Alimentary Pharmacology & Therapeutics

Systematic review: the effects of carbonated beverages on gastro-oesophageal reflux disease

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Publication data
Submitted 6 November 2009
First decision 29 November 2009
Resubmitted 31 December 2009
Accepted 3 January 2010
Epub Accepted Article 4 January 2010

This uncommissioned systematic review was subject to full peer-review.

SUMMARY

Background
Carbonated beverages have unique properties that may potentially exacerbate gastro-oesophageal reflux disease (GERD), such as high acidity and carbonation. Cessation of carbonated beverage consumption is commonly recommended as part of lifestyle modifications for patients with GERD.

Aims
To evaluate the relationship of carbonated beverages with oesophageal pH, oesophageal motility, oesophageal damage, GERD symptoms and GERD complications.

Methods
A systematic review.

Results
Carbonated beverage consumption results in a very short decline in intra-oesophageal pH. In addition, carbonated beverages may lead to a transient reduction in lower oesophageal sphincter basal pressure. There is no evidence that carbonated beverages directly cause oesophageal damage. Carbonated beverages have not been consistently shown to cause GERD-related symptoms. Furthermore, there is no evidence that these popular drinks lead to GERD complications or oesophageal cancer.

Conclusions
Based on the currently available literature, it appears that there is no direct evidence that carbonated beverages promote or exacerbate GERD.

Aliment Pharmacol Ther **31**, 607–614

doi:10.1111/j.1365-2036.2010.04232.x

INTRODUCTION

Man-made sparkling water was 'invented' in the mid to late 1700s in England, where scientist and clergyman Joseph Priestley suspended water above a vat of fermenting beer, producing carbon dioxide, which was then passively dissolved in the water. The effervescence was found by people to be pleasing. Presently, carbonated beverages are ubiquitous, commonplace and day-to-day drinks. They are a staple of the modern culinary repertoire, ranging from sparkling water to beer, soda pop or cola. Carbonated beverages, which include sodas, sparkling waters and beers, have unique properties. Although not necessarily common to all types of carbonated beverages, the principal properties of note are carbonation, acidity and high levels of sugar or artificial sweeteners. Carbonation, which produces the characteristic effervescence and bubbling associated with these drinks, is the result of dissolving gaseous CO_2 in a liquid under pressure. Temperature and pressure influence the rate at which dissolved carbon dioxide converts into gas and is released, thus producing bubbles when a beverage container is opened. Acidity is a common chemical property of many carbonated beverages. Colas, sodas and beers are known to be among the most acidic beverages consumed in modern society. In part, 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. Sugars and artificial sweeteners are added to many carbonated beverages, such as sodas, to impact a sweet taste, while beverages like beer have other forms of carbohydrate used in the fermentation process. Sugars and other carbohydrates add calories and increase the osmolality of the beverage. Artificial sweeteners provide a sugary taste without increasing the caloric content of the beverage. Other additives such as caffeine and alcohol may also be present, depending on the type of beverage, and may have unique or synergistic effects on the gastrointestinal tract. These will not be discussed in this review.

The effects of carbonated beverages on the human body have been the centre of much attention in the last decade, specifically, the consequences of carbonation, acid load and high carbohydrate consumption. Several studies have suggested that carbonated beverages may exacerbate GERD, dyspepsia and bloating.[1] In addition, high consumption of sweetened carbonated beverages has been linked to the increased body mass index (BMI) and obesity epidemic.[2] Obesity and elevated BMI have in turn been associated with increased frequency and severity of GERD-related symptoms and oesophageal mucosal injury.[3–6] The rate of soft drink consumption is at an all time high in the United States for both youth and adults (Table 1 and Figure 1). Recent statistics also suggested that daily calories from fruit and soda drinks have tripled since the mid 1970s, significantly contributing to increased daily calorie consumption and weight gain.[7, 8]

Cessation of carbonated beverage consumption is commonly recommended as part of lifestyle modifications for patients with GERD.[9] Thus far, it has been assumed that carbonated beverages can exacerbate GERD. Consequently, the aim of this systematic review is to determine the impact of carbonated beverages on GERD. Overall, this systematic review will provide a summary of the recent published literature and thus elucidate the role of carbonated soft drinks on GERD and its associated symptoms as well as complications.

