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Induction of Acidic Imbalance by Carbonated Beverages and the Development of Type 2 Diabetes

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Regular and excessive ingestion of substances that contain or produce acid can increase blood acidity either by building up acid load or loss of bicarbonate; either way can result in mild metabolic acidosis. Excessive and regular intake of carbonated beverages leads to weight gain and increase sugar and acid load in the body. Major characteristic properties of carbonated beverages are high carbon dioxide content, acidity and high levels of sugar or artificial sweeteners. Cessation of carbonated beverage consumption is commonly recommended as part of lifestyle modifications for patients with type 2 diabetes mellitus. Carbonated beverage consumption can result in a transient decline in stomach pH. In addition, it may also lead to a transient reduction in the level bicarbonate buffer leaving so many bicarbonate depending metabolic processes compromised.

The high acidic and sugar content of some carbonated beverages makes them a good candidate for inducing systemic acid-base imbalance overtime and result in mild metabolic acidosis which have been shown to be one among other factors responsible for insulin resistance. The present review attempts to link excessive consumption of carbonated beverages, insulin resistance and the development of type 2 diabetes.

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1. INTRODUCTION

The human requirement for nourishment remains relatively constant throughout life. Good nutrition is essential for maintaining a healthy body and prevents the development of metabolic diseases such as diabetes mellitus. Nourishing the body with nutrients that may impair the normal functioning of metabolic processes may have a negative effect on the overall bodily function. Carbonated beverages are one class of nutrients with high acidic and sugar content that could impair some metabolic processes if consumed excessively on a regular basis. Carbonated beverages are drinks that have been super-saturated with carbon dioxide, to create the pleasant bubbly sensation. When carbon dioxide mixes with water, it becomes carbonic acid. Carbonic acid can lower the pH level of the stomach further, causing a rise in the acid load already in the stomach environment. The stomach plays a very important role contributing to much of the digestion, and some of the absorption of nutrients. Healthy digestion and absorption of nutrients is dependent upon the secretion of gastric acid. When gastric secretions are reduced the result can lead to nutritional impairment and impaired metabolic function which can lead to chronic disorders such as diabetes mellitus. Diabetes mellitus is a complex metabolic disorder of absolute or relative insulin deficiency characterised by persistent hyperglycemia that is very difficult to treat especially in the long term.

Despite many decades of research in diabetes mellitus, the disease still remains a serious cause of morbidity and mortality, causing devastating personal suffering and huge economic cost driving many families into poverty. Estimated number of people presently living with diabetes worldwide is approximated to be 425 million with an expected increase to 693 million people by the year 2045 [1]. Among the different types of diabetes, type 2 diabetes is the most common, accounting for around 90% of all cases [2,3,4]. Genetic, dietary and environmental factors have been reported to play an important role in the development of type 2 diabetes, but dietary modification pattern points towards the metabolic component that plays an important etiological role in the development of type 2 diabetes. Considerable evidence indicates that diet, stress, physical activity, obesity and aging, plays an important role in the development of the disease, but dietary habits such as intake of sugar-sweetened beverages are associated with cardiometabolic diseases [5,6] and also influence many risk factors for cardiometabolic health, including heart disease, stroke, and type 2 diabetes [7]. The prevalence of diabetes has increased rapidly in the past in parallel to the obesity epidemic [8,9]. Association between the intake of sugar sweetened beverages and the risk of obesity in children has been suggested [10]. High consumption of sweetened carbonated beverages has been linked to the increased body mass index (BMI) and obesity [11]. Obesity and elevated BMI have in turn been associated with an increased risk of developing type 2 diabetes. Besides contributing to obesity, sugar-sweetened beverages might increase the risk of diabetes because they contain large amounts of high-fructose corn syrup, which raises blood glucose similarly to sucrose [12].

Sugar-sweetened beverages (SSB) provide a high dose of added sugar, leading to a rapid spike in blood glucose and insulin [13], providing a plausible explanation to link consumption to the development of impaired glucose tolerance and diabetes. Artificial sweeteners have been shown to cause glucose intolerance in mice by altering gut microbiota and are associated with dysbiosis and glucose intolerance in humans [14]. Indeed, diabetes mellitus was found to be more prevalent in those who regularly consumed artificially sweetened beverages [15].

Higher consumption of sugar-sweetened beverages was associated with a greater magnitude of weight gain and an increased risk for development of type 2 diabetes in women [16]. Recently dietary factors were estimated to be associated with a substantial proportion of deaths from heart disease, stroke, and type 2 diabetes [17].

