Acta Odontologica Scandinavica, 2012; 70: 49–55

ORIGINAL ARTICLE

Effect of soft drinks on the physical and chemical features of nickel-titanium-based orthodontic wires

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Abstract

Objective. The purpose of this study was to evaluate the effect of three popular soft drinks on the Young's modulus, hardness, surface topography and chemical composition of widely used nickel-titanium-based orthodontic wires. ***Materials and methods.*** Thirty-two specimens (20 mm in length) were cut from the straight portion of pre-formed 0.019 × 0.025 inch Nitinol Heat-Activated archwires and randomly divided into four groups of eight specimens each: Group A1 (Coca Cola® regular); Group A2 (Santal® orange juice); Group A3 (Gatorade®); Group B (distilled, deionized water; dH_2O). Each specimen was immersed in 10 ml of one of the soft drinks or dH_2O, control, for 60 min, at 37°C. At the end of the soaking time, the Young's modulus and hardness were determined using a nanoindenter. Scanning Electron Microscope–Energy Dispersive Spectroscopy (SEM-EDS) was used to characterize the effects on the topography and chemical composition of the wires. ***Results.*** No statistically significant differences were found between the groups either in the Young's modulus or in hardness after the selected soaking protocol. Besides some surface colour changes, the topography and the chemical composition of the wires were not affected by the immersion in any of the chosen soft drinks. ***Conclusions.*** These *in-vitro* results suggest that the consumption of soft drinks cannot be acknowledged as one possible reason for the degradation of the physical and chemical properties of heat activated nickel titanium orthodontic wires in patients undergoing fixed orthodontic treatment.

Key Words: *nanoindentation, orthodontic wires, soft drinks*

Introduction

Nickel-titanium-based orthodontic wires are widely used because of their properties of superelasticity and shape memory which allow the teeth to move under almost constant force over a prolonged treatment time [1]. This increases treatment efficiency by longer periods between visits and decreased number of wire changes needed for each patient [1]. Despite good corrosion resistance of titanium-based alloys [2,3], orthodontic wires sometimes fracture in the oral cavity [3–5]. This involves several factors including intra-oral ageing [5,6], biomechanical overload [5] and hydrogen absorption from the surrounding environment which is known to adversely affect the mechanical properties of nickel-titanium-based alloys,especially in the presence of fluoride [3,7]. An acid pH of the oral environment can also accelerate the corrosion process of orthodontic wires [8,9], thus leading to negative clinical consequences ranging from lower forces being delivered to the teeth to wire fractures [10].

Recently, the consumption of soft drinks is increasing, especially among children and adolescents [11]. Their role in enhancing caries and dental erosion is well documented [12,13], while little is known with respect to their clinical consequences in patients undergoing fixed orthodontic treatment. In this regard, the literature is confined to a few studies aiming at determining the influence of these beverages on bond strength and microleakage beneath brackets [14,15]. To date, the acid environment created by the consumption of soft drinks has not been investigated as one possible reason for the degradation of the physical and mechanical properties of orthodontic wires.

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(Received 8 January 2011; revised 12 February 2011; accepted 2 March 2011)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2012 Informa Healthcare
DOI: 10.3109/00016357.2011.575083

Previous studies have used a variety of methods to measure the mechanical and physical properties of orthodontic wires, including three- and four-point bend tests [16,17], tensile tests [16,18], dynamic vibrational tests [19], Rockwell and Vickers hardness test. Nanoindentation is a relatively new technique [20–22] offering the great advantage of precision in the determination of the Young's modulus and hardness for specific small regions at the surface of a specimen, where the chemical attack is usually more pronounced.

Our aim in the present *in vitro* study was therefore to evaluate the effect of soft drink agents on the Young's modulus and hardness of heat activated nickel titanium orthodontic wires by performing nanoindentation test and also to qualitatively and quantitatively characterize their effect on the topography and chemical composition of the wire surface and section by means of scanning electron microscopy–energy dispersive spectroscopy (SEM-EDS).

Materials and methods

Pre-formed 0.019 × 0.025 inch Nitinol Heat-Activated archwires (50–60% nickel [Ni], 40–50% titanium [Ti]; lot Z0753, Ref 4297-920, 3M Unitek, Monrovia, CA) were investigated because of their increasing popularity of use. The chemical composition of the wires was provided by the manufacturers.

