lower Bound for Difference
67.4	35.9

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 > 0$

T-Value	DF	P-Value
3.60	38	0.000



This test shows that the mean of carbohydrate consumption in the ‘after’ phase is lower than ‘before’ phase at $\alpha = 0.05$ level significance with a *p*-value of 0.000.

Improve: Hypothesis Testing for Blood Sugar Levels ‘Before’ & ‘After’

Two-Sample T-Test and CI: Level-Before, Level-After

Method

μ_1: population mean of Level-Before
μ_2: population mean of Level-After
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Level-Before	20	186.65	5.10	1.1
Level-After	22	163.2	16.1	3.4

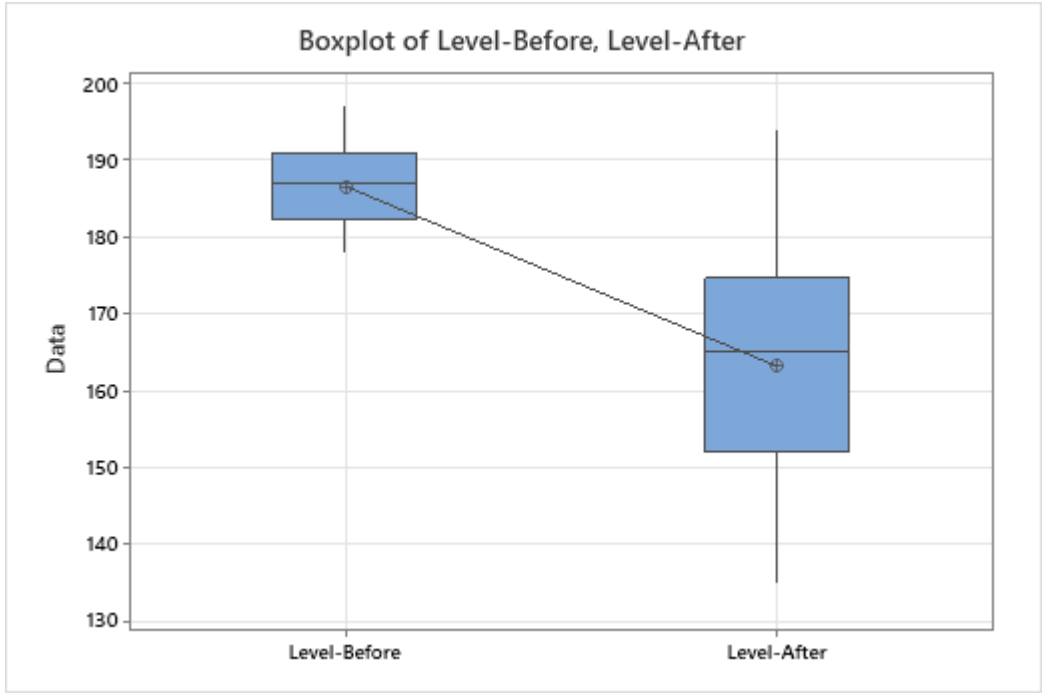
Estimation for Difference

Difference	95% Lower Bound for Difference
23.47	17.27

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 > 0$

T-Value	DF	P-Value
6.47	25	0.000



This test shows that the mean of blood sugar levels in the ‘after’ phase is lower than ‘before’ phase at $\alpha = 0.05$ level significance with a *p*-value of 0.000. The hypothesis testing in slides 11, 12 & 13 of mean levels of exercise, carbs consumed, and blood sugar levels combined with the regression model, it is evident that for the Y metric of blood sugar level, the vital X’s are the amount of exercise done and the carbohydrates consumed during the day.

Control: What do I need to do to maintain my Blood Sugar Levels ≤ 160 mg/dL?

- Reduce everyday total carbohydrate consumption to 325 g or less.

- Maintain exercise time at 50-70% max HR (88-122 bpm) at 45 mins or higher. It was pointed out in Slide 2 that research indicates lesser exercise time is needed if I can exercise at > 70% max HR (> 122 bpm). As my fitness improves, with consultation from physician, this will be implemented.

- As noted in the Business Case, the long-term goal is weaning off prescription medication. To achieve this, further careful analysis of my diet to achieve carbohydrate consumption in the 250-275 g will be required. This will include substituting rice with healthier millets, increasing protein content through shakes or powder and reducing calorie intake. These changes will have a direct impact on maintaining my blood sugar levels below 160 mg/dL.

Conclusions

- I was successful in reducing my average daily blood sugar level to less than 160 mg/dL at the end of 6-weeks. The average of the final 7 days was 148.6 mg/dL.

- I was able to achieve this by reducing mean carbohydrate consumption from 395.2 g (06/01/2021 – 06/20/2021) to 327.8 g (06/21/2021 – 07/12/2021) and increasing my exercise time at 50-70% max HR from 25 mins to 44.32 mins per day.

- The regression model: Y (level, mg/dL) = $143.2 + 0.1183*X_1 – 0.324 *X_2$ with $R^2 = 50.42\%$ (where X_1 is the amount of carbs(g) consumed in a day and X_2 (exercise time in mins)) describes the relation to the blood sugar levels. I point out that adding interaction terms or quadratic terms improved the fit considerably however further data collection is desired to improve the robustness of the model.

- The other X's that I monitored like 'Alcohol Consumption' and 'Medication Taken or Not' did not impact the final regression model. However, it is understood that correlation or lack thereof is causation. Skipping medication must be avoided at all costs.