Studies linking artificially sweetened beverage consumption to negative health consequences are on the rise, such as consumption of high sweetened carbonated beverages has been linked to the increased body mass index (BMI) and obesity epidemic [18]. Sugars and artificial sweeteners are added to many carbonated beverages to impact a sweet taste. Artificial sweeteners such as saccharin, acesulfame, aspartame, neotame, or sucralose provide a

sugary taste without increasing the caloric content of the beverage and these synthetic substances are much more potent than sucrose, with only trace amounts needed to generate the sensation of sweetness [13]. Cessation of carbonated beverage consumption is commonly recommended as part of lifestyle modifications for patients with type 2 diabetes.

2. CARBONATED BEVERAGES CONSUMPTION, METABOLIC ACIDOSIS AND INSULIN RESISTANCE

Carbonated beverages consumption can alter systemic acid-base balance over time due to their extremely low pH and high acidic content. Carbonation of beverages makes the drink more acidic, which serves to sharpen the flavour and taste [19]. The effects of carbonated beverages on the human body have been the center of much attention in the last decade, specifically, the consequences of carbonation, acid load and high carbohydrate consumption.

Acidity is a common chemical property of many sugar sweetened carbonated beverages. Colas, sodas and beers are known to be among the most acidic beverages consumed in modern society, the acidic nature of sodas (pH ~3) is derived from conversion of dissolved CO_2 to HCO_3^- and H^+ by interaction with H_2O as well as additives such as citric acid and phosphoric acid [18]. The mechanism underlying the link between consumption of sugar-sweetened carbonated beverages and weight gain, obesity [20,21] and the development of type 2 diabetes are still unclear. Therefore a clear understanding of how consumption can lead to weight gain and the development of type 2 diabetes will be invaluable in understanding the pathophysiologic process of type 2 diabetes.

Carbonated beverages have high acid content, whose metabolism consumes more bicarbonate than is generated, further depleting the exhaustible bicarbonate reserve in the body. The content of these carbonated beverages make the stomach more acidogenic, generating an acid load that cannot be neutralised by the less available buffer causing a state of unnoticed and growing metabolic acidosis. The growing metabolic acidosis may thus slowly influences systemic acid-base status, being an independent negative predictor of plasma bicarbonate deficiency. Excessive consumption of carbonated beverages may increase the body acid load and induce metabolic acidosis by increasing H^+ concentration and depleting bicarbonate ions, thus creating a state of mild metabolic acidosis. It was previously demonstrated in healthy individuals that even a very mild degree of metabolic acidosis results in decreased sensitivity to insulin and subsequent impairment of glucose tolerance [22].

Excessive carbonated beverages consumption can be associated with a mild and transient metabolic acidosis, which over time can alter the gastrointestinal function. It was reported in a study where 300 ml carbonated water was consumed by women and men just after a solid–liquid meal, CO_2 was liberated from the carbonated water in the stomach, where it led to increased distension and a greater retention of meal components during the postprandial lag phase [23]. It has been reported that the release of dissolved CO_2 from sugar sweetened carbonated beverages in the stomach may influence gastric pH, food digestion and absorption by impacting on the intestinal pH. Increased acidity in foods and beverages has been linked to delayed gastric emptying [24,25,26]. Carbonated beverage-induced acidosis may impair gastrointestinal function at the metabolic and hormonal level, thus promoting obesity and development of type 2 diabetes.

Continuous and increased carbonation over a long period of time may have significant effect on gastric acidity and hence may influence nutrient absorption and assimilation. A key substrate in the production of gastric acid is CO_2, and diffusion of CO_2 through the basal surface of the parietal cells appears to be the rate limiting step in acid synthesis. Hydrogen ions are generated within the parietal cell from dissociation of water [27]. Adding more CO_2 load through excessive intake of carbonated beverages will definitely increase CO_2, thus generating more hydrogen and thus creating a favourable condition for insulin resistance and development of diabetes mellitus. Sofi et al. [28] reported to have observed in female non-obese diabetic (NOD) mice given neutral water (NW) (pH 7.0–7.2) or acidic water (AW) with added HCl (pH 3.0–3.2). They discovered that mice that had been given AW since birth developed hyperglycemia rapidly compared with the group given NW. They reported that NOD mice that were given AW exhibited faster onset and progression of T1D, similar to the mice receiving AW since birth. Previously, Stacher et al. [29] found an inverse relationship between blood glucose and