METHODS

We conducted a systematic review of the medical literature to identify original studies evaluating a potential relationship between GERD and carbonated beverages. We searched Ovid Medline, Cochrane Library, Web of Science, BIOSIS Previews, and CINAHL (Cumulated Index to Nursing and Allied Health Literature) for English-language articles that were published between

Table 1. Daily beverage consumption among men and women aged 20–39 years according to data from the National Health and Nutrition Examination Survey (NHANES) 1999–2002[8] (used with permission)

Variable	Men 20–39 years	Women 20–39 years
Fruit juice (g)	97.8	85.2
Coffee (g)	225.4	163.2
Tea (g)	193.9	143.5
Milk products (g)	178.6	146.8
Regular fruit drinks/ades (g)	100.4	82.3
Low-energy fruit drinks/ades (g)	42.2	20.7
Regular carbonated soft drinks (g)	637.9	430.2
Diet carbonated soft drinks (g)	96.9	108.1
Energy from nonbeverage sources (kcal)	2224.0	1649.0
Energy from beverage sources (kcal)	629.9	381.4
Sample size	1372	1845

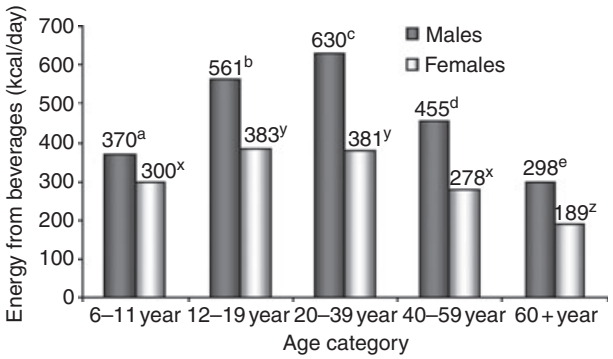

Figure 1. Estimated average daily energy intake from beverages in the National Health and Nutrition Examination Survey 1999–2002 by males and females (kcal/day). The numbers above the bars represent the mean energy (kcal/day) from beverages for that age category. Bars within gender sharing a common superscript (a, b, c, d, e and x, y, z) are not statistically distinguishable from one another at the $P = 0.05$ level (used with permission).[8]

1965 and 2009. To be included in the systematic review, we required that studies be fully published articles including at least 1 search term related to oesophageal diseases and another search term related to carbonated beverages. We included studies that described a potential relationship between carbonated beverages and heartburn by any methodology including oesophageal pH monitoring, manometric analysis, symptom survey, or other methodology as reported in Table 2.

The terms included in the bibliographic search were oesophageal diseases, indigestion, GERD or GORD, esophagitis, reflux, heartburn, regurgitation, oesophageal cancer, Barrett's oesophagus, oesophageal stricture and soda, soft drink, sparkling, cola, pop, pepsi, coke, mountain dew, carbonated beverages, beverages, carbonation, carbonated or carbon dioxide. Additional articles were identified through manual search and from other doctors and experts in the field.

RESULTS

We identified 393 records through database searching including 87 from BIOSIS Previews, 24 in CINAHL, 34 from Cochrane Library, 132 in Ovid Medicine, and 101 in the Web of Science. Thirteen additional articles were obtained that did not appear in the search. We screened 346 records and identified 29 full-text relevant articles. Twelve articles were excluded for the following reasons: (1) article did not cover the subject matter ($N = 3$); (2) article did not present data ($N = 6$); (3) article described treatment of GERD with cola ($N = 1$); (4) article described effect of soft drinks on dental erosions ($N = 2$). Overall, 17 published studies were included in the review (Figure 2).

