



Color Stability of Different Denture Teeth Following Immersion in Staining Solutions

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ABSTRACT

Objectives: This study aimed to assess the color change (ΔE_{00}) of 7 brands of denture teeth (conventional acrylic and composite teeth) following immersion in staining solutions.

Materials and Methods: Maxillary central incisor denture teeth made of 4 conventional acrylic resins (Vitapan, SR Vivodent PE, Beta Star and Crystal) and 3 composite resins (Finex, Emerald and Phonares II) were randomly divided into four groups ($n=5$). Denture teeth of different brands were immersed in tea, coffee, cola, and turmeric solutions. The solutions were incubated at 37°C. The baseline color of the teeth was measured using an intraoral spectrophotometer. The color of the teeth was measured after 24 h (ΔE_{12}), 1 week (ΔE_{13}), 2 weeks (ΔE_{14}), and 1 month (ΔE_{15}). ΔE_{00} was calculated and analyzed using one-way ANOVA. Pairwise comparisons were performed by the Tukey's post-hoc test ($P<0.05$).

Results: The color stability of all teeth was significantly affected by the solutions ($P<0.001$). The type of tooth and coloring solution had significant interactions at all times ($P<0.05$). Turmeric caused the maximum color change in all teeth after 1 month. Repeated measures ANOVA showed that ΔE_{00} of all teeth was significantly affected by the duration of immersion in the solutions ($P<0.001$).

Conclusion: within the limitations of this study, 1-month immersion of denture teeth in coffee, tea and cola solution altered the ΔE values; however, they were within the acceptable range, except for Beta Star. Turmeric solution caused unacceptable color change in all denture teeth even after 24 h of immersion.

Keywords: Acrylic Resins; Tooth, Artificial; Color

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INTRODUCTION

Removable dentures have long been used to restore esthetics and masticatory function in fully edentulous and partially edentulous patients [1]. Considering the increased life expectancy from an average of 72 years in 2006 to 77 years in 2017, and 70% prevalence of edentulism in patients over 65 years, a rise

is expected in the number of patients requiring complete denture [2]. Denture teeth that are used for the fabrication of complete dentures should have reasonable mechanical properties to withstand masticatory forces during function. Denture teeth should be resistant to wear and pH alterations but easily adjustable in the mouth. Equally important, they must

present optimal esthetics and color stability. Moreover, adequate bond strength to denture base resin is crucial for their longevity [3-5]. Methacrylate resin, reinforced methacrylate resin, and composite resin are among the most commonly used materials for the fabrication of denture teeth. Several manufacturers attempted to modify the resin structure of denture teeth to enhance their wear resistance with different polymers, inter-penetrating polymer network, and double cross-links. Composite teeth consist of organic and inorganic components in the form of microfiller and nanofiller particles. They were introduced to enhance wear resistance, color stability, and mechanical properties such as toughness, energy absorption and energy distribution following stress application [3-5]. Color stability is a key factor for optimal esthetics of denture teeth. Discoloration or staining occurs due to intrinsic or extrinsic factors [1, 6-8]. Extrinsic staining is defined as accumulation of plaque or stains of coloring agents such as coffee, tea, and cigarette smoke on tooth surfaces. Extrinsic staining may be magnified by poor oral hygiene, and low frequency and inappropriate application of cleaning agents. Contrarily, intrinsic discoloration occurs as a result of physical and chemical reactions within a material, leading to enhanced absorption of coloring agents, increased reaction of tooth surface to coloring agents, and greater water sorption. Some other factors such as the degree of polymerization, the monomer content, the filler content, particle size, and the amount of C=C double bonds in composite resins also affect the color stability of denture teeth [1,6-8]. Ideally, discolored denture teeth should be replaced. However, it poses a great financial burden on patients. There are few in vitro studies evaluating the color stability of denture teeth. However, different staining media and/or denture tooth brands were examined and a consistent result was not obtained [1,9-12]. Ansari et al. [9] evaluated the color stability of composite resin and acrylic resin teeth in tea and coffee and showed better performance of acrylic teeth.

