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Health risks of phosphoric acid in cola drinks

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Abstract
Cola is a sweetened carbonated soft drink flavored with *cola flavor*. The cola flavor is the signature flavor among carbonated soft drinks and is enormously popular worldwide. Cola flavor (including an acidic flavoring agent such as phosphoric acid) and sweeteners are the required ingredients for the production of colas. Other ingredients, such as color, caffeine and preservatives, are added (as needed) as complementary or auxiliary ingredients.
Phosphoric acid (also known as orthophosphoric acid) is a solid, non-toxic inorganic acid. The most common form of phosphoric acid is colorless, odorless 85% syrupy aqueous solution. Food-grade 85% phosphoric acid has a pH level below 1, meaning it should be distributed by licensed professionals and manufacturing staff who interact with this chemical should wear proper safety attire and equipment.
The American Beverage Association defines phosphoric acid as follows: "This flavoring agent in soft drinks is a preservative that provides tartness."
Numerous health risks due to the use of phosphoric acid in colas have been reported in the scientific literature. Careful review of the scientific literature shows that there are three major health risks associated with phosphoric acid in colas: risk to bone health, risk to kidney health and risk to teeth health. Consumers deserve to be informed about the presence of phosphoric acid in their cola drinks. It is reasonable to demand use of appropriate cautionary language about phosphoric acid on the labels of cola drinks.

Keywords: cola, cola drink, phosphoric acid, health risks, bone health, kidney health, teeth health

Introduction
According to a Market Research Report (2018) [11], the global carbonated soft drinks market was worth USD 392.6 billion in 2016. North America accounted for the major revenue share of 30.3%.
According to the report *Breaking Down the Chain: A Guide to the Soft Drink Industry* (2011) [1], soft drinks can be divided into six main segments: 1) carbonated soft drinks, 2) fruit beverages, 3) bottled waters, 4) functional beverages, 5) sport drinks and 6) others.
As the name implies, Carbonated Soft Drinks (CSD) or sparkling drinks are soft drinks that are carbonated. During the carbonation process, carbon dioxide (CO_2) gas under pressure is dissolved in the soft drink. Carbonation causes the drink to become effervescent. Carbonation increases in a solution as temperature decreases. The simplest CSD is carbonated (sparkling) water, also called seltzer.
The carbonated soft drink segment is broken down into two subsegments, colas and noncolas.
Cola is a sweetened carbonated soft drink flavored with *cola flavor*. The cola flavor is the signature flavor among carbonated soft drinks and is enormously popular worldwide. Cola flavor (including an acidic flavoring agent such as phosphoric acid) and sweeteners are the required ingredients for the production of colas. Other ingredients, such as color, caffeine and preservatives, are added (as needed) as complementary or auxiliary ingredients.

Material: Phosphoric Acid
- **General Properties**

Phosphoric acid (also known as orthophosphoric acid) is a solid, non-toxic inorganic acid. The most common form of phosphoric acid is colorless, odorless 85 % syrupy aqueous solution (Fig 1). Food-grade 85 % phosphoric acid has a pH level below 1, meaning it should be distributed by licensed professionals and manufacturing staff who interact with this chemical should wear proper safety attire and equipment. At moderate concentrations phosphoric acid solutions are irritating to the skin. Contact with concentrated solutions can cause severe skin burns and permanent eye damage.
The dominant use of phosphoric acid is for fertilizers which consume approximately 90% of its production. However, it is also used in soaps and detergents, food industry, water treatment and tooth pastes. Some specific applications of phosphoric acid include anti-rust treatment by phosphate conversion coating, phosphoric acid fuel cells, activated carbon production, and sanitizing agent in the dairy, food, and brewing industries.