Three soft drinks were chosen because of their widespread use and commercial availability: Coca Cola® regular (pH 2.74), Santal® orange juice (pH 3.75) and Gatorade® (pH 3.78). It was ascertained that their shelf-life had not expired at the time of the experiment. The pH of each drink was measured at room temperature before each test. Measurements were performed in triplicate and average values calculated.

Specimen preparation

Thirty-two wire specimens (20 mm in length) were cut from the straight portions of eight pre-formed archwires from a single batch. The samples were randomly assigned to four groups, each made of eight wire specimens:

- *Group A*: Twenty-four specimens underwent immersion in soft drinks: eight specimens were immersed in Coca Cola® (*Group A1*), eight in Santal® orange juice (*Group A2*) and eight in Gatorade® (*Group A3*).
- *Group B*: Eight specimens underwent immersion in distilled, deionized water (dH_2O): served as control.

Immersion test

The specimens were totally immersed in 10 ml of one of the soft drinks or dH_2O, control, for 60 min, at 37°C. After the soaking time was completed, each specimen was removed from its respective solution, rinsed with distilled water, dried and put into clean individual plastic vials, which were each marked by a numerical code and stored at 37°C prior to wire mechanical testing. The selected soaking time was based on a previous study by Johansson et al. [23], which reported the average plaque pH to be <5.5 for more than 40 min and <6.2 during 60 min test period after a careful mouth rinse for 2 min with Coca Cola regular or orange juice under dry mouth conditions.

Nanoindentation test

Nanoindentation was performed using a commercial nanoindenter (Nanoindenter mod. XP, MTS Systems Inc., Oak Ridge, TN) fitted with a Berkovich indenter tip (Figure 1). The specimens were glued onto an aluminium cylinder. The loading–unloading cycle consisted in a loading ramp up 200 mN in 60 s, no holding time and an unloading ramp with the same speed as the loading one. The indenter tip geometry was properly calibrated on a standard fused silica. The Oliver–Pharr analysis method [24] was used by the software TestWork ver. 4.06a to calculate the Young's modulus and hardness. The software automatically subtracts the machine compliance and the thermal drift from the raw data. For the Young's modulus calculation a Poisson ratio of 0.32 was used. Randomly selected specimens from each experimental condition group were tested by performing 25 indentation cycles on each, spaced 50 μm from each other. Differences in the averaged values amongst the groups were analysed by the ANOVA (analysis of variance) using a commercial statistical software (STATISTICA 8, StatSoft, Inc., Tulsa, OK) with a predetermined α-level of significance of 95%.

SEM-EDS analysis

Following mechanical testing, two representative specimens from each experimental condition group

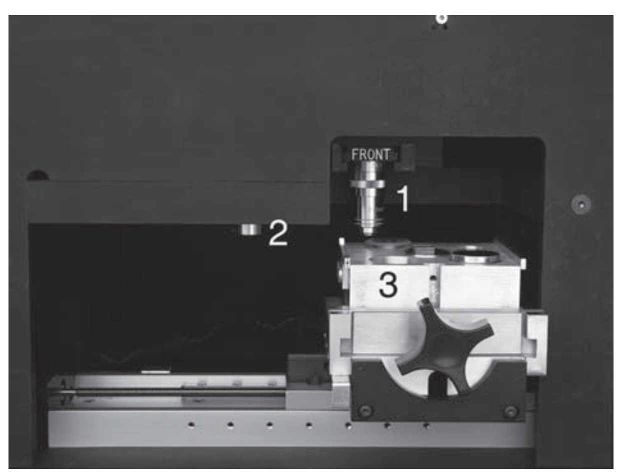

Figure 1. Closed view of the nanoindenter assembly: (1) microscope, (2) indentation tip, (3) sample tray.

were examined using a SEM-EDS INCA Energy 300 (Link Analytical–Oxford Instruments) with a microanalytical digital processor and digital control of the scanning.