Kundu et al. [10] found that hybrid and nano-filled composite denture teeth were superior to conventional composite and acrylic resin teeth in terms of surface smoothness and staining resistance. Kurtulmus-Yilmaz and Deniz [11] evaluated the staining susceptibility of several types of resin artificial teeth and stain removal efficacy of denture cleansers. They demonstrated that cross-linked acrylic and nanocomposite resin teeth were more susceptible to staining. Considering the presence of conflicting results and wide variety of denture teeth available in the market, evaluation of staining resistance of denture teeth is necessary to help clinicians and lab technicians in selection of the best available option. Thus, the aim of this study was to assess the color stability of seven brands of denture teeth after exposure to different commonly used staining solutions. The null hypothesis was that there would be no significant color change in any of the denture teeth irrespective of the type of staining solution and measurement periods.

MATERIALS AND METHODS

In this in vitro experimental study, artificial maxillary central incisors (10 pairs of each type) were collected; 5 teeth of each brand (Table 1) were randomly immersed in each of the coloring solutions.

For the purpose of technical standardization of color measurement, the largest available size in A1 shade was used. The staining media included tea, coffee, cola, and turmeric solution [4] were prepared as follows: 1000 mL of cola drink (Coca Cola) was used in the cola group. Three teabags (Ahmad, Iran) were immersed in 1000 mL of boiling water for 10 min and removed. Also, 20 g of instant coffee (Nestle, France) and 20 g of turmeric (Shahsavand, Iran) were separately immersed in 1000 mL of tap water, stirred and heated to boil and cooled to 37°C [4,12,13]. The teeth were labeled on their lingual surface prior to immersion in the solutions. A grid was used to keep the teeth well immersed in the solutions to ensure complete exposure of their labial surface to the solution [4,6,13].

Table 1. Specifications of the dental materials used in this study

Type of material	Manufacturer	Matrix	Filler
Composite resin denture teeth			
Finex	Betadent	UDMA-Nano hybrid	Polyurethane resin filler
Emeral	Betadent	UDMA- Nano composite	---
Phonares II	Ivoclar Vivadent	Nanocomposite	Inorganic filler
Conventional acrylic resin denture teeth			
Vitapan	Vita Zahnfabrik-Germany	Cross-linked PMMA	Inorganic filler
SR Vivodent PE	Ivoclar Vivadent	Cross-linked PMMA	Organic filler
Crystal	Betadent	Cross-linked PMMA	---
Beta Star	Betadent	Co-polymer methacrylate	---

The solutions were refreshed every 3 days and stirred to prevent deposition of particles [12]. A portable spectrophotometer (VITA Easy shade; Compact, Vita Zahnfabrik, Bad Sachingen, Germany) was used to measure the CIE L*a*b* color parameters of the teeth. The initial color of each tooth was measured prior to immersion in the solutions. The immersed specimens were kept in an incubator at 37°C for subsequent measurements at time intervals of 24 h (ΔE_{12}), 1 week (ΔE_{13}), 2 weeks (ΔE_{14}), and 4 weeks (ΔE_{15}). The teeth were rinsed with distilled water before each measurement. The device was calibrated prior to each measurement, and the measurements were made three times for each tooth. The mean values were considered as the final value [14,15].

**Fig. 1:** Transparent acrylic resin mold with a tooth positioned in the central part in silicone material**Fabrication of the mold:**

An individual mold was fabricated for each tooth using transparent acrylic resin to

standardize the color measurements.

The mold had an upper and a lower compartment (Figs. 1 and 2), with a window in the upper compartment corresponding to the middle third of the labial surface which matched the size of the intraoral spectrophotometer probe for direct contact with the labial surface of the tooth [1].

**Fig. 2:** Assembled mold with the measuring probe

Color difference (ΔE_{00}) was calculated using the following formula [16]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_t S_t}\right)^2 + \left(\frac{\Delta C'}{K_c S_c}\right)^2 + \left(\frac{\Delta H'}{K_h S_h}\right)^2 + R_t \left(\frac{\Delta C'}{K_c S_c}\right) \left(\frac{\Delta H'}{K_h S_h}\right)}$$

The equation has two sets of coefficients, the K-coefficient, also known as the parametric factor that refers to the effect of influencing color difference judgment.