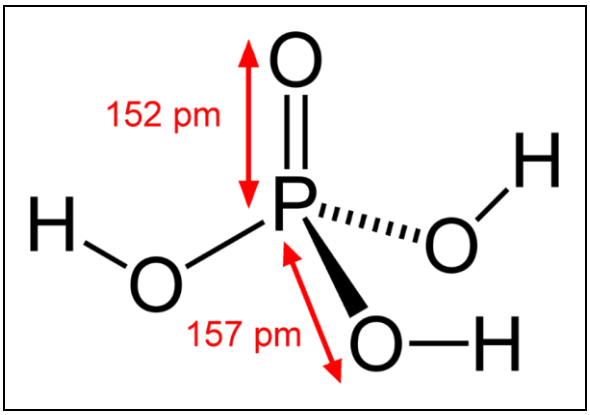


Fig 1: Phosphoric Acid Chemical Formula (H_3PO_4)

To produce food-grade phosphoric acid, phosphate ore is first reduced with a coal derivative in an electric arc furnace, to make elemental phosphorus. Elemental phosphorus is distilled out of the furnace and burned with air to produce high-purity phosphorus pentoxide (anhydride of phosphoric acid) which is dissolved in water to make phosphoric acid. The resultant phosphoric acid may be further purified by removing compounds of arsenic and other potentially toxic impurities.

- **Phosphoric Acid in Cola Drinks**

The American Beverage Association defines phosphoric acid as follows: "This flavoring agent in soft drinks is a preservative that provides tartness." It is known in the industry that phosphoric acid is used in colas as a flavor enhancer to provide a tangy or sour taste.

Ingredients of the following sixty-nine (69) brands of commercially available cola carbonated soft drinks were reviewed: Thirty-five (35) cola brands from the two leading companies *Coca-Cola* and *Pepsi* (including *SodaStream*) and thirty-four (34) cola brands from the third-position leader *Dr Pepper Snapple Group* (including *RC Cola* and *Diet Rite*), and *Hansen's Natural*, *Blue Sky*, *Zevia*, *Whole Foods*, *Fentimans*, *Faygo*, *Double Cola*, *Jarriots*, *Jolt Cola*, *Jones Soda* and *Sam's*. Phosphoric acid was found in 62 out of 69 (89.8%) brands of commercially available cola carbonated soft drinks (Table 1).

In the United States, phosphoric acid is a generally recognized as safe (GRAS) food substance when used in accordance with good manufacturing practice. In the European Union, phosphoric acid is a permitted food additive (E338) as an acidity regulator and chelating agent. Despite its regulatory status, numerous health risks due to the use of phosphoric acid in colas have been reported in the scientific literature. Mullen and Shield (2014) from Academy of Nutrition and Dietetics in a review titled "Hard Facts about Soft Drinks" concluded: "They provide essentially no key nutrients".

Table 1: Phosphoric Acid in Commercially Available Carbonated Cola Drinks

Acid (s)	Brands of Cola Drink
Phosphoric acid	29
Phosphoric acid + Citric acid	26
Phosphoric acid + Citric acid + Tartaric acid or Malic acid	5
Phosphoric acid + Tartaric acid or Malic acid or Lactic acid	2
Total	62

Method: Review of Health Risks of Phosphoric Acid

Consumers increasingly realize the role of foods and beverages in their health and therefore increasingly demand healthier and more nutritious foods and beverages. Sugar and phosphoric acid are considered to be the main undesirable ingredients in cola carbonated soft drinks. Although inexpensive and enjoyable, it is fair to say that educated consumers, nutritionists, dietitians, academic researchers and health authorities have a rather negative view of all sugary and most diet colas in the marketplace.

- **Risk to Bone Health**

Hintz (1980) in his article "calcium, cola, calamity" has reviewed some of the criticisms about soft drink industry and provides comments on the adverse effects of soft drink consumption on nutritional status. This researcher believes that soft drinks contain no nutrients other than sugar, whereas milk contains many nutrients. Thus, the substitution of soft drinks for milk results in great decreases of minerals, protein, and vitamins but calcium is a nutrient of particular concern because milk is the major source of calcium. Calcium inadequacy may be involved in the development of osteoporosis and periodontal disease. As far as acids in soft drinks (below pH 3.0) is concerned, Hintz refers to decry on ingestion of soft drinks by many patients, but especially those receiving antacid therapy for peptic ulcers. He also mentions earlier reports on erosion of teeth to be caused by cola drinks.

Mazariegos-Ramos *et al* (1995) [12] reported a case-control study on consumption of soft drinks with phosphoric acid as a risk factor for the development of hypocalcemia in children. A comparison of 57 cases (in children with serum calcium concentration < 2.2 mmol/L) and 171 controls (in children with serum calcium level > or = 2.2 mmol/L) was carried out to assess whether the intake of at least 1.5 L/week of soft drinks containing phosphoric acid is a risk factor for the development of hypocalcemia. A significant association was found: odds ratio = 5.27; 95% confidence interval, 3.17 to 8.75; $p < 0.001$.