Effect of carbonated beverages on oesophageal pH

Given the fact that many carbonated beverages are highly acidic, alterations in intra-oesophageal pH that can result in GERD-like symptoms have been of major concern (see Table 3). In addition, carbonated beverages may serve as an acid load and thus may raise gastric acid volume, leading to increased likelihood of gastro-oesophageal reflux. Two studies have demonstrated that carbonated beverages can reduce the oesophageal pH < 4 and potentially cause GERD-related symptoms. By using oesophageal impedance and pH in normal subjects, Agrawal *et al.* compared lemonade, strawberry juice, white wine, red wine, ketchup, apple juice, orange juice, coffee and tea with carbonated beverages.[10] The authors demonstrated that consumption of carbonated beverages resulted in the lowest intra-oesophageal pH (1.9). However, while the drop in intra-oesophageal pH was immediate, it lasted only 90 s on an average, which was the shortest period as compared with the other consumed beverages. The authors also found, from 100 patient diaries, that carbonated beverages are the most commonly consumed acidic food (45%) as compared with the other products. Shoenut *et al.* demonstrated that while acidic beverages altered intra-oesophageal pH, the effect was temporary and not long lasting.[11] The total time pH < 4 during consumption of cola (7.7 ± 6.0 min) was significantly longer than for beer (3.3 ± 3.7 min), tea/coffee (1.4 ± 6.5 min) and water (1.1 ± 25 min). Although cola and juice in this study had the greatest impact on intra-oesophageal pH, the effect did not exceed 0.5% of the entire 24-h pH study. Thus, the authors of this study concluded that the impact of cola (as well as other acidic fluids) on intra-oesophageal pH is so minimal that their effect could be disregarded in most patients.

Carbonated beverages have been shown to increase postprandial oesophageal acid exposure.[12] However, only alcoholic carbonated beverages were studied, and thus it remains unclear if it is the alcohol or the carbonation that causes an increase in oesophageal acid exposure.

Table 2. Characteristics of the studies included in the systematic review

Year	Author	Subjects	Study type	Main outcomes
1991	Zachwieja *et al.*[15]	Subjects during exercise (N = 15)	Prospective gastric analysis	Gastric volume
1992	Zachwieja *et al.*[14]	Male cyclists (N = 8)	Prospective gastric analysis & survey	Gastric volume, dyspeptic symptoms
1995	Feldman and Barnett[23]	Subjects with GERD (N = 394) and without GERD (N = 69)	*In vitro* studies; prospective questionnaire	Osmolality, GERD symptoms
1997	Pouderoux *et al.*[18]	Healthy volunteers (N = 8)	Prospective, gastric emptying	Radionuclide gastric emptying
1998	Shoenut *et al.*[11]	GERD (N = 82)	Prospective pH monitoring	Total time oesophageal pH<4
1999	Kapicioglu *et al.*[19]	Healthy rats (N = 20)	Prospective pathological analysis	Post-mortem pathological analysis
1999	Oliveria *et al.*[21]	GERD subjects (N = 2000)	Prospective survey	GERD symptoms
2002	Cuomo *et al.*[17]	Patients with dyspepsia (N = 21)	RCT, gastric emptying	Dyspepsia score, satiety test by a liquid meal, radionuclide gastric emptying
2005	Agrawal *et al.*[10]	Healthy volunteers (N = 10)	Prospective (N = 10) Retrospective (N = 100) pH monitoring	Oesophageal pH-impedance
2005	Fass *et al.*[20]	Subjects with nocturnal GERD (N = 3806)	Prospective survey	GERD symptoms
2006	Hamoui *et al.*[13]	Healthy volunteers (N = 9)	Prospective manometry	LES resting pressure, relaxation, and length
2006	Lagergren *et al.*[24]	OAC (N = 189); controls (N = 820)	Retrospective case-control	Odds ratios of OAC
2006	Mayne *et al.*[25]	OAC (N = 282); control (N = 687)	Retrospective case-control	Odds ratios of OAC
2006	Pehl *et al.*[12]	GERD (N = 25)	Prospective pH monitoring	Time pH<4, total reflux episodes, reflux episode duration
2008	Cuomo *et al.*[16]	Healthy volunteers (N = 13)	Prospective pH monitoring	Oesophageal ph-impedance, octanoic acid breath test
2008	Dore *et al.*[22]	GERD (N = 300), controls (N = 200)	Prospective survey	GERD symptoms
2008	Ibiebele *et al.*[26]	OC (N = 857); controls (N = 1494)	Retrospective case-control	Odds ratios of OC

OAC, oesophageal adenocarcinoma; OC, oesophageal cancer.

The aforementioned studies have numerous limitations, as they did not assess intragastric volume or pH. In addition, the magnitude of carbonated beverage consumption is significantly different from one individual to another. Nevertheless, the impact of carbonated beverages on intra-oesophageal pH appears to be very limited.