intragastric acid output, their finding showed that low blood glucose levels were associated with high rates of acid secretion and high blood glucose levels with low acid secretion. This is not surprising considering the fact that the body naturally will adjust its net acid production when there is exogenous acid load as part of its adaptive control. The low acid production that leads to hyperglycemia in the previous study might be due to inhibition of acid secretin enzymes as previously shown that inhibition of carbonic anhydrase is associated with increased mucosal injury after exposure to acidic luminal fluid [30,31]. It has been shown previously that the gastric mucosa of mammals is very rich in carbonic anhydrase which seems to be localised in the parietal cells, and suggested the possibility that carbonic anhydrase takes part in the secretion of hydrochloric acid [32]. Acid secretion is a physiologically important process of the stomach as gastric acid induces pepsinogen activation to initiate the digestive process and kills bacteria and other microbes ensuring a stable intragastric environment [33].

Acidosis is thought to interfere with the ability of insulin to bind to its receptor or to initiate post-receptor binding events [34]. Plasma insulin concentration has been found to be at its lowest during glucose tolerance tests in cows with metabolic acidosis, suggesting that insulin secretion in response to a glucose challenge was impaired during metabolic acidosis [35]. Metabolic acidosis in humans (ketoacidotic diabetics) is most often associated with tissue resistance to insulin rather than with the inability to secrete insulin [36,37]. Correction of acidosis with an alkalinising agent, such as sodium bicarbonate, was found to restore the responsiveness of tissues to insulin [36], indicating the role acidity plays in insulin activity.

In response to the metabolic acidosis imposed by excessive intake of carbonated beverages, the kidney implements adaptive processes aimed to restore the acid-base balance, by excreting excess of H^+ or reabsorption of bicarbonate. Increased rates of endogenous acid production are also associated with reduced kidney tubule calcium reabsorption, resulting in hypercalciuria and negative calcium balance [38]. The urinary excretion of calcium is enhanced even with mild reductions of arterial pH to values still within the normal range [39,40]. The incidence of diabetes mellitus and glucose intolerance is much higher in persons with a lower urinary pH than in normal volunteers [41]. The relationship between hypercalciuria and metabolic acidosis is further confirmed by population studies, in which urinary calcium excretion is lower when the urine is more alkaline, whereas more acidic urine is associated with higher urinary calcium excretion [42]. Recent observational studies confirm an association between insulin resistance and indicators of metabolic acidosis, such as low serum bicarbonate, high serum anion gap, hypocitraturia, and low urine pH in participants in the 1999-2000 and 2001-2002 National Health and Nutrition Examination Surveys (NHANES) [43]. Both lower bicarbonate and higher anion gap are independently associated with insulin resistance [44].

In response to metabolic acidosis, significant functional changes take place in the kidney, including an increase in renal plasma flow (RPF) and glomerular filtration rate (GFR), which probably serve to remove the excess acid load [45,46,47]. Elevated RPF, GFR, and kidney size are noted in diabetic patients early in the course of the disease compared with nondiabetic individuals [48,49]. Therefore excessive consumption of sugar sweetened carbonated beverages over a prolonged period of time can contribute to the onset of impaired insulin secretion and hyperglycemia.

