COLOR STABILITY OF CERAMIC LAMINATE VENEERS: A COMPREHENSIVE IN VIVO ANALYSIS ACROSS MULTIPLE TIME INTERVALS

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Abstract

Background: The precise selection of ceramic laminate veneers by clinical practitioners is crucial due to their capacity to impart a natural and consistently uniform aesthetic to teeth, accompanied by the assurance of enduring color stability over an extended duration**.**

Objective: This study aimed to evaluate and compare the clinical color stability of three different manufacturing techniques of ceramic laminate veneer preparation, IPS e.max CAD/CAM, IPS e.max press, and Refractory Die, over a 2-year study period. The study also aimed to assess the average color changes within each technique and differences between them. This study will enhance our understanding of the efficacy of clinical color stability in long-term dental restoration applications.

Methods: The study sample comprised of 17 patients (9 males, 8 females) who received 27 veneers on their anterior teeth. After responding to a questionnaire regarding the potential frequency of consuming pigmented foods and beverages, the patients were divided into three groups. The refractory die technique was applied to 7 patients (11 teeth), while both IPS e.max press and IPS e.max CAD/CAM techniques were applied to 5 patients (8 teeth) each, with a veneer thickness of 0.5 mm for all veneers and luting with light-cured resin cement. Patients were monitored over three time intervals spanning two years. Student and ANOVA tests were employed to compare discoloration)ΔEab) within and between groups.

Results: Our results revealed statistically significant differences in mean ΔEab between 6 months and both 12 and 24 months in the three groups ($P < 0.05$). However, comparisons between the 12- and 24-month time point revealed statistical differences only in the refractory die group. No significant statistical differences were observed when comparing the three groups with each other ($P > 0.05$).

Conclusion: Our study determined that ΔE_{ab} values in all groups were deemed clinically acceptable, with no observable visual changes. Additionally, our investigation highlighted that IPS e.max Press exhibited the least discoloration values compared to other alternative methods.

Keywords: Ceramic, Color Stability, CIELab, Refractory Die, IPS e.max press, IPS e.max CAD

Introduction

Ceramic veneers function to restore teeth and achieve aesthetics, which are two of the main goals of restorative dentistry. In recent times, full ceramic restoration has become very common due to its excellent cosmetic appearance and visual properties. It offers the possibility of lighter and more natural-looking teeth, preparation with minimal wear, the ability to change shape, and improved aesthetics (1). The selection of ceramic materials relies on their mechanical properties and distinctive optical behavior (2). For example, feldspathic ceramic, the earliest form of all-ceramic materials to be made available, displays exceptional optical qualities (3), and recently, heat-pressed glass-ceramic lithium disilicate-reinforced ceramics (IPS e.max press) has become more popular among all ceramic materials due to their optimum aesthetic properties and high strength in extremely thin restoration cases (4).

Color stability is considered as one of the most important factors in maintaining the desired aesthetics and longevity of ceramic restorations. Conversely, discoloration of

ceramic restorations is considered as one of the most common problems experienced by patients (5). The color stability of cement can be influenced by several extrinsic factors, such as intensity and duration of polymerization, exposure to environmental factors (including ambient and UV irradiation, heat, water, food colorants), and intrinsic factors associated with the physical and chemical properties of the material (6). On the other hand, the increasing demand for cosmetic facial treatments with ceramic veneers requires caution from dentists in choosing the bonding material, as it is of great importance for the long-term success of these treatments (7). In addition to having sufficient mechanical properties and durability characteristics that approach or exceed those of natural teeth, contemporary aesthetic restorative materials should match the color and appearance of natural teeth (8). The luting agents available for laminate veneer restorations are either light-cured resin cement, dual-polymerization cement, or chemically activating cement (9). These luting materials play a major role in the aesthetic outcome of ceramic veneers by matching the shade with adjacent teeth. The reason being is that any changes in the color of the cement used significantly affects the final appearance of the cosmetic treatment and, consequently, its success or failure (10).

In this study, we aimed to determine the clinical color stability of ceramic laminate veneers produced using three different manufacturing processes (CAD/CAM, Hot press, and Refractory Die). Our two major hypotheses are that (i) there is no statistically significant difference in mean discoloration for each type of ceramic laminate veneer used, and (ii) there is no statistically significant difference in mean discoloration between the types of ceramic sheets used.