The S-coefficient accounts for the lack of visual uniformity of the CIE La*b*. In addition, a rotational factor (R_T) was added to correct the deficiency in the blue-violet region in which L', C', and H' are the transformed forms of LCH and $K_L S_L$ is lighting weighting function, $K_c S_c$ is chroma

weighting function, $K_H S_H$ is hue weighting function and RT is a rotational factor. In the present study, the parametric factors of the ΔE_{00} color difference formula were set to 1 [16].

In the present study, the acceptable level of ΔE_{00} was set to 1.8 according to ISO standard [16-18]. Color difference was analyzed by repeated measures ANOVA, with two between-unit factors (seven materials and four solutions) and one within-unit factor (four measurement times) to assess the main effects and possible interactions between the factors. Two-way ANOVA at each immersion time was used to test the significance of the factors involved. Where significant differences were found, one-way ANOVA and Tukey's multiple comparisons test were applied for each between-unit factor ($P < 0.05$).

RESULTS

The mean and standard deviation of color change (ΔE_{00}) of 7 brands of denture teeth following immersion in four coloring solutions for 24 h, 1 week, 2 weeks, and 1 month are summarized in Tables 2-5. Comparison of the mean ΔE_{00} values is shown in Tables 2-5. Two-way ANOVA showed that the interaction effect of tooth and coloring solution was significant at all intervals.

Thus, one-way ANOVA and Tukey's post-hoc test were applied to assess the interaction effect of type of tooth and type of solution on color change. Repeated measures ANOVA showed that ΔE_{00} of all teeth was significantly affected by the duration of immersion ($P < 0.001$). The type of tooth and type of coloring solution had significant interactions at all time points. Therefore, the effect of type of tooth and type of coloring solution on color change could not be determined individually. At 24 h, one-way ANOVA showed a significant difference in color change of different teeth immersed in turmeric solution ($P < 0.001$), and no significance difference in tea, coffee and cola solution ($P > 0.05$).

At one week, one-way ANOVA showed a significant difference in color change of different teeth immersed in all solutions ($P < 0.001$).

At 2 weeks, one-way ANOVA showed a significant difference in color change of different teeth immersed in turmeric and cola solutions ($P < 0.001$), and no significance difference in tea and coffee solutions ($P > 0.05$).

At 4 weeks, one-way ANOVA did not show any significant difference in color change of different teeth immersed in the solutions ($P > 0.05$).

Table 2. Color difference from baseline to 24 hours (ΔE_{12}) of immersion in coloring solutions

Type of Tooth	ΔE_{00} standard deviation of studied solutions				P	F
	Turmeric	Cola	Coffee	Tea		
Finex	3.25±1.28 ^{Aa}	1.93±0.44 ^{Aab}	1.5±0.52 ^{Ab}	1.71±0.67 ^{Ab}	0.014	4.81
Emeral	1.61±0.91 ^{Aa}	1.25±0.61 ^{Aa}	1.28±0.41 ^{Aa}	1.42±0.82 ^{Aa}	0.856	0.25
Beta Star	1.65±0.69 ^{Aa}	1.06±0.51 ^{Aa}	1.38±1.06 ^{Aa}	0.74±0.4 ^{Aa}	0.252	1.5
Crystal	2.49±1.06 ^{Ab}	1.19±0.65 ^{Aa}	1.21±0.64 ^{Aa}	0.41±0.17 ^{Ba}	0.003	7.33
Vita Pan	3.78±1.57 ^{Ab}	1.02±0.27 ^{Aa}	0.64±0.59 ^{Aa}	1.04±0.38 ^{Aa}	<0.001	13.73
SR Vivodent PE	12.12±0.99 ^{Bb}	1.±0.62 ^{Aa}	1.19±0.83 ^{Aa}	1.57±0.59 ^{Aa}	<0.001	244.21
Phonares II	11.04±0.72 ^{Bb}	1.77±1.13 ^{Aa}	1.12±0.43 ^{Aa}	1.33±0.78 ^{Aa}	<0.001	178.37

ΔE_{00} : color difference; Acceptable level: $\Delta E_{00} \leq 1.8$

Different superscripted lowercase letters represent significant differences between different types of solutions

Different superscripted uppercase letters represent significant differences between different types of teeth

Table 3: Color difference from baseline to 1 week (ΔE_{13}) of immersion in coloring solutions