The effect of carbonated beverages on upper gut motility

The effect of carbonated beverages on lower oesophageal sphincter (LES) tone has been evaluated by one study.[13] In this study, oesophageal manometry was performed in nine healthy volunteers after ingestion of tap water and different carbonated beverages (caffeinated and noncaffeinated Pepsi and carbonated water). All carbonated beverages produced at least a 20-min reduction of approximately 30–50% in lower oesophageal sphincter (LES) resting pressure, overall length, and intra-abdominal length. The authors postulated that the decrease in LES pressure is mediated by gaseous distention of the stomach because of the carbonation. The authors further proposed that the aforementioned effect of carbonated beverages on the LES is the underlying mechanism for heartburn in subjects consuming these drinks. However, the study was conducted in a small number of healthy subjects. In addition, the authors did not measure changes in

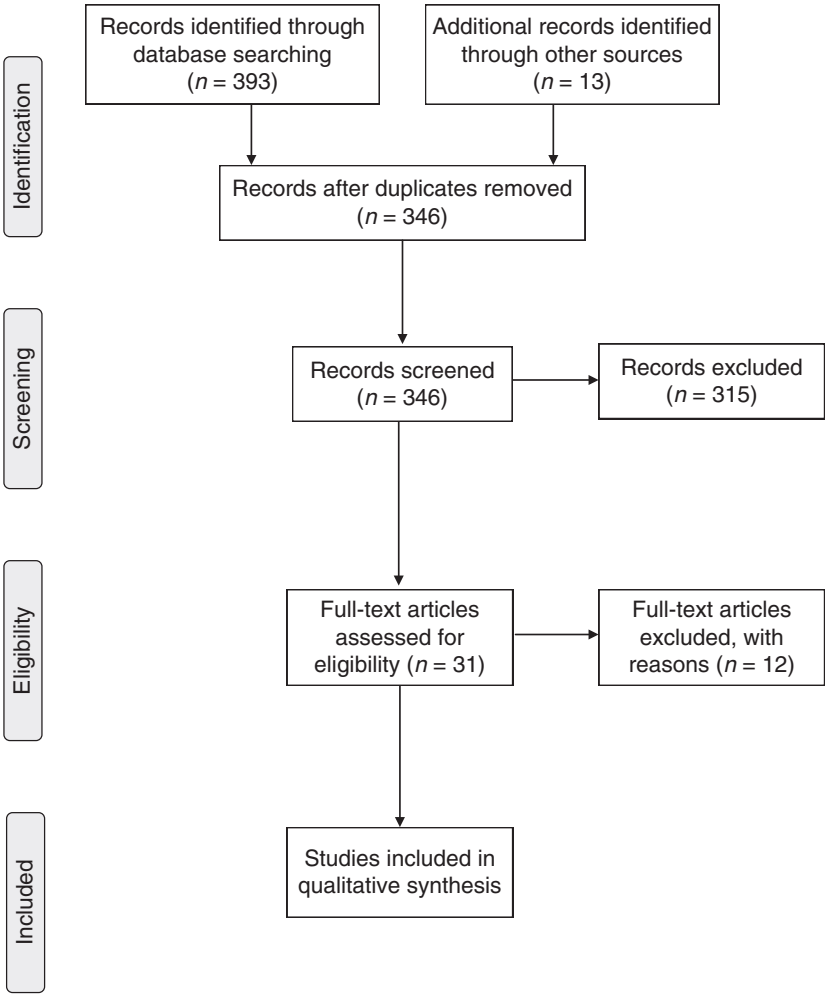

Figure 2. Flow diagram of literature search.

transient LES relaxation rate or demonstrated any evidence of increase in oesophageal acid exposure as a result of carbonated beverage consumption.