In general, resin-based luting agents possess aesthetic characteristics that give a natural-looking cemented ceramic veneer. In addition, adhesive cementation can strengthen the fragile ceramic veneer (11).

In this study, we used light-cured resin in the luting process as other types of luting involve chemical treatment (dual-polymerization cement or chemically activating cement) and may cause reactions that lead to discoloration (12). Overall, the results of this research will assist clinical practitioners in choosing the appropriate type of ceramic veneer when luting with light-cured resin due to the long follow-up period (up to two years).

Materials and Methods

Research sample

Sample size

The study sample comprised of 17 patients who collectively underwent treatment involving the installation of 27 veneers on their anterior teeth. The sample size was determined using G*Power 3.1 (13), aiming for an alpha error of 5% and a power of 95%, resulting in a calculated sample size of 5 teeth per group. Considering potential dropouts, the sample size was increased to 27 teeth for all groups (11 teeth for the first group, 8 teeth each for the second and third groups).

Questionnaire and data validation

Patients responded to a questionnaire assessing the potential frequency of consuming dyed foods and beverages. Subsequently, validation of the questionnaire data was performed via daily consumption records documented over 7 days for each patient (Table 1). Calculation of Kappa coefficient (Kappa = 0.895, > 60%) was employed for validation, confirming that the responses accurately reflect the patients' habits and deemed consistent for this study.

Table 1: Research sample responses on food consumption frequency

Types of food	Frequency	Never	Less than once a week	Once a week	2-3 times a week	Once a day	Twice a day	Three times or more a day
Coffee	n	1	1	2	2	4	4	3
	%	5.88%	5.88%	11.76%	11.76%	23.53%	23.53%	17.65%
Tea	n	0	0	1	3	8	3	2
	%	0.00%	0.00%	5.88%	17.65%	47.06%	17.65%	11.76%
Mate	n	3	1	1	2	6	3	1
	%	17.65%	5.88%	5.88%	11.76%	35.29%	17.65%	5.88%
Soft Drink (Cola)	n	4	2	6	2	1	1	1
	%	23.53%	11.76%	35.29%	11.76%	5.88%	5.88%	5.88%
Colored soft drink	n	5	3	4	3	1	1	0
	%	29.41%	17.65%	23.53%	17.65%	5.88%	5.88%	0.00%
Chocolate	n	0	2	3	4	4	3	1
	%	0.00%	11.76%	17.65%	23.53%	23.53%	17.65%	5.88%

Table 1: Research sample responses on food consumption frequency (continued)

Types of food	Frequency	Never	Less than once a week	Once a week	2-3 times a week	Once a day	Twice a day	Three times or more a day
Raw root	n	4	10	2	1	0	0	0
	%	23.53%	58.82%	11.76%	5.88%	0.00%	0.00%	0.00%
Colored medicine	n	16	1	0	0	0	0	0
	%	94.12%	5.88%	0.00%	0.00%	0.00%	0.00%	0.00%
Ketchup	n	5	8	3	1	0	0	0
	%	29.41%	47.06%	17.65%	5.88%	0.00%	0.00%	0.00%
Red wine	N	15	2	0	0	0	0	0
	%	88.24%	11.76%	0.00%	0.00%	0.00%	0.00%	0.00%
Turmeric	n	15	1	1	0	0	0	0
	%	88.24%	5.88%	5.88%	0.00%	0.00%	0.00%	0.00%
Pomegranate molasses	n	14	2	1	0	0	0	0
	%	82.35%	11.76%	5.88%	0.00%	0.00%	0.00%	0.00%
Capsicum Molasses	n	7	2	5	2	1	0	0
	%	41.18%	11.76%	29.41%	11.76%	5.88%	0.00%	0.00%

Restoration procedures and exclusion criteria

The restoration of central incisors, with or without the inclusion of lateral incisors, was performed, irrespective of whether the remaining teeth were compensated with ceramic veneers. Exclusion criteria for the study encompassed patients exhibiting vestibular gingival recession, maxillary retrusion, mandibular prognathism, tetracycline staining, enamel, or dentin defects, and those who smoked.