SEM observation was used to qualitatively characterize the topography of the wire surfaces and sections, while EDS analysis was used to determine their chemical composition. The sections of the specimens were obtained from a portion of the wire whose end was polished. The polishing was necessary to obtain correct EDS results; for this procedure, a portion of the wire was englobed in a transparent resin then polished with cloths and diamond pastes down to 1 μm. All the specimens were ultrasonicated in acetone for 5 min before starting the experiments. Operative conditions in SEM were the following: acceleration tension = 15 kV; probe current = 100 pA for the observation and = 1 nA for EDS; chamber pressure = ~ $1.3 \cdot 10^{-4}$ Pa.

Results

Nanoindentation test

The mean values and the relative standard deviations of the Young's modulus and hardness are reported in Table I as a function of the group. No statistically significant differences between the groups were assessed with the ANOVA for both the measured properties. This indicated no significant effect of the three soft drinks (Groups A1, A2 and A3) on both the Young's modulus and hardness, as compared to the dH_2O (Group B, control).

The values of Young's modulus and hardness are shown in Figures 2 and 3 as histogram plots. Since there were no statistically significant differences between Groups A1, A2 and A3, they are presented together under the term 'soft drinks'. Independently on the measured property (Young's modulus or hardness), the data of either the control (Group B) or the 'soft drinks' (Groups A1, A2 and A3) showed an unimodal distribution and presented a positive skewness.

SEM-EDS analysis

Regarding surface topography, the wires exposed to dH_2O (Group B, control) appeared to have some scratches which might be by-products of the manufacturing process. As compared to these control wires, following exposure to both Coca Cola (Group A1), orange juice (Group A2) and Gatorade (Group A3), the overall wire surface appeared smoother and the scratches were less accentuated.

Some dark areas did appear on the wire surfaces after immersion in Coca Cola (Group A1): a representative SEM image is shown in Figure 4. The relative EDS spectra indicated that no change had occurred in their chemical composition, as compared to the surrounding surface (Figure 4).

The wire sections, independently of the experimental condition group, appeared to have numerous dark areas irregularly disposed along their whole structure (Figure 5). Again, the relative EDS spectra indicated that no change had occurred in their chemical composition, as compared to the surrounding unaffected areas (Figure 5).

The EDS analysis showed no difference in the chemical composition of the wire surfaces and sections exposed to soft drinks (Groups A1, A2 and A3), as compared to those exposed in the dH_2O (Group B, control).

Table I. Means and standard deviation (SD) for Young's modulus and hardness.

	Number of tests	Young's modulus (GPa)		Hardness (GPa)	
		M	SD	*M*	SD
Group A1 (Coca Cola)	50	64.1	5.2	2.9	0.4
Group A2 (Orange juice)	50	65.9	5.2	2.9	0.3
Group A3 (Gatorade)	50	64.5	4.3	2.9	0.3
Group B (dH_2O)	50	67.4	6.8	3.0	0.6

Discussion

The good corrosion resistance of nickel-titanium-based alloys is due to oxide layers that form on their surface [2,3]. The acid pH of topical fluoride agents (between ~ 3.5 and neutral [4]), as well as the fluoride concentration, are known to play an important role in the breakdown of such protective layers, thus leading to potential hydrogen absorption, mechanical properties degradation and associated fracture susceptibility of orthodontic wires [2,4,7]. Since fluoride prophylactic agents are commonly prescribed during fixed orthodontic treatment to reduce the risk of enamel decalcifications and to prevent caries, such an issue is of great clinical significance and has already been widely investigated.

The marked increase in soft drinks consumption is also raising questions about their potential harmful effects on the corrosion of the orthodontic appliances, since these beverages contain several acids and their pH may be very close to 2.0 or 3.0 [25]. However, to date, there have been no other reported studies on the effect of soft drink agents on the physical and mechanical properties of orthodontic wires. If the frequency of wire fracture is to be reduced and predictable forces are to be delivered to the teeth then clinicians should be aware of any effect that exposure to this type of beverages might have in terms of mechanical property changes of orthodontic wires. To this end, three popular soft drinks (Coca Cola® regular, orange juice and Gatorade®) were chosen and the Young's modulus and hardness of 0.019 × 0.025 inch heat activated nickel titanium orthodontic wires were tested after immersion in 10 ml of the drinks for 60 min.