Type of Tooth	ΔE_{00} standard deviation of studied solutions				P	F
	Turmeric	Cola	Coffee	Tea		
Finex	8.43±0.74 ^{ACb}	2.23±0.9 ^{Aa}	1.5±0.52 ^{ABa}	1.87±0.46 ^{Aa}	<0.001	116.47
Emeral	8.98±2.03 ^{Aa}	1.74±0.41 ^{Aa}	1.28±0.41 ^{ABa}	1.62±0.6 ^{Aa}	<0.001	56.94
Beta star	10.32±1.44 ^{ADb}	1.09±0.53 ^{Aa}	1.38± 1.06 ^{ABa}	1.68±0.78 ^{Aa}	<0.001	87.33
Crystal	10.47±1.58 ^{ABDb}	1.02±0.37 ^{Aa}	0.82±0.41 ^{ABa}	0.6±0.24 ^{Ba}	<0.001	162.94
Vita pan	5.39±2.03 ^{Cb}	1.24±0.84 ^{Aa}	0.65±0.4 ^{Aa}	1.32±0.61 ^{Aa}	<0.001	17.62
SR Vivodent PE	13.6±1.97 ^{Bb}	0.88±0.57 ^{Aa}	0.91±0.77 ^{ABa}	1.41±0.6 ^{Aa}	<0.001	150.74
Phonares II	12.58±0.83 ^{Bb}	1.04±0.93 ^{Aa}	2.2±1.13 ^{Ba}	1.42±0.13 ^{Aa}	<0.001	207.04

ΔE_{00} : color difference; Acceptable level: $\Delta E_{00} \leq 1.8$

Different superscripted lowercase letters represent significant differences between different types of solutions

Different superscripted uppercase letters represent significant differences between different types of teeth

Table 4: Color difference from baseline to 2 weeks (ΔE_{14}) of immersion in coloring solutions

Type of Tooth	ΔE_{00} standard deviation of studied solutions				P	F
	Turmeric	Cola	Coffee	Tea		
Finex	7.83±0.65 ^{Ab}	0.88±0.57 ^{Aa}	0.98±0.43 ^{Aa}	1.47±0.76 ^{ABa}	<0.001	147.62
Emeral	9.06±2.52 ^{Abb}	1.18±0.78 ^{Aa}	1±0.48 ^{Aa}	1.31±0.74 ^{ABa}	<0.001	40.07
Beta star	11.22±1.58 ^{Bb}	0.86±0.23 ^{Aa}	0.9±0.58 ^{Aa}	1.29±0.26 ^{Aa}	<0.001	175.46
Crystal	8.1±1.71 ^{Ab}	1.15±0.46 ^{Aa}	0.65±0.3 ^{Aa}	0.72±0.27 ^{Aa}	<0.001	79.64
Vita pan	6.9±1.14 ^{Ab}	2.42±0.74 ^{Ba}	1.25±0.3 ^{Aa}	1.75±0.8 ^{ABa}	<0.001	51.39
SR Vivodent PE	12.17±1.19 ^{Bb}	1.31± 0.65 ^{ABa}	0.76±0.47 ^{Aa}	1.31±0.49 ^{ABa}	<0.001	261.2
Phonares II	12.81±0.37 ^{Bb}	1.33 ± 0.59 ^{ABa}	2.39±1.02 ^{Ba}	2.08±1.08 ^{Ba}	<0.001	211.57

ΔE_{00} : color difference; Acceptable level: $\Delta E_{00} \leq 1.8$

Different superscripted lowercase letters represent significant differences between different types of solutions

Different superscripted uppercase letters represent significant differences between different types of teeth

Table 5. Color difference from baseline to 1 month (ΔE_{15}) of immersion in coloring solutions