Patient categorization

The patients were distributed into three groups using a random allocation list generated from the online randomization tool “Random.org”. This website is known for its reliability in generating random sequences, ensuring a fair and unbiased allocation process.

Group 1: Comprised of 7 patients with 11 teeth treated using ceramic veneers fabricated via the refractory die method.

Group 2: Comprised of 5 patients with 8 teeth treated using ceramic veneers fabricated via the hot press IPS e.max press method.

Group 3: Comprised of 5 patients with 8 teeth treated using ceramic veneers fabricated via the IPS e.max CAD/CAM method.

Sample characteristics

All ceramic laminate veneers were luted with light-cured resin cement. Table 2 outlines the characteristics of the research sample.

Table 2: Characteristics of research sample

Group	No. patients	No. teeth	Gender	Age (Mean ± SD)
Feldspathic	7	11	4(m), 3(f)	30.00 ± 4.00
IPS e.max press	5	8	3(m), 2(f)	31.00 ± 7.65
IPS e.max. CAD	5	8	2(m), 3(f)	32.20 ± 5.36
				f = female; m = male

Ethics

All procedures performed in the study involving human participants were approved by the Scientific Research Board - Tishreen University (Approval No. 1396; Date 15 August 2019). The study was conducted in accordance with the Declaration of Helsinki (1964) and its subsequent amendments.

Data analysis

Statistical analysis was performed using SPSS Version 25 (14). The Kolmogorov-Smirnov test was employed to verify the normal distribution of the data. All data had a normal distribution ($P > 0.05$). One-way analysis of variance (ANOVA) and the Student Test were utilized to compare the averages of discoloration among the three groups and within each group.

Samples preparation

All sample veneers in each group were prepared and standardized to a uniform vestibular surface thickness of

0.5 ± 0.1 mm using Diamond Burs FG834.021 Veneer Depth Marker (Horico, Berlin, Germany). Conical, round-headed Diamond Burs FG199.O18 (Horico, Berlin, Germany) was used to prepare the gingival finish line and connect the holes at the specified depth. The incisal edge was prepared using the butt joint incisal finish line technique which is characterized by its preservation of tooth structure, stability, and natural aesthetics for dental restorations (15), with a reduction of approximately 1.5 ± 0.1 mm for all teeth in the three groups. Preparation of the entire surface within the enamel was completed without sharp angular corners. After the preparation was finished, finishing burs and rubber heads were used to smoothen the prepared surfaces. Changing of burs was considered after the complete preparation of four teeth to ensure good cutting; the preparation was done under water spray. Impressions of the studied samples were taken using Virtual (Ivoclar, Pforzheim, Germany), a polyvinyl siloxane impression material with medium viscosity. The impressions were then poured with an improved dental stone to obtain working models. Figure 1 shows a representative model of a case, demonstrating the method used for determining the amount of cutting with depth burs.

Figure 1: Preparation of a case showing the method used for determining the amount of cutting with depth burs.

Treatment by ceramic laminate veneers

After completion of teeth preparation, ceramic laminate veneers were fabricated via the refractory die method using materials sourced from BEGO (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Germany). These facings were applied to seven patients (Figure 2). The IPS e.max® Ceram porcelain system (Ivoclar Vivadent, Schaan, Liechtenstein) was also utilized. IPS e.max® Press ceramic molds were prepared using a pressing technique with various shades, and IPS e.max® CAD ceramic blocks, prepared for milling using the CAD/CAM technique, were applied to five patients for each technique (Figure 2). The porcelain furnace used was the Programat EP3000-G2 (Ivoclar Vivadent, Pforzheim, Germany). The Arum Dental Mill 5X-400 (Doowon USA Inc., Pennsylvania, USA) was used for fabrication of the thin facings using the CAD/CAM technique.

Ceramic laminate veneers were cemented onto the incisors in each group using Variolink N light-curing resin cement (Ivoclar Vivadent, Schaan, Liechtenstein) in either white shade or Bleach XL. A specific amount of resin cement was directly applied to the inner surface of the ceramic laminate veneer and then pressed onto the prepared tooth surface using finger pressure. Excess cement was removed with a probe after five seconds of curing, followed by light-curing via exposure to visible light for 40 seconds. Small excesses at the edges were removed with finishing burs when present, and finishing was done with rubber points.