Fernando *et al* (1999) [4] investigated the relationship between the consumption of phosphoric acid-containing soft drinks and hypocalcemia in postmenopausal women. A case control study was designed to include 21 cases and 64 controls, matched by age and menopausal duration with similar family income, scholarship, and daily dietary intakes. Clinical and dietetic conditions that may produce hypocalcemia were considered as exclusion criteria. Cases were defined as a serum Ca level < or = 8.8 mg/dl, and controls as a serum Ca level > 8.8 mg/dl. Women in the case group had a higher consumption of phosphoric acid-containing soft drink, and showed increased serum levels of PTH and hyperphosphaturia, than those in the control group without significant differences in 1,25 (OH) 2D3. In the multivariate regression analysis, consumption of one or more bottles per day of cola soft drinks showed association with hypocalcemia (1.28, CI 95% 1.06-1.53). The consumption of soft drinks with phosphoric acid should be considered as an independent risk factor for hypocalcemia in postmenopausal women.

Wyshak (2000) [20] explored the possible association between carbonated beverage consumption and bone fractures among teenaged girls. A cross-sectional (retrospective) study was done on four hundred sixty 9th- and 10th-grade girls attending the high school by completing a self-administered questionnaire relating to their physical activities and personal and behavioral practices. The girls' self-reports on physical activity, carbonated beverage consumption, and bone fractures were analyzed. In the total sample, carbonated beverage consumption and bone fractures are associated. Among physically active girls, the cola beverages, in particular, are highly associated with bone fractures.

McGartland *et al* (2003) [13] examined the relationship between carbonated soft drinks (CSD) consumption and bone mineral density (BMD) in a representative sample of adolescents. They conducted a cross-sectional observational study in 36 post-primary schools in Northern Ireland. Participants included 591 boys and 744 girls either 12 or 15 years old. BMD was measured by DXA, and usual beverage

consumption was assessed by the diet history method. These researchers concluded that CSD consumption seems to be inversely related to BMD at the dominant heel in girls. It is possible that the apparent association results from the displacement of more nutritious beverages from the diet. Although the inverse association observed between CSD consumption and BMD is modest and confined to girls, this finding may have important public health implications given the widespread use and current upward trend in CSD consumption in Western populations.

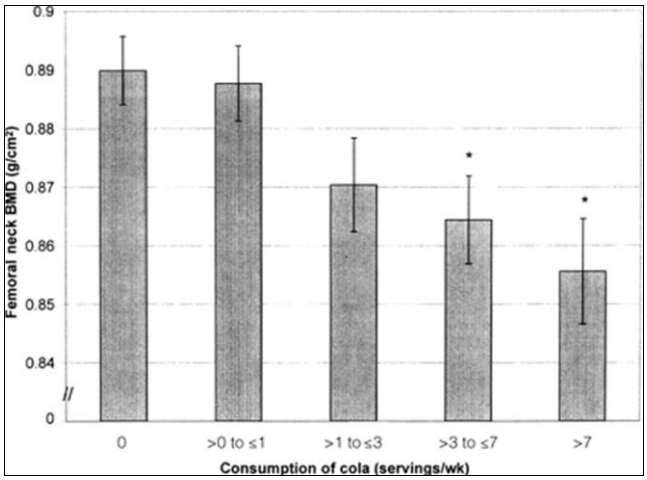
Kristensen *et al* (2005) [9] conducted a 10-day intervention study in young men on short-term effect of replacing milk with cola beverages on bone turnover. These investigators demonstrated that over a 10-day period high intake of cola with a low-calcium diet induces increased bone turnover compared to a high intake of milk with a low-calcium diet. Thus, the trend towards a replacement of milk with cola and other soft drinks, which results in a low calcium intake, may negatively affect bone health as indicated by this short-term study.

