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The pH of bottled water commercially available in Australia and its implications for oral health

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ABSTRACT

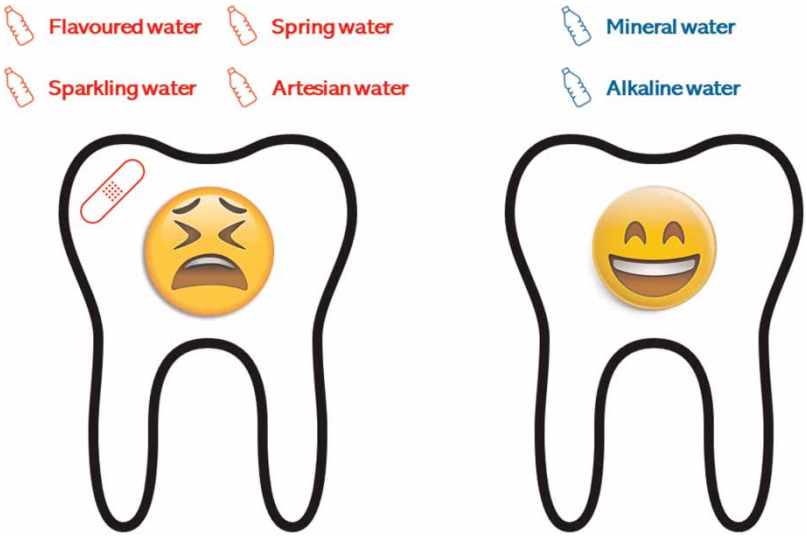
With a higher pH level and being unlikely to erode the tooth, bottled water has been considered a safe alternative to acidic beverages. However, recent studies have reported some bottled water products in different countries to be acidic. The present paper aimed to examine the pH values of 42 bottled waters commercially available in Australia, using a pH meter and probe, and classify their risks to cause erosive tooth wear in comparison with the critical pH of enamel and dentine. Of the 42 bottled water samples collected, 81.0 and 73.8% were considered erosive to tooth dentine and enamel, respectively. Flavoured waters were the most acidic, followed by sparkling waters, spring waters, artesian waters, mineral waters, and alkaline waters. All sparkling waters and flavoured waters showed an erosive risk to the enamel and dentine. A portion of spring waters and artesian waters was also acidic enough to erode tooth structures. The findings of this work were of concern given the risk of sustaining erosive tooth wear from consuming bottled waters. Health promotion strategies including public awareness and education on oral health consequences related to the consumption of bottled water are needed. Future epidemiological and *in vivo* investigations are also warranted.

Key words: Australia, bottled water, erosive tooth wear, oral health, pH

HIGHLIGHTS

- The majority of bottled waters sold in Australia could result in erosive tooth wear.
- Flavoured waters were the most acidic bottled water products.
- Awareness and knowledge of oral health consequences related to bottled water consumption is relevant.

GRAPHICAL ABSTRACT



Bottled water, or so-called packaged water, is defined as '*a food for sale that consists of water presented in packaged form*'. Under the Australian standards, spring water, mineral water, sparkling water, and flavoured water are all included in the classification of bottled water (Australian Government Department of Health 2017), while the United States Food and Drug Administration (2022) excludes sparkling water and flavoured water from bottled water. During the past decade, the decline in the consumption of sugar-sweetened beverages accompanied an increasing trend of drinking plain water, with more than 20% of total fluid intakes from commercially available bottled water (Vieux *et al.* 2020). Compared with the consumption of other unimproved water sources and tap water, drinking bottled water could lower the risk of diarrhoea (Komarulzaman *et al.* 2019) and water lead exposure (Pieper *et al.* 2019). Nevertheless, a higher prevalence of dental caries (tooth decay) in children who have regularly consumed bottled water has also been reported (El Mir *et al.* 2020).

Unlike dental caries, erosive tooth wear is the loss of tooth substance caused by chemical dissolution without bacterial involvement (Schlueter *et al.* 2020). The manifestations of erosive tooth wear, including softened tooth surfaces and hypersensitivity, often require dental attention (Kaidonis *et al.* 2018). When the pH of the oral environment drops to 5.5 or below, tooth enamel (the outermost tissue of tooth structure) begins to dissolve (Harper *et al.* 2021). Furthermore, the critical pH for exposed dentine (the tooth substance underneath the enamel) is as high as 6.7 (Surmont & Martens 1989). Because the pH values of bottled waters recently tested in Kuwait (Al-Qallaf & Alali 2022) and Romania (Dippong *et al.* 2020) were all greater than or equal to 6.7, which would not demineralise tooth dentine and enamel, the suggestion to drink bottled water such as sparkling or still mineral water as a safe alternative to acidic beverages seemed reasonable (Parry *et al.* 2001).