Table 3. The pH values of the different carbonated beverages[27]

RC Cola	2.4
Coke	2.5
Pepsi	2.5
Cherry Coke	2.5
Dr. Pepper	2.9
Squirt	2.9
Diet Pepsi	3.0
Mountain Dew	3.2
Diet Dr Pepper	3.2
7-Up	3.2
Diet Coke	3.3
Sprite	3.3
Diet Mountain Dew	3.4
Diet 7-Up	3.7
Mug Root Beer	4.0

Thus far, there are no studies that evaluated the effect of carbonated beverages on oesophageal body motor function. However, several studies evaluated the effect of carbonated beverages on gastric function. Overall, it does not appear that carbonated beverages alter gastric motility. In a study by Zachwieja *et al.*, eight male cyclists consumed four different beverages (carbonated, carbonated and sugary, noncarbonated and noncarbonated and sugary) during 120-min period of cycling.[14] Following each exercise, the content of each cyclist's stomach was aspirated. There was no difference in the retained volume after each of the beverages. The authors concluded that carbonated beverages have no impact on gastric emptying. These study results corroborated the results of an earlier study by the same authors in which there was no difference in gastric emptying characteristics of 20 exercising subjects who again were given different drinks including sugary carbonated and noncarbonated sports drinks as well as water and carbonated water.[15] In another study

by Cuomo *et al.*, 13 healthy subjects consumed 300 mL of either water containing increased concentrations of carbon dioxide or sweetened commercial flavoured drinks with and without carbon dioxide.[16] Thereafter, gastric emptying was assessed using octanoic acid breath test. The authors were not able to show any significant difference in gastric emptying among all beverages studied. Similar findings were documented by Cuomo and colleagues in an earlier study.[17] In that study, 22 patients with dyspepsia and secondary constipation underwent gastric emptying assessment after consuming carbonated water or tap water for almost 15 days. Water without carbonation demonstrated a shorter gastric emptying duration, but it did not reach statistical significance.

Lastly, Pouderoux *et al.* compared the gastric emptying time of a radio-labelled meal in eight healthy volunteers who also consumed either distilled or carbonated water.[18] The authors found no significant difference in gastric emptying of both solids and liquids, including the duration of the lag phase between the two drinks. However, there was a greater retention of food (both solids and liquids) in the proximal stomach with carbonated water as compared with distilled water. There was retention of the meal within the proximal stomach, which ended with the lag phase and was likely related to proximal gastric distention. The authors concluded that gastric distention by liberated CO_2 from carbonation was not associated with alteration in overall gastric emptying, but more with modification of intragastric distribution of a meal.

Overall, the aforementioned studies demonstrated that consumption of a carbonated beverage with a meal does not significantly alter gastric emptying.

Oesophageal damage

It has been hypothesized that chronic, repetitious ingestion of carbonated, highly acidic beverages might cause oesophageal mucosal damage that can potentially lead to chronic oesophageal inflammation and even cancer. Presently, there are very little data to support or contradict this hypothesis. Rats that were exposed to either cola or saline demonstrated no evidence of oesophageal histopathological abnormalities.[19] However, the rats that were exposed to cola demonstrated a higher regenerative index by flow cytometry than those exposed to saline, suggesting some irritating effect.

Despite the high consumption of acidic carbonated beverages, there are no studies clearly demonstrating an increased risk for oesophageal mucosal injury in the form of oesophagitis, oesophageal ulceration or even oesophageal stricture. Part of the explanation is likely due to the unique capability of oesophageal mucosa to withstand acid even in very high concentrations.

Carbonated beverages and GERD symptoms

Overall, carbonated beverages have not been consistently shown to cause GERD-related symptoms.[1] Fass *et al.* have demonstrated that consumption of carbonated beverages increased the risk of having heartburn that awakens subjects from sleep during the night by 24% (OR 1.24 95% CI 1.07–1.45).[20] In contrast, several population-based studies were unable to demonstrate any relationship between GERD-related symptoms and carbonated beverage consumption.[21, 22] Furthermore, a systematic review of lifestyle modifications for GERD could not find even one study that evaluated the effect of cessation of carbonated beverage consumption on GERD-related symptoms.[9] Consequently, the authors were unable to make any evidence-based recommendation related to carbonated beverage consumption.