Tucker *et al* (2006) [19] noted that soft drink consumption may have adverse effects on Bone Mineral Density (BMD), but studies have shown mixed results. Colas contain caffeine and phosphoric acid which may adversely affect bone. These investigators hypothesized that consumption of cola is associated with lower BMD. They measured BMD at the spine and 3 hip sites in 1413 women and 1125 men in the Framingham Osteoporosis Study by using dual-energy X-ray absorptiometry. Dietary intake was assessed by food-frequency questionnaire. They regressed each BMD measure on the frequency of soft drink consumption for men and women after adjustment for body mass index, height, age, energy intake, physical activity score, smoking, alcohol use, total calcium intake, total vitamin D intake, caffeine from noncola sources, season of measurement, and, for women, menopausal status and estrogen use. They found that cola intake was associated with significantly lower ($P < 0.001$-0.05) BMD at each hip site, but not the spine, in women but not in men. The mean BMD of those with daily cola intake was 3.7% lower at the femoral neck and 5.4% lower at Ward's area than of those who consumed <1 serving cola/mo. Similar results were seen for diet cola and, although weaker, for decaffeinated cola. No significant relations between noncola carbonated beverage consumption and BMD were observed. Total phosphorus intake was not significantly higher in daily cola consumers than in non-consumers; however, the calcium-to-phosphorus ratios were lower. They concluded that intake of cola, but not of other carbonated soft drinks, is associated with low BMD in women (Fig 2).

Calvo and Tucker (2013) [2] asked if the phosphorus intake that exceeds dietary requirements is a risk factor in bone health because phosphorus intake in excess of the nutrient needs of healthy adults is thought to disrupt hormonal regulation of phosphorus, calcium, and vitamin D, contributing to impaired peak bone mass, bone resorption, and greater risk of fracture. These researchers concluded that there is accumulating evidence that phosphorus added to the food supply may be contributing to the burden of osteoporosis in the population. Further work is needed to accurately quantify the effects of exposure to differential phosphorus sources in the diet. The example of cola as a source of added phosphorus without the associated nutrients usually found in pure food dietary sources suggests that this is an important consideration for bone health and fracture prevention.

Fung *et al* (2014) [5] examined the association of soda, including specific types of soda, and risk of hip fracture in postmenopausal women. An analysis was conducted in postmenopausal women from the Nurses' Health Study cohort (n = 73,572) and RRs was computed for hip fractures by the amount of soda consumption by using Cox proportional hazards models with adjustment for potential confounders. These investigators concluded that increased soda consumption of all types may be associated with increased risk of hip fracture in postmenopausal women; however, a clear mechanism was not apparent on the basis of these observational data.

Kim and Yoo (2020) [8] aimed to elucidate the relationship between cola consumption and bone mineral density (BMD) in Korean adolescents and young adults. A total of 2499 adolescents and young adults aged 12–25 years were included. The study participants were classified as cola drinkers and non-cola drinkers according to 24-h dietary recall data. BMD was measured using dual X-ray absorptiometry. In the male population, whole body, whole femur and femoral neck BMD in cola drinkers were lower than that of noncola drinkers by 4% (95% CI −0·071, −0·007), 5% (−0·092, −0·012) and 5% (−0·090, −0·001), respectively. In both sex groups, cola drinkers had less frequent milk consumption than non-cola drinkers. However, there were no significant differences in cola consumption according to calcium intake in both sexes. In conclusion, cola intake and BMD were inversely associated with Korean male adolescents and young adults. Considering the importance of peak bone mass attainment at adolescents and the increasing trend in carbonated beverage consumption in South Korea, further studies are needed to elucidate the causality between cola intake and lower BMD.



(Source: Tucker *et al*, 2006)

Fig 2: Femoral neck bone mineral density versus total cola intake in women

- **Risk to Kidney Health**

Saldana *et al* (2007) [17] indicated that carbonated beverage consumption has been linked with diabetes, hypertension, and kidney stones, all risk factors for chronic kidney disease. They mentioned that cola beverages, in particular, contain phosphoric acid and have been associated with urinary changes that promote kidney stones. These researchers examined the relationship between carbonated

beverages (including cola) and chronic kidney disease, using data from 465 patients with newly diagnosed chronic kidney disease and 467 community controls recruited in North Carolina between 1980 and 1982. They found that drinking 2 or more colas per day was associated with increased risk of chronic kidney disease. Results were the same for regular colas and artificially sweetened colas. Noncola carbonated beverages were not associated with chronic kidney disease. They concluded that their preliminary results suggest that cola consumption may increase the risk of chronic kidney disease.