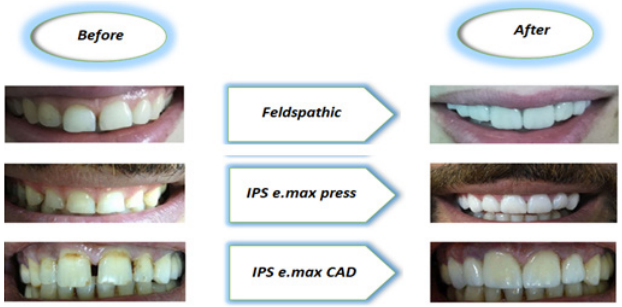

Figure 2: Before and after treatment by ceramic laminate veneers.

Discoloration value

Color parameters were determined after 24 h and after 6, 12, and 24 months. Color stability was assessed by determining the differences between color measurements and baseline, using *L*, *a,* and *b* coordinates from the CIELab (ΔE_{ab}), where *L* indicates luminosity, *a* represents the green (-*a*) and red color (+*a*), and *b* represents blue (-*b*) and yellow (+*b*) color. The values of *a*, *b*, and *L* were calculated using the VITA® Easyshade® Compact device and was calculated using the formula (16,17):

$$\Delta E_{ab} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Results

Discoloration in study groups

Figure 3 shows the values of ΔE_{ab} in the study groups, where an increase in the values of discoloration was observed during the study periods. Table 3 shows the descriptive statistics for the values of discoloration. Table 4 shows the results of the Student's t test to compare the average discoloration during the study period. The results in each group are as follows.

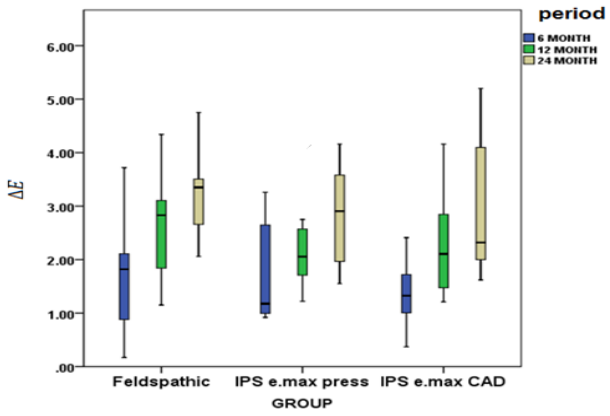

Figure 3: values in each study group.

Table 3: ΔE_{ab} values in each study group.

Group	Period (month)	$E_{ab}\Delta$		
		Mean ± SD	Min	Max
Feldspathic	6	1.65 ± 1.04	0.17	3.72
	12	2.57 ± 0.95	1.15	4.34
	24	3.23 ± 0.80	2.06	4.75
IPS e.max press	6	1.73 ± 0.96	0.92	3.26
	12	2.28 ± 0.77	1.53	3.91
	24	2.79 ± 1.04	1.25	4.16
IPS e.max CAD	6	1.36 ± 0.61	0.37	2.41
	12	2.28 ± 1.01	1.21	4.16
	24	2.96 ± 1.35	1.62	5.20

Table 4: Mean ΔE_{ab} in each group

Group	Period1	Period2	Mean diff	Student	p
Feldspathic	6 months	12 months	0.92	4.33	0.00
		24 months	1.58	8.73	0.00
	12 months	24 months	0.67	5.60	0.00
IPS e.max press	6 months	12 months	0.55	2.67	0.03
		24 months	1.06	5.11	0.00
	12 months	24 months	0.51	2.08	0.08
IPS e.max CAD	6 months	12 months	0.92	2.84	0.03
		24 months	1.60	3.10	0.02
	12 months	24 months	0.68	1.30	0.23

Feldspathic Veneers group: A significant increase was observed in mean discoloration ($P < 0.05$) after 12 and 24 months compared to 6 months by 55.59% and 95.92%, respectively. A significant increase of 25.89% was also observed in the average discoloration ($P < 0.05$) after 24 months compared to 12 months.

IPS e.max press: A significant increase was observed in mean discoloration ($P < 0.05$) after 12 and 24 months compared to 6 months by 31.72% and 61.42%, respectively. Also, non-significant increase was observed in the average discoloration ($P > 0.05$) after 24 months compared to 12 months by 22.53%.