Type of Tooth	ΔE_{00} standard deviation of studied solutions				P	F
	Turmeric	Cola	Coffee	Tea		
Finex	9.43±0.6 ^{Ab}	1.69±0.46 ^{Aa}	1.73±0.7 ^{Aa}	2.04±0.88 ^{Aa}	<0.001	151.09
Emer al	9.17±1.24 ^{Ab}	0.88±0.48 ^{Aa}	0.84±0.7 ^{ABa}	1.74±0.78 ^{Aa}	<0.001	112.75
Beta star	12.71±1.01 ^{Bc}	0.97±0.51 ^{Aa}	0.89±0.12 ^{ABa}	3.02±1.01 ^{Ab}	<0.001	270.54
Crystal	12.7±2.71 ^{Bb}	1.06±0.6 ^{Aa}	0.55±0.3 ^{Ba}	1.71±0.4 ^{Aa}	<0.001	84.96
Vita pan	12.62±0.76 ^{Bb}	1.69±0.42 ^{Aa}	1.48±0.43 ^{ABa}	2.21±0.83 ^{Aa}	<0.001	357.14
SR Vivodent PE	12.03±1.34 ^{ABb}	1.20±0.65 ^{Aa}	1.29±0.53 ^{ABa}	1.55±0.65 ^{Aa}	<0.001	193.84
Phonares II	11.18±1.26 ^{ABb}	1.06± 0.6 ^{Aa}	1.61±0.35 ^{Aa}	2.17±0.34 ^{Aa}	<0.001	208.29

ΔE_{00} : color difference; Acceptable level: $\Delta E_{00} \leq 1.8$

Different superscripted lowercase letters represent significant differences between different types of solutions

Different superscripted uppercase letters represent significant differences between different types of teeth

Color changes of teeth was significantly different in coloring solutions ($p < 0.001$). The highest ΔE_{00} constantly occurred in Phonares II and SR Vivodent PE in Turmeric at all time points, followed by Finex.

DISCUSSION

In this study, color stability of seven brands of denture teeth including acrylic and composite denture teeth were studied following immersion in common coloring solutions. Color difference (ΔE_{00}) was measured after 24 h, 1 week, 2 weeks, and 4 weeks.

The results showed that duration of immersion significantly affected the ΔE_{00} of all teeth, and the type of tooth and staining solution had significant interactions with different time points. Therefore, the null hypothesis was rejected.

Our findings were supported by studies performed by Koksall and Dikbas [4], Mousavi et al, [12] and Akyil and Bayindir [19]. The present study showed the highest color change of denture teeth in turmeric solution. All the tested denture teeth showed unacceptable ΔE_{00} after 1 week, 2 weeks, and 1 month in turmeric solution. This finding was in agreement with that of Singh and Aggarwal [13], and Satoh et al [20]. It was explained by the stronger polarity of the colorant molecules and constituents of turmeric.

Stronger polarity means more hydrophilicity and more affinity to bond to hydrophilic surfaces such as denture teeth [21]. Tea was the second coloring solution that caused maximum staining after 4 weeks. Akyil and Bayindir [19] and Satoh et al, [20] also found similar results in tea solution. It can be explained by the yellow colorants in tea that are more polar and hydrophilic than the yellow colorants in coffee [21]. On the contrary, several researchers found that coffee was more chromogenic than tea [6, 22-25]. Such a controversy could be due to differences in material brands and methods of preparing the tea and filtered coffee solutions. It is noteworthy that the discoloration induced by tea was found to be more superficial compared with coffee.

It is assumed that both adsorption and absorption phenomena are involved in coffee staining, while tea produces stains on the surface of denture teeth only by adsorption. Accordingly, denture cleansing agents can remove the stains to a great extent [12,26]. After 4 weeks of immersion of all tooth types in cola, ΔE_{00} showed discoloration to an acceptable level. Discoloration in cola is due to the caramel color additive produced by heating glucose or sugar in presence of minerals or acrylic acid [12]. After 2 weeks of immersion of Phonares II in coffee ($\Delta E_{00}=2.39$) and tea ($\Delta E_{00}=2.7$) and Vitapan in cola ($\Delta E_{00}=2.42$), unacceptable color change occurred.

It may be due to accumulation of pigments on the surface of denture teeth. The color difference decreased to an acceptable level after 1 month. It seems that by increasing the immersion time, the accumulation of pigments reached to a saturation point, where they could be detached and washed out by washing the teeth [26].

In the present study, the type of tooth and type of coloring solution had significant interactions at all time points. This finding was in agreement with the results of Goiato et al, [15], Akyil and Bayindir [19], and Kurtulmus-Yilmaz and Deniz [11].