The relationship between acidity and osmolality of various beverages and their propensity to cause GERD symptoms was evaluated by Feldman and Barnett.[23] The authors studied 11 different carbonated beverages as well as citrus drinks and juices, alcoholic beverages and milk. The authors surveyed participants who rated

Table 4. Prevalence of frequent heartburn reported with carbonated beverages[23] (used with permission)

Beverage	% with frequent heartburn
Diet Dr Pepper	21.1
Coca Cola	20.8
Pepsi Cola	19.8
Dr Pepper	19.3
Diet Coke	15.9
Diet Pepsi	15.3
Diet 7-Up	13.7
Root beer	13.3
Mountain Dew	12.3
Sprite	12.3
7-Up	10.1

frequency of heartburn symptoms associated with specific drinks. Of those who returned the questionnaire, between 10% and 19.8% reported frequent heartburn with consumption of the different carbonated beverages (see Table 4). Of the soft drinks studied, Diet Dr Pepper was the most commonly associated with heartburn (21.1%) and 7UP the least (10.0%). The frequency of reported heartburn symptoms was not different between diet and regular carbonated beverages. The authors also found that osmolality of the beverage was not an important factor in determining association with GERD-related symptoms. Unfortunately, the authors of this study did not evaluate sparkling water alone. That would have allowed the determination if carbonation *per se* is responsible for subjects' heartburn.

Presently, there are very few studies supporting the role of carbonated beverages in causing heartburn or any other GERD-related symptom. Despite the general impression that carbonated beverages are strongly associated with gastro-oesophageal reflux disease, the literature lacks clear data to support this notion. As the consumption of carbonated beverages continues to be highly popular, a prospective trial should determine if carbonated beverages are a significant risk factor for GERD symptoms.

Carbonated beverages and GERD complications

Currently, there are no studies demonstrating any relationship between carbonated beverage consumption and complications of GERD such as oesophageal ulcers, peptic stricture, or Barrett's oesophagus. However, three studies did evaluate carbonated beverage consumption and risk for oesophageal malignancy. In a study by Lagergren *et al.*[24] that utilized Swedish nationwide population-based data, the authors demonstrated that frequency of intake of carbonated soft drinks was not associated with increased risk of oesophageal or cardia adenocarcinoma. However, high consumers (>6 time a week) were at a statistically nonsignificant decreased risk compared with newer users. In a U.S multicentre, population-based, case-control study, the authors found that high carbonated soft drink consumption was not associated with increased risk of any oesophageal or gastric cancer subtypes in men or women.[25] In fact, the authors found an inverse relationship between carbonated soft drink consumption (especially diet) and the risk of oesophageal adenocarcinoma. Ibiebele and colleagues also could not find any relationship between consumption of carbonated beverages and the risk of either adenocarcinoma or squamous cell carcinoma of the oesophagus.[26] The authors did demonstrate an inverse relationship between soda consumption and squamous cell carcinoma of the oesophagus (OR = 0.4, 95% CI 0.20–0.78).

Overall, it does not appear that carbonated beverage consumption is more commonly associated with severe GERD. Surprisingly, soda consumption appears to be protective against both adenocarcinoma and squamous cell carcinoma of the oesophagus through an unknown mechanism. Further support for the protective effect of soda against oesophageal cancer is needed from well-designed prospective trials.

CONCLUSIONS

This systematic review revealed that despite the increased consumption of carbonated beverages in the last few decades and their proposed relationship with GERD, studies that specifically evaluated their role in promoting acid reflux or reflux-related symptoms are relatively scarce. The currently available literature does not support a strong relationship between carbonated beverages and GERD. Thus far, there are only conflicting data about their role in generating GERD-related symptoms and apparently no evidence that they directly cause oesophageal inflammation or GERD-related complications. Thus, it appears that there is no direct evidence that carbonated beverages promote or exacerbate GERD. Consequently, sweeping recommendations for cessation of all carbonated beverages as part of lifestyle modifications should be re-evaluated. Regardless, sugary carbonated beverages have been blamed for their contribution to the obesity epidemic in westernized societies and may contribute to GERD through increase in BMI. Additional research is required to delineate further the role of these ubiquitous soft drinks in causing GERD.

ACKNOWLEDGEMENTS

Declaration of personal interests: Dr Ronnie Fass is a consultant for Takeda, Vecta, AstraZeneca, GSK, Eisai and XenoPort. He receives grant/research support from Takeda, Wyeth, Addex and AstraZeneca and is a member of the speaker's bureau at Takeda and Eisai. Dr Lauren Gerson is a consultant for Takeda, Eisai and XenoPort and receives grant support from Santarus and XenoPort. Dr Timothy Johnson, Dr Tiberiu Hershcovici

and Mr Christopher Stave have no disclosures or competing interests. *Declaration of funding interests:* This manuscript was supported in part by The Coca-Cola Company in Portugal.

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