IPS e.max CAD: A significant increase was observed in mean discoloration ($P<0.05$) after 12 and 24 months compared to 6 months by 67.36% and 117.37%, respectively. Also, non-significant increase was observed in the average discoloration ($P > 0.05$) after 24 months compared to 12 months by 29.77%.

Comparison of discoloration between the three groups

ANOVA was used to compare the mean ΔE_{ab} during the study period (Table 5). No statistically significant differences were observed in mean discoloration between the studied groups after 6 months of treatment ($P > 0.05$). The IPS e.max CAD group had the lowest mean discoloration among the studied groups compared to IPS e.max Press group (by 21.21%) and the Feldspathic group (by 35.56%). The mean discoloration in the IPS e.max Press group came in second and was lower than the Feldspathic group (by 18.21%).

It was also noted that there were no statistically significant differences in the mean discoloration between the studied groups after 12 months of treatment ($P > 0.05$), noting that the discoloration mean in the IPS e.max CAD group was the lowest among the studied groups. It was less than the IPS e.max Press group by 3.49%, and the Feldspathic group by 23.49%. The mean discoloration in the IPS e.max Press group came in second at 20.72% lower than the Feldspathic group.

Finally, it was noted that there were no statistically significant differences in mean discoloration between the studied groups after 24 months of treatment, noting that the IPS e.max Press group was the lowest among the studied groups. It was less than the IPS e.max CAD group by 9.37%, and the Feldspathic group by 11.12%. Mean discoloration in the IPS e.max CAD group came in second, with a lower percentage than the Feldspathic group at 1.93%.

Table 5: ANOVA results comparing mean ΔE_{ab} between the three groups.

Period	2.06	P
6 months	0.37	0.69
12 months	0.33	0.73
24 months	0.43	0.66

Discussion

The most popular techniques for fabricating ceramic laminate veneers are the refractory die method, IPS e.max press, and IPS e.max CAD. Results of our study showed that there were statistically significant differences in mean discoloration for each type of ceramic laminate veneer used between the individual time periods. Also, our results revealed that there were no statistically significant differences in mean discoloration between the types of ceramic sheets used. Feldspathic porcelain has been one of the earliest materials used in the fabrication of ceramic laminate veneers. It is currently still used today, despite the availability of ceramic materials and advancements in ceramic laminate veneer manufacturing techniques (1, 18, 19). Feldspathic ceramic laminate veneers are known for being the least damaging to tooth structure while achieving functional and aesthetic aspects. Furthermore, they do not require special equipment and can provide aesthetics with minimal thickness (1). The IPS e.max ceramic system stands out in dentistry due to its advanced preparation techniques, including the Press technique and Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) methods, which ensure excellent aesthetics. The IPS e.max system is one of the most widely used ceramic systems in the world after its introduction over a decade ago (11, 19, 20). Its innovative and reliable components have impressed scientists, dentists, and patients alike, where the ceramic material used in this system exhibits a translucency that mimics the transparency of natural teeth, as well as varying degrees of gloss and brilliance, thus achieving highly aesthetic results that closely resemble natural teeth. Blocks and molds with low translucency (LT) have been used to fabricate facial features through an injection method with the assistance of a computer (2, 11, 18, 19).

In this study, ceramic veneers were fabricated with a thickness of 0.5 mm. This thickness was chosen because it is the average thickness of commonly manufactured ceramic veneers, which typically ranges from 0.3 to 0.7 mm (20). The CIELab color space has been used as an accepted method for color measurement in dentistry because each color has its own specific location in the three-dimensional color space. Most studies on discoloration in dental materials have used the CIELab color space (18-20). The majority of color changes in resin cement occur within the first 24 hours. Hence, ceramic veneers typically do not achieve their final color until after 24 hours of luting (21-23).