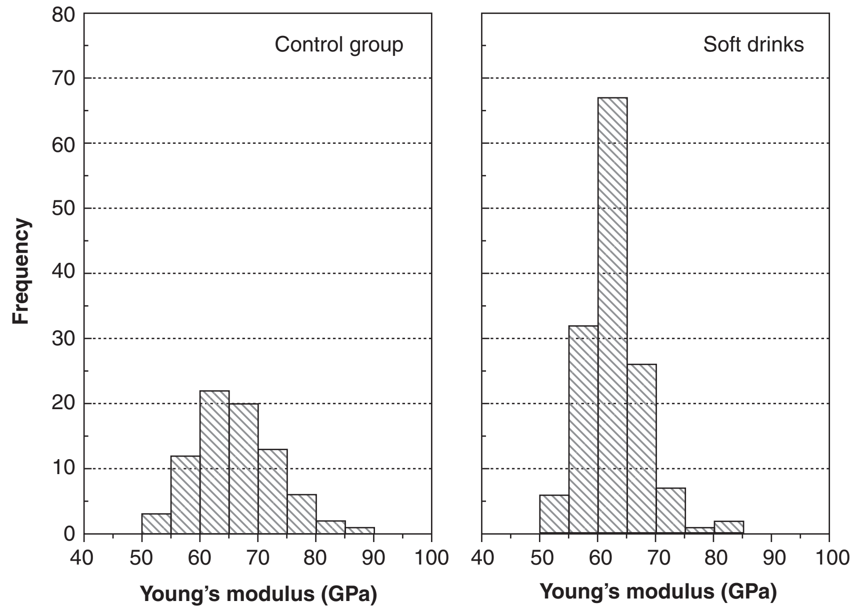

Figure 2. Frequency histograms of the Young's modulus values.

As with any *in vitro* investigation, it was virtually impossible to design a model that mimicked the real-life situation in which drink probably contacts only shortly with the wire surface before it is swallowed and washed away by saliva. *In vivo* exposure would not be a continuous exposure time and the soft drink would be diluted with saliva. Furthermore, the characteristics of the saliva (composition, pH, secretion flow, rate and volume), as well as the drinking habits (frequency of consumption or drinking techniques [23]) vary from one individual to another. It was, therefore, decided to assay orthodontic wires in extreme conditions which were more favourable to mechanical properties degradation than those found in the oral cavity under physiological conditions (pH 6.5). The 60 min soaking time protocol in this study attempted to simulate the greater pH fall in dental plaque, for a longer period of time, occurring after gentle mouth-rinsing for 2 min with 10 ml of Coca Cola® regular or orange juice under dry mouth conditions. Under these extreme conditions, the average plaque pH proved to be <5.5 for more than 40 min and <6.2 during 60 min test period, as reported by Johansson et al. [23] Undoubtedly, the experimental model used in the present study couldn't really represent the clinical environment, but our aim was to design a model that mimicked an extreme real-life situation.

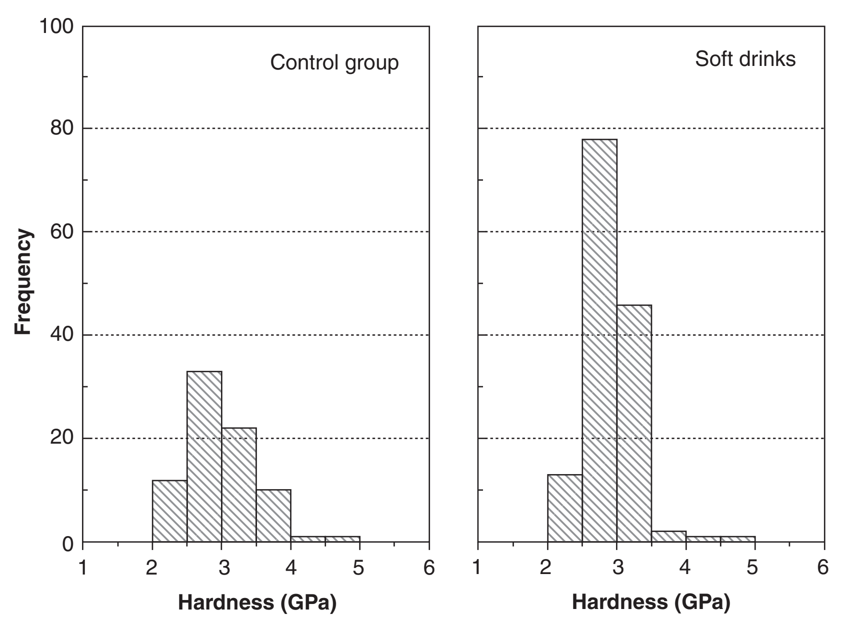

Figure 3. Frequency histograms of the hardness values.