3. CONCLUSION

Sweetened carbonated beverages have been associated with weight gain and obesity which are known to be risk factors for the development of type 2 diabetes. But the currently available literature does not explain any strong relationship between carbonated beverages consumption and the development of type 2 diabetes. It appears that there is a correlation between sweetened carbonated beverages and obesity, metabolic syndrome. Sweetened carbonated beverages may also promote insulin resistance or development of type 2 diabetes. Further research is required to understand the link between excessive consumption of sweetened carbonated beverages and possible insulin resistance and development of type 2 diabetes.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. International Diabetes Federation. Diabetes Atlas, 8th edition. Abu Dabhi, UAE; 2017.
2. Evans JM, Newton RW, Ruta DA, et al. Socio-economic status, obesity and prevalence of Type 1 and Type 2 diabetes mellitus. Diabet Med J Br Diabet Assoc. 2000;17:478–80
3. Bruno G, Runzo C, Cavallo-Perin P, et al. Incidence of Type 1 and Type 2 diabetes in adults aged 30–49 years: The population-based registry in the province of Turin, Italy. Diabetes Care. 2005;28:2613–19.
4. Holman N, Young B, Gadsby R. Current prevalence of Type 1 and Type 2 diabetes in adults and children in the UK. Diabet Med J Br Diabet Assoc. 2015;32:1119–20.
5. Dhingra R, Sullivan L, Jacques PF, Wang TJ, Fox CS, Meigs JB, et al. Soft drink consumption and risk of developing cardiometabolic risk factors and the metabolic syndrome in middle-aged adults in the community. Circulation. 2007;116: 480–488.
6. Fung TT, Malik V, Rexrode KM, Manson JE, Willett WC, Hu FB. Sweetened beverage consumption and risk of coronary heart disease in women. Am J Clin Nutr. 2009;89:1037–1042.
7. Mozaffarian D. Dietary and policy priorities for cardiovascular disease, diabetes, and obesity: A comprehensive review. Circulation. 2016;133(2):187-225. Mokdad AH, Bowman BA, Ford ES, Vinicor F, Marks JS, Koplan JP. The continuing epidemics of obesity and diabetes in the United States. JAMA. 2001a;286:1195-1200.
8. Mokdad AH, Ford ES, Bowman BA, et al. Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001b. JAMA. 2003;289:76-79.
9. Mokdad AH, Ford ES, Bowman BA, et al. Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001b. JAMA. 2003;289:76-79.
10. Ludwig DS, Peterson KE, Gortmaker SL. Relation between consumption of sugar-sweetened drinks and childhood obesity: A prospective, observational analysis. Lancet. 2001;357:505-508
11. Lim S, Zoellner JM, Lee JM, et al. Obesity and sugar-sweetened beverages in African-American preschool children: A longitudinal study. Obesity (Silver Spring) 2009;17:1262–8.
12. Akgun S, Ertel NH. The effects of sucrose, fructose, and high-fructose corn syrup meals on plasma glucose and insulin in non-insulin-dependent diabetic subjects. Diabetes Care. 1985;8:279-283.
13. Ludwig D. Artificially sweetened beverages cause for concern. JAMA. 2009;302:2477–2478.
14. Suez J, Korem T, Zeevi D, Zilberman-Schapira G, Thaiss CA, Maza. Artificial sweeteners induce glucose intolerance by altering the gut microbiota. Nature. 2014;514:181–186.
15. Matthew PP, Jayandra JH, Alexa SB, Hugo JA, Claudia LS, Ramachandran SV, Sudha S, Paul FJ. Sugar- and artificially sweetened beverages and the risks of incident stroke and dementia: A prospective cohort study. Stroke. 2017;48: 1139-1146.
DOI:10.1161/STROKEAHA.116.016027
16. Schulze MB, Manson JE, Ludwig DS, Colditz GA, Stampfer MJ, Willet WC, HU FB. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. JAMA. 2004;292:927-934
17. Renata Micha, RD, Jose LP, Frederick C. Fumiaki I. Colin D. R. Dariush M. Association between dietary factors and mortality from heart disease, stroke, and Type 2 diabetes in the United States. JAMA. 2017;317(9):912-924.
18. Johnson T. Gerson L. Hershcovici T. Stave C. Fass R. Systematic review the effects of carbonated beverages on gastro-oesophageal reflux disease. 2010;31:6: 607–614.
19. Taylor B. Ingredients and formulation of carbonated soft drinks, in Carbonated Soft Drinks: Formulation and Manufacture, D. Steen and P. R. Ashurst, Eds. 2006;48–86. Blackwell Publishing, Oxford, UK.
20. Bachman CM, Baranowski T, Nicklas TA. Is there an association between sweetened beverages and adiposity? Nutr Rev 2006;64:153–174.
21. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight

gain: A systematic review. Am J Clin Nutr. 2006;84:274–288.
22. DeFronzo RA, Beckles AD. Glucose intolerance following chronic metabolic acidosis in man. Am J Physiol. 1979;236: E328–E334.
23. Pouderoux P, Friedman N, Shirazi P, Ringelstein JG, Keshavarzian A. Effect of carbonated water on gastric emptying and intragastric meal distribution. Dig Dis Sci. 1997;42:34–39.
24. Hunt JN, Knox MT. The slowing of gastric emptying by four strong and three weak acids. J Physiol 1972;222:187–208.
25. Liljeberg HGM, Bjorck IME. Delayed gastric emptying rate as a potential mechanism for lowered glycemia after eating sourdough bread: studies in human and rats using test products with added organic acids or an organic salt. Am J Clin Nutr. 1996;64:886–963.
26. Ostman E, Granfeldt Y, Persson L and Bjorck IME. Vinegar supplementation lowers glucose and insulin responses and increases satiety after a bread meal in healthy subjects. Eur J Clin Nutr. 2005;59, 983–988.
27. Forte JG, Zhu L. Apical recycling of the gastric parietal cell H, K-ATPase. Annu Rev Physiol. 2010;72:273–96.
28. Sofi, et al. pH of drinking water infl uences the composition of gut microbiome and type 1 diabetes incidence. Diabetes. 2014;63:632–644.
29. Stacher G, Bauer P, Schulze D, Pointner H, Landgraf M. Effect of alterations of blood glucose levels on gastric acid secretion, plasma gastrin, and plasma osmolality in man. Am J Dig Dis. 1976;21(7):563-8.
30. Davies RE, Edelman J. The function of carbonic anhydrase in the stomach. Biochem J. 1952;50:190-194.
31. Werther JL, Hollander F, Altamirano M. Effect of acetazolamide on gastric mucosa in canine vivo-vitro preparation. Am J Physiol. 1965;209:127-133.
32. Davenport HW. Gastric carbonic anhydrase. J Physiol. 1939;97:32.
33. Herling AW, Weidmann K. Burger's Medicinal chemistry and drug discovery (5th edn.), John Wiley and Sons Inc., New Jersey; 1996.
34. Cuthbert C, Alberti KGM. Acidemia and insulin resistance in the diabetic ketoacidotic rat. Metabolism. 1978;27: 1903.
35. Bigner DR, Goff JP, Faust MA, Burton JL, Tyler HD, Horst RL. Acidosis glucose effects on insulin response during tolerance tests in jersey cows. Journal of Dairy Science. 1996;79:12.
36. Schade DS. Eaton RP, Alberti KGM, Johnston DG. Insulin resistance. Page 116 in Diabetic Coma: Ketoacidotic and Hyperosmolar. Univ. New Mexico Press, Albuquerque; 1981.
37. Walker BG, Phear DN, Martin FIR, Baird CW. Inhibition of insulin by acidosis. Lancet. 1963;2:964.
38. Adeva MM, Souto G. Diet-induced metabolic acidosis Clinical Nutrition. 2011;30:416-421.
39. Maurer M, Riesen W, Muser J, Hulter HN, Krapf R. Neutralization of Western diet inhibits bone resorption independently of K intake and reduces cortisol secretion in humans. Am J Physiol Ren Physiol. 2003;284:F32-40
40. Lemann Jr J. Relationship between urinary calcium and net acid excretion as determined bydietary protein andpotassium: A review. Nephron. 1999;81(Suppl. 1):18-25.
41. Sakhaee K, Adams-Huet B, Moe OW, Pak CY. Pathophysiologic basis for normouricosuric uric acid nephrolithiasis. Kidney Int. 2002;62:971-9.
42. Hu JF, Zhao XH, Parpia B, Campbell TC. Dietary intakes and urinary excretion of calcium and acids: A cross-sectional study of women in China. Am J Clin Nutr 1993;58:396-406.
43. Farwell WR, Taylor EN. Serum bicarbonate, anion gap and insulin resistance in the National Health and Nutrition Examination Survey. Diabet Med 2008;25:798–804.
44. Jehle S, Zanetti A, Muser J, Hulter HN, Krapf R. Partial neutralization of the acidogenic Western diet with potassium citrate increases bone mass in postmenopausal women with osteopenia. J Am Soc Nephrol. 2006;17:3213-22.
45. Gyorke ZS, Sulyok E, Guignard JP. Ammonium chloride metabolic acidosis and the activity of renin-angiotensin-aldosterone system in children. Eur J Pediatr. 1991;150:547-9.
46. Sartorius OW, Roemmelt JC, Pitts RF, Calhoon D, Miner P. The renal regulation of acid-base balance in man. The nature of the renal compensations in ammonium

chloride acidosis. J Clin Invest. 1949;28: 423-39.
47. Sulyok E, Guignard JP. Effect of ammonium-chloride-induced metabolic acidosis on renal electrolyte handling in human neonates. Pediatr Nephrol. 1990;4: 415-20.
48. Christiansen JS, Parving HH. The relationship between kidney size and function in short-term diabetic patients. Diabetologia. 1982;22:494.
49. Inomata S. Renal hypertrophy as a prognostic index for the progression of diabetic renal disease in non-insulin-dependent diabetes mellitus. J Diabetes Complications. 1993;7:28-33.

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