ΔE_{ab} values less than 1 are considered undetectable by the naked eye, values between 1 and 3.5 can only be detected by dentists using measurement devices, and thus they are considered acceptable, while values greater than 3.5 can be visually detected and are considered unacceptable (24-28). The mean discoloration (ΔE_{ab}) of Feldspathic ceramic veneers throughout the study period was 3.23 (6 months), 2.57 (12 months), and 1.65 (24 months), respectively. Therefore, the overall mean discoloration after 24 months was below 3.5, indicating clinical acceptability and no visible observation. Similarly, the mean of IPS e.max Press ceramic veneers during the study periods was 1.73 (6 months), 2.28 (12 months), and 2.79 (24 months), respectively. Again, the overall mean discoloration after 24 months was below 3.5, indicating clinical acceptability and no visible observation. Finally, the mean ΔE_{ab} of IPS e.max CAD ceramic veneers during the study periods was 1.36 (6 months), 2.28 (12 months), and 2.96 (24 months), respectively. The mean discoloration after 24 months was also below 3.5, indicating clinical acceptability and no visible observation.

After 24 months, it was observed that the mean discoloration in the IPS e.max Press group was the lowest, despite the absence of significant differences among the three groups. Therefore, it is recommended to be used when cemented with light-cured resin cement. It was also observed that the mean discoloration between 12 and 24 months was not significant in both the IPS e.max Press and IPS e.max CAD groups, indicating color stability. Our results pertaining to the IPS e.max Press ceramic veneers are in agreement with the findings by Marchionatti *et al.* (29), who found that the color stability of ceramic veneers manufactured using the IPS e.max Press method was clinically acceptable throughout their study period despite the inclusion of upper incisors without any preparation. It was also observed that the mean discoloration in Feldspathic veneers was highest after 24 months, which is in agreement with the findings of a vitro study (30) where they found that the color change values after two years were unacceptable for the feldspathic ceramic veneers used in their study. The results of our study were in agreement with the findings of an in vitro study (21) by Rodrigues *et al.* where they found that the feldspathic ceramic exhibited a higher degree of discoloration compared to the e.max lithium disilicate. This difference in color change may be attributed to variations in optical properties between feldspathic porcelain and lithium disilicate, which can be attributed to their microstructure.

We found that the discoloration values in the IPS e.max Press group after two years were lower than those in the IPS e.max CAD group. Results of our study were in agreement with two other studies (31, 32) which reported that the performance of the former may be attributed to better occlusion and less microleakage compared to IPS e.max CAD. Bagis & Turgut (27) found that the optical properties of ceramic systems are mainly related to its chemical composition rather than the method of manufacturing. Their study showed that all ceramic systems used in their study, which includes IPS e.max Press, IPS e.max CAD, IPS Empress Esthetic, IPS e.max Ceram, IPS Inline, and IPS ZirPress, had discoloration values less than 3.5 after aging testing, and were therefore clinically acceptable. Even though IPS e.max Press underwent more changes in yellow and red color, it remained within the parameters of clinical admission. This differs from our study in that IPS e.max Press showed the lowest discoloration values compared to other methods. This may be because their study was performed *in vitro*, while ours was *in vivo*.

Although this study has yielded robust and valuable results, it is crucial to acknowledge some limitations that may impact the interpretation of our findings. Firstly, it is worth noting that the subjects used in this study was limited in both its sample size and the diversity of participants. Variations in individual characteristics among participants could potentially influence the generalizability of the results to a broader population. Furthermore, it is important to highlight that the maximum follow-up period in this study was only up to 24 months. While acceptable, the duration may not be sufficient enough to assess long-term changes in ceramic veneer discoloration. Additional color changes may become apparent after a more extended period, emphasizing the need for long-term follow-up studies to determine the sustained visibility of results over a longer duration. Despite these limitations, our results are of significant importance in the field of ceramic veneer manufacturing, particularly concerning the use of techniques such as IPS e.max Press and IPS e.max CAD. Enhancing the robustness of this study can be achieved by expanding the sample size in future studies and extending the follow-up period to gain a deeper understanding on the temporal effects of ceramic veneer discoloration.

Conclusions

Significant changes in the average color change were individually observed for each method, yet they consistently remained within clinically acceptable limits. Notably, no discernible differences among the three methods were observed, but the IPS e.max Press method demonstrated results better than other techniques. To further advance research in this field, exploring extended follow-up periods, diversifying sample demographics, comparing with alternative materials, investigating in both clinical and laboratory settings, and evaluating the impact of various tooth preparation techniques on ceramic veneer discoloration outcomes are recommended.

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Competing interests

The authors declare that there are no competing interests.

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