Santucci *et al* (2010) [18] reported a case of severe delayed methotrexate (chemotherapy agent and immune system suppressant) elimination attributable to consumption of a cola beverage. They investigated unexplained low urinary pH in a lymphoma patient treated with high-dose methotrexate and found unexpected urinary acidity, despite administration of large amounts of sodium bicarbonate, could be attributed to repeated consumption of a cola beverage which resulted in a delayed elimination of methotrexate and acute renal failure. Discontinuation of cola drinks, increase in calcium folinate rescue and in sodium bicarbonate allowed satisfactory elimination of methotrexate on day 12 after infusion and recovery from renal impairment without other severe toxicity. No other cause of delay in methotrexate elimination could be identified. These medical investigators concluded that cola beverages have a low pH due to their phosphoric acid content that is excreted by renal route. They recommended patients receiving high dose methotrexate abstain from any cola drink within 24 hr. before and during methotrexate administration and until complete elimination of the drug.

Lin and Curhan (2011) [10] explored how sugar or artificially sweetened soda may be related to kidney function decline on 3318 women participating in the Nurses' Health Study with data on soda intake and albuminuria. The results showed consumption of ≥ 2 servings per day of artificially sweetened (diet) soda was independently associated with estimated Glomerular Filtration Rate (eGFR) decline ≥ 30% and ≥ 3 ml/min per 1.73 m^2 per year. No increased risk for eGFR decline was observed for <2 servings per day of diet soda. These researchers concluded that consumption of ≥ 2 servings per day of artificially sweetened soda is associated with 2-fold increased odds for kidney function decline in women.

A Clinical Practice Guideline from the American College of Physicians on Dietary and Pharmacologic Management to Prevent Recurrent Nephrolithiasis (kidney stone) in Adults (Qaseem *et al* 2014) [15] has the following clinical consideration: "*Evidence showed that patients who decreased intake of soda that was acidified by phosphoric acid had reduced kidney stone recurrence. Clinicians should encourage patients to avoid colas as opposed to fruit-flavored soft drinks, which are often acidified by citric acid.*"

- **Risk to Teeth Health**

Harding *et al* (2003) [6] conducted a cross sectional study in 202 5-year-old Irish school children to examine dental erosion and associated factors. They found the prevalence of dental erosion overall was 47%, in 21% erosion affected the dentine or pulp. Levels in fluoridated and non-fluoridated areas were similar. Low socio-economic status and frequency of fruit squash and carbonated drink consumption were associated with erosion extending to dentine or pulp.

Cheng *et al* (2009) [3] reported a case of dental erosion and severe tooth decay related to soft drinks. The inherent acids and sugars in soft drinks have both acidogenic and cariogenic potential, resulting in dental caries and potential enamel erosion. In this report, they presented a 25-year-old man complaining with the severe worn-out of the front teeth during the past 3 years. He had a history of drinking cola for more than 7 years and had a poor oral hygiene. Severe decays were present in the incisors and the canines, while less severe lesions were noted on the premolars and the molars. Their review is to show the relationship between dental erosion and caries and soft drinks.

Reddy *et al* (2016) [16] defines dental erosion as chemical dissolution of tooth structure in the absence of bacteria when the environment is acidic (pH < 4.0). Their research indicates that low pH is the primary determinant of a beverage's erosive potential. In addition, citrate chelation of calcium ions may contribute to erosion at higher pH. The authors purchased 379 beverages from stores and assessed their pH. They found that 93% beverages had a pH of less than 4.0, and 7% had a pH of 4.0 or more. Relative beverage erosivity zones based on studies of apatite solubility in acid indicated that 39% of the beverages tested in this study were considered extremely erosive (pH < 3.0), 54% were considered erosive (pH 3.0 to 3.99), and 7% were considered minimally erosive (pH ≥ 4.0). Comprehensive pH assessment of commercially available beverages in the United States by these researchers shows that most are potentially erosive to the dentition. These researchers believe that specific dietary recommendations for the prevention of dental erosion may now be developed based on the patient's history of beverage consumption.

Conclusion

The above literature review showing that phosphoric acid in cola drinks is a risk factor to the health of bones, kidneys and teeth cannot be ignored. Consumers deserve to be informed about the presence of phosphoric acid in their cola drinks. It is reasonable to demand use of appropriate cautionary language about phosphoric acid on the labels of cola drinks.

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