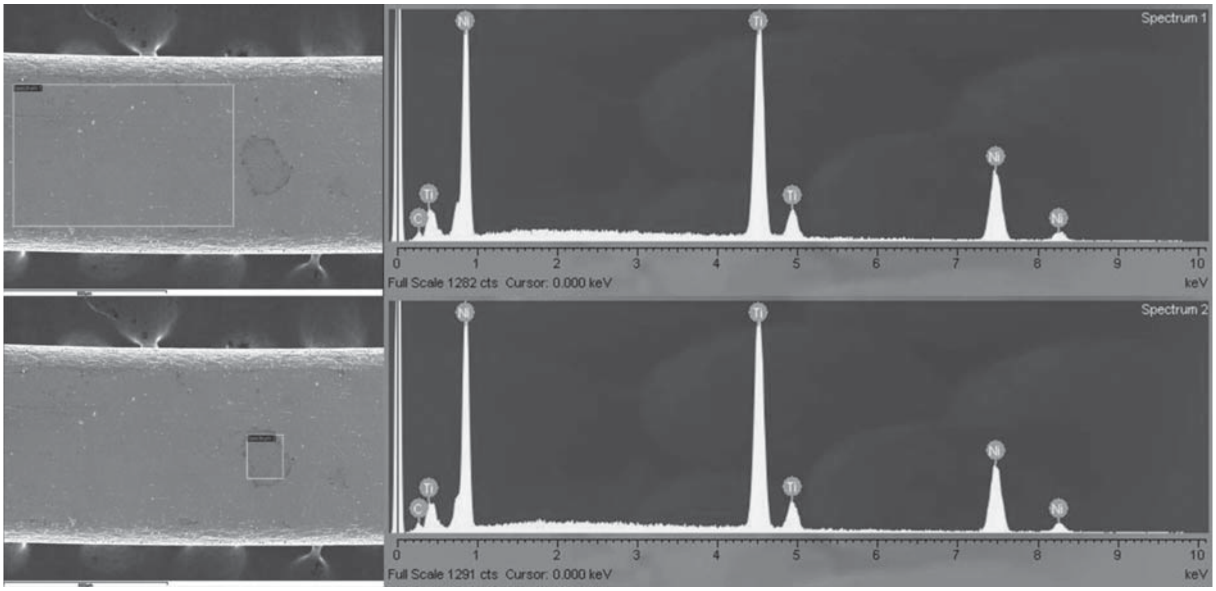

Figure 4. Representative SEM image of the wire specimens exposed to Coca Cola (Group A1): a typical dark area is visible on the surface of the wire. The corresponding EDS spectra are shown.

In the present study, using nanoindenter test, neither soft drink agents had a statistically significant effect on the Young's modulus and hardness as compared with control dH_2O. Corrosive changes in surface and section topography were not observed after exposure to soft drinks by means of qualitative SEM analysis. Furthermore, the EDS analysis showed no difference in the chemical composition of the wire surfaces and sections exposed to soft drinks as compared to those exposed the dH_2O.

These findings are in contrast with previous studies which reported an acid pH of the oral environment to favour the corrosion of nickel-titanium-based orthodontic wire and, as a consequence, to adversely affect their mechanical properties [9,26,27]. However, direct comparison with the current study is inappropriate because none of the previous studies examined the effect of soft drink agents. To date, surface characterizations, corrosion resistance and mechanical properties of nickel–titanium orthodontic wires have been investigated following immersion in artificial saliva of various degrees of acidity, acidulated fluoride agents or decontamination media [2,4,7–9,21].