On the contrary, the pH values of bottled waters (including flavoured waters, sparkling waters, and mineral waters) available on the American market ranged from 2.7 to 6.1 (Reddy *et al.* 2016), which are far below the critical pH of enamel and dentine. Approximately 60% of bottled mineral waters sold in Portugal also had a pH between 5.4 and 6.6 (Morgado *et al.* 2019). Moreover, Chile (Daniele *et al.* 2019) and Malawi (Chidya *et al.* 2019) have a bottled water product of pH 5.7. These pH values are safe for enamel but harmful to the dentine exposed to the oral environment due to tooth wear or inadequate restorations (Surmont & Martens 1989). These data were of concern given the risk of erosive tooth wear from consuming bottled waters. With limited global data on this subject after 2015 and a lack of Australian data over a decade, there was a critical need to evaluate the potential risk of bottled water on the occurrence of erosive tooth wear in Australia.

Previously we have reported the pH values of Australian non-alcoholic beverages (Schmidt & Huang 2020). To extend the recently published research, the present work extracted the data of 42 different brands of bottled water according to the definition specified in the Australia New Zealand Food Standards Code (Australian Government Department of Health 2017), and categorised the bottled water samples as alkaline waters, artesian waters, mineral waters, spring waters, sparkling waters, and flavoured waters. Using the criteria different from our previous effort, the risks of each bottled water to demineralise

tooth structures were presented in relation to the critical pH for enamel (Harper *et al.* 2021) and dentine (Surmont & Martens 1989). Also, we discuss the implications of drinking bottled water for oral health.

The bottled waters were examined at 22 °C, with a temperature calibrated benchtop pH meter and probe (Eutech™ pH 700, Thermo Fisher Scientific, Waltham, MA, USA) using Certipur buffer solutions (pH 10, 7, and 4 Buffer Solutions, Certipur®). The pH of each sample was tested three times immediately after the bottle was opened. The probe was cleaned using neutral water and Kimwipes™ between samples (Kimwipes™, Kimtech Science™). Calibration was verified using Certipur buffer solutions every five samples.

The mean pH of each bottled water tested ranged from 2.62 to 10.29, with an average pH of 4.69 among the 42 products. Thirty-four (81.0%) and 31 (73.8%) of 42 bottled waters were erosive to tooth dentine (pH<6.7) and enamel (pH<5.5), respectively (Table 1). Overall, flavoured waters were the most acidic (mean pH=3.30), followed by sparkling waters

Table 1 | Mean pH and erosive potential of the tested bottled waters (*n*=42)

Product type and name	pH[a]	Erosive risk	
		Enamel[b]	Dentine[c]
Sparkling waters			
Schweppes® – Raspberry Sparkling	2.62 ± 0.00	+	+
Schweppes® – Indian Tonic	2.63 ± 0.01	+	+
Woolworths® – Tonic	2.68 ± 0.00	+	+
Woolworths® – Diet Tonic	2.71 ± 0.01	+	+
Schweppes® – Lime Sparkling (SF)	2.97 ± 0.01	+	+
Waterfords® – Lite and Fruity Sparkling Lemon Lime Bitters	3.10 ± 0.00	+	+
Schweppes® – Diet Indian Tonic	3.19 ± 0.01	+	+
Waterfords® – Lite and Fruity Sparkling Apple Berry	3.26 ± 0.01	+	+
Waterfords® – Lite and Fruity Sparkling Tahitian Lime	3.39 ± 0.01	+	+
Mount Franklin® – Sparkling Wild Berry	3.76 ± 0.01	+	+
Mount Franklin® – Sparkling Raspberry and Lemon	3.95 ± 0.01	+	+
Mount Franklin® – Lightly Sparkling	4.00 ± 0.01	+	+
Mount Franklin® – Lightly Sparkling Lime	4.03 ± 0.01	+	+
Mount Franklin® – Lightly Sparkling Lemon	4.12 ± 0.01	+	+
Woolworths® – Soda Water	4.24 ± 0.01	+	+
Icelandic® – Glacial Sparkling	4.33 ± 0.01	+	+
Woolworths® – Lightly Sparkling Lemon (SF)	4.38 ± 0.01	+	+
Woolworths® – Lightly Sparkling	4.48 ± 0.01	+	+
Schweppes® – Soda Water	5.14 ± 0.01	+	+
Flavoured waters			
Schweppes® – Lemon Water	3.03 ± 0.00	+	+
Gatorade® – Active Electrolyte Lemon (SF)	3.21 ± 0.01	+	+
Gatorade® – Active Electrolyte Orange (SF)	3.25 ± 0.01	+	+
Cool Ridge® – Restore Raspberry and Blueberry Flavour	3.30 ± 0.01	+	+
Cool Ridge® – Immunity Blood Orange and Lemon Flavour	3.41 ± 0.01	+	+
Cool Ridge® – Revitalise Green Tea and Peach	3.44 ± 0.00	+	+
Gatorade® – Active Berry Water	3.44 ± 0.01	+	+
Spring waters			
Pump®	4.28 ± 0.01	+	+