Oppositely, Kundu et al. [10] showed that hybrid composite teeth (nanofilled in particular) were more resistant to staining than acrylic teeth in staining solutions. Koksall and Dikbas [4] examined the color change of acrylic and porcelain denture teeth in coloring solutions and reported superior results for porcelain teeth.

This controversy can be explained by the differences in denture tooth brands and different type of media and immersion times. Comparing the tooth types, different color change of resin teeth can be attributed to their manufacturing process and factors such as degree of polymer conversion and the amount of remaining unreacted monomer and initiators such as dibenzoyl peroxide [27]. Moreover, polymer matrix may absorb water that leads to discoloration.

Water sorption of a methacrylate polymer depends on the resin network heterogeneity and its chemical structure. The hydrophilic nature of polymer matrix could also affect water sorption of resin in the oral environment [28]. Three composite teeth used in the present study have a hydrophilic monomer (UDMA) in their structure. The hydrophilicity of the matrix and the quality of bonding between the coupling agent (silane) and fillers can enhance water uptake and, consequently, color stability. Additionally, many characteristics of composite resins are determined by the amount, type, geometry, and size of fillers. SR Phonares II is a nano-hybrid composite tooth with polymethyl methacrylate clusters incorporated in its matrix. Three filler types in SR Phonares II control its color stability, strength and abrasion resistance properties [29].

In this study, cola, tea, coffee and turmeric solutions were used as coloring agents. Tea, coffee, and cola are highly popular drinks in Iran, and turmeric is a commonly used spice in the Iranian traditional dishes. Also, turmeric has many therapeutic properties and is commonly used in the Iranian traditional medicine [30,31].

In the present study, the 4-week time period was chosen because it is the minimum time period required to see the cumulative staining effect [4,6]. According to Gregorious et al, [1] exposure to coffee is on average 5-10 min a day. The 7-day exposure to a single solution, therefore, corresponds to 34 to 67 months of its consumption and resultant staining.

A1 shade of denture teeth was used in this study, which is the lightest shade available for the denture tooth brands used in the present study because evidence shows that lighter shades of teeth experience greater discoloration than darker shades [4, 6, 32]. In the present study, the middle third of the labial surface of the teeth was used for assessment of color change at all time points because the composition of denture teeth in their gingival third is different from that in other parts [33, 34]. In this study, color change was assessed by calculating ΔE_{00} . Although many previous studies [4,11,12] used ΔE_{ab} but a more recent

study [31] showed that the sensitivity of the eye to color change calculated by the ΔE_{00} method is more than that calculated by ΔE_{ab} . In ΔE_{ab} formula, despite the equal colorimetric intervals of the colors in the $L^*a^*b^*$ system, it is not completely compatible with color perception by the human eye. In order to eliminate the difference between the formula and the human perception threshold, the ΔE_{00} version was introduced [16, 18].

In this study, we used Easy Shade spectrophotometer. Dozić et al. [17] compared the accuracy and reproducibility of different digital spectrophotometers including Shade Scan, Easy Shade Eye, Identa Color μ , Ikam and Shade spectrophotometers.

They concluded that Ikam and Easy Shade were more reliable in the oral cavity than other intraoral devices. The main drawback of spectrophotometer is that it has higher systematic errors when used for curved areas or translucent specimens. In order to overcome this shortcoming, we selected teeth with a smooth surface, made of materials with low degree of translucency, and the middle third of the labial surface of the teeth was subjected to spectrophotometry [35].

This study had some limitations such as inability to simulate the presence of saliva and its enzymes and proteins. Also, we only washed the teeth with distilled water and did not employ other cleaning methods, which did not perfectly simulate the clinical setting. Moreover, some studies conducted mainly on composite teeth had a control group that was subjected to immersion in distilled water while some others did not have a control group. In our study, color change in different solutions over time was compared with the baseline color parameters.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn: Time had a significant effect on color change of all denture teeth including Vitapan, SR Vivodent PE, Beta Star, Crystal, Finex, Emerald, and Phonares II. Color change of all artificial teeth (except Beta Star) after 1 month of immersion in cola, tea, and coffee was within a clinically acceptable

range. Turmeric solution caused unacceptable color change, regardless of the artificial tooth group. The type of tooth and coloring solution had significant interactions at all times.

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CONFLICT OF INTEREST STATEMENT

None declared.

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