In agreement with previous findings, SEM analysis demonstrated that the wires immersed in dH_2O had pre-existing surface defects [8,21], with scratches which might be caused by the manufacturing process. There was some evidence that, after immersion in soft

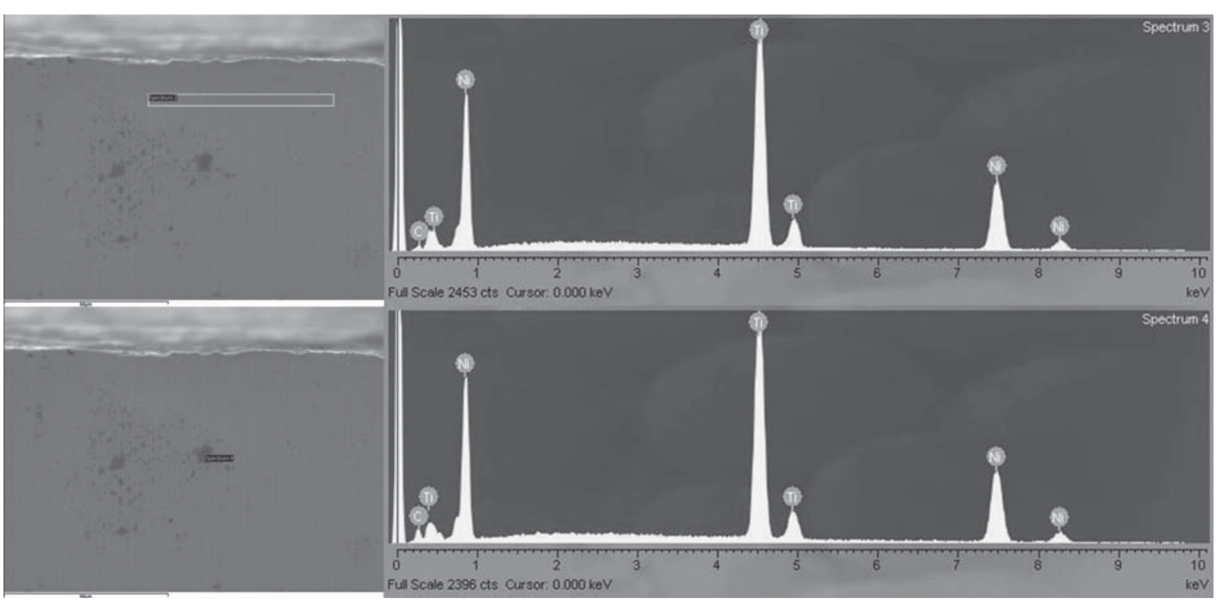

Figure 5. Representative SEM image of the section of the wires independently of the experimental condition group (soft drinks or dH2O): numerous dark areas are irregularly disposed along the whole section of the wire. The corresponding EDS spectra are shown.

drinks, the overall wire surface appeared smoother and the scratches were less accentuated, as compared to those immersed in dH_2O. This is in contrast with a previous SEM investigation, reporting the acidulated fluoride agent to cause more aggressive surface degradation than the neutral agent nickel-titanium-based orthodontic wires [2]. However, once again, such a comparison may be inappropriate since, in addition to pH, the fluoride concentration could also be an important predisposing factor to the breakdown of the protective layer that form on the wire surface [2]. Furthermore, it is still controversial whether surface defects produced during the manufacturing process can increase the susceptibility to localized corrosion of nickel–titanium orthodontic wires [8].

Also of note was the appearance of some dark areas on the wire surfaces after immersion in Coca Cola (Group A1, Figure 4), even though no difference in their chemical composition was found by the EDS analysis as compared to the surrounding area (Figure 4). This may be of little clinical significance since the Young's modulus and hardness were unaffected, but may require further investigation.

In the section analysis, numerous dark areas irregularly disposed along their whole structure appeared in all the wire specimens, independently of the experimental group condition (Figure 5). These dark areas were morphologically different from those on the surfaces of the wires immersed in Coca-Cola (Group A1), but, again, the EDS analysis showed no chemical differences in their composition as compared to the surrounding unaffected area (Figure 5). Furthermore, the fact that they can be also found in the sections of the wire immersed in dH_2O suggests that they may be due to the manufacturing process.

These *in vitro* results seem to suggest that consumption of soft drinks does not promote degradation of the investigated physical and chemical properties of nickel-titanium-based orthodontic wires, thus not influencing tooth movement in patients undergoing fixed orthodontic treatment.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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