(*Continued.*)

Table 1 | Continued

Product type and name	pH[a]	Erosive risk	
		Enamel[b]	Dentine[c]
Mount Franklin®	4.38 ± 0.01	+	+
Balance® – Cleanse	4.39 ± 0.01	+	+
Balance® – with Flower Essence	4.40 ± 0.01	+	+
Cool Ridge®	5.17 ± 0.00	+	+
Aroona® – Water	5.56 ± 0.01	–	+
Frantelle® – Water	6.28 ± 0.02	–	+
Woolworths® – Spring Water	6.90 ± 0.01	–	–
Thank You® – Water	6.92 ± 0.02	–	–
Icelandic Glacial® – Water	8.47 ± 0.02	–	–
Artesian waters			
Voss® – Water	6.02 ± 0.02	–	+
Fiji® – Water	7.15 ± 0.01	–	–
Mineral Waters			
Evian® – Water	7.41 ± 0.02	–	–
Acqua Panna® – Toscana Water	8.13 ± 0.00	–	–
Alkaline waters			
Aqua Love® – Water	9.18 ± 0.01	–	–
Alka Power® – Water	10.29 ± 0.02	–	–

[a]Mean ± standard deviation.
[b]pH<5.5.
[c]pH<6.7.

(mean pH=3.63), spring waters (mean pH=5.68), and artesian waters (mean pH=6.59). In comparison, mineral waters (mean pH=7.77) and alkaline waters (mean pH=9.74) were not acidic. All sparkling waters and flavoured waters showed an erosive risk to enamel and dentine. Five (50%) and seven (70%) spring waters were erosive to enamel and dentine, separately. One (50%) artesian water was considered erosive to dentine, but none was risky to enamel. None of the mineral waters and alkaline waters were erosive to enamel and dentine.

This paper has reported a high percentage of Australian bottled waters that had a potential risk to cause erosive tooth wear. This agreed with the recent data collected in Portugal (Morgado *et al.* 2019) and the USA (Reddy *et al.* 2016) but not with other studies (Chidya *et al.* 2019; Daniele *et al.* 2019; Dippong *et al.* 2020; Al-Qallaf & Alali 2022). Different types of bottled waters included in the present and past studies could be a reason for the diverse acidity reported. However, the pH of a beverage is the most relevant determinant of erosive potential (Cochrane *et al.* 2009). People should also bear in mind that pH 5.5 initiated the dissolution of tooth enamel and pH 4.0 resulting in a complete mineral loss *in vitro* (Harper *et al.* 2021). Almost 75% of the bottled waters tested in the present study were so acidic that they could dissolve enamel. Furthermore, the pH values of all flavoured waters and most sparkling waters including an unflavoured sparkling spring water were lower than or equal to 4.0, which could entirely remove the minerals from a tooth after 3 weeks of exposure. Also, in the absence of salivary protection, dental erosion would occur immediately at pH 3.0 (Mann *et al.* 2014). Thus, bottled waters should be consumed with some caution. They are still good for hydration, but sipping flavoured or sparkling waters over a long period of time should be avoided. This would also apply to unflavoured still waters of low pH.

The acidification of the bottled water products could be attributed to the filtration and disinfection processes carried out by manufacturers (Nir *et al.* 2015; World Health Organization 2017). The addition of food acids during the manufacturing process to create a likeable taste also acidifies the bottled waters (Reddy *et al.* 2016). It would be wise to include bottled water manufacturers together with the government and communities to develop health promotion strategies for erosive tooth wear and other health conditions related to acidic beverage consumption, such as laryngopharyngeal reflux (Lechien *et al.* 2020).

The first steps are to raise awareness and educate the public on health issues associated with the consumption of acidic beverages including bottled water, since raised awareness and better knowledge can help reduce unhealthy consumption behaviour (Schmidt & Huang 2022). Interprofessional collaboration among scientists, educators, and health professionals should also be encouraged to provide sound dietary information and enhance appropriate selection and consumption of bottled water products.

In conclusion, some bottled waters are as acidic as juices or soda soft drinks. Flavoured waters, sparkling waters, and some spring/artesian waters possess a risk to cause erosive tooth wear. Although acidification of bottled waters may be unavoidable during the manufacturing process, it is important to launch joint efforts with the manufacturers, government and communities to raise the public awareness of the oral health consequences and educate the public on healthy hydration. Future epidemiological and/or *in vivo* investigations into the erosive potential and other adverse health outcomes secondary to the consumption of bottled water are indicated.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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