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Original Article

Trueness of intraoral scanning for different tooth-size arch-length deficiencies

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KEYWORDS
Crowding arch;
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Abstract *Background/purpose:* As science and technology continue to advance, the utilization of intraoral scanners (IOSs) has become increasingly popular in the orthodontic workflow. The aim of this study was to discuss whether the degree of crowded arches affects scan accuracy.
Materials and methods: Three different crowding levels of dental models (model MI: mild, model MO: moderate, and model SE: severe) were scanned using both an IOS and desktop scanner. Stereolithographic files were obtained and superimposed via CAD software to calculate differences between each measuring point of a model and the farthest corresponding point. The deviations from three models were compared with statistical analysis.
Results: The trueness of different crowding arches showed that the deviation value of model SE was the maximum, followed by model MI, and model MO in the maxillary arch. In the mandibular arch, the order of the deviation from greatest to least was firstly model SE, then model MO, and model MI. Significant differences were observed among the maxillary models ($P < 0.001$), but there was no significant difference between models in the mandible ($P = 0.669$).
Conclusion: The trueness of the three crowded arches is in the clinically acceptable range. The degree of crowding increases, the trueness of scanning at each position decreases. In the maxillary arch, more severe crowding corresponds to higher deviations. In the mandible, the degree of crowding is not explicitly related to the maximum deviation; therefore, the clinician should notice the deviation when using IOSs for crowding cases.

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Introduction

The gradual introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) into various fields is a result of rapid advancements in technology where digital workflows provide simplified processes, fast manufacturing and predictable outcomes. The use of these in dentistry dates back to the early 1970s when Drs. Francois Duret and Christian Termoz revolutionized the field by patenting the first dental procedure for indirect restorations. Optical impressions with intraoral scanners would indicate a significant watershed and connection between traditional methods and digital method in clinical practice, as in the past, conventional impressions required impression trays and impression materials, consisting of material science and clinical techniques.[1] More recently, intraoral scanners (IOSs) have improved significantly, providing another efficient impression method with great accuracy.[2–4] Such scanners are now widely used in special dental fields, especially for prosthodontic and orthodontic applications.[5–7]

The accuracy of dental model analysis is essential for using digital models as diagnostic tools in planning treatments and fabricating orthodontic appliances; accordingly, greater accuracy is now required for 3D digital models recently.[8,9] Many factors affect the accuracy of the intraoral scanner when it is used clinically, including the scan strategies, the type of intraoral scanner,[10–13] gestures during scanning[14] and scanning environments,[15,16] while and the degree of tooth crowding will also affect it.[17] Recording full-arch digital data is helpful for orthodontic treatment. Medina-Sotomayor[18] has demonstrated low-scan deviation in a single crown, but full-arch scanning still had its discrepancies and limitations. At the same time, Kim et al.[19,20] tested trueness from different IOS scanners and revealed the deviations ranged from 17.80 μm to 200.24 μm among the scanners, with scan distance and depth of field would affecting the final results of scan images.[21] Considering environmental factors, Arakida et al.[15] demonstrated that ambient light of 3900 K and 500 lux would be the most suitable lighting conditions for IOS.

Crowding is a common clinical situation, and it might be different for the elderly and children. As it is not easy to implant teeth, the dentist recommends orthodontic methods include traditional fixed edgewise appliance and digital aligner. The traditional impression is not easy in some patients, especially for children, to pull out or even find a suitable tray. Although digital oral scanning is convenient and patients can be more comfortable, the environmental impact of the oral scanning operation might be more obvious among people with crowded dental arches. Spatial (space) analysis of dental casts is necessary because treatment varies by severity.

Although the definition of crowding is still controversial, the principles of spatial analysis are (1) by measuring the circumference of the dental arch from the mesial of one first molar to the other, passing through the contact point of the posterior teeth and the margins being cut (contact point of each tooth) to calculate the available space; and (2) secondly, to calculate the amount of space required to align the teeth. This is done by measuring the mesial-distal width of each erupted tooth from contact point to contact point, estimating the size of the unerupted permanent teeth, and then adding the widths of the individual teeth. Manual arch length measurements can be made by dividing the arch into segments that can be measured as a straight-line approximation of the arch, or by drawing a wire outlining the occlusal line and then straightening it to take measurements.[22] To determine tooth-arch discrepancy, one can calculate the difference between the sum of the mesiodistal width of the second premolar to the opposite second premolar and the sum of the sectional arch length. The degree of tooth-arch discrepancies can be divided into different levels.[17] Crowded dental arches could make it difficult for the light to reach certain areas and cause incomplete images, resulting in discrepancy. In operation, the scanning time is prolonged to inject light into the crowded teeth area, causing the machine to overheat and reduce the accuracy of machine scanning.[22,23] However, since the imaging principle of the oral scanner is to stack images into a digital model, the longer the scanning time, the more images are captured, and repeated image superposition will also increase the error value.

Many studies have accessed the accuracy of different IOSs and the effect of scanning sequences, although only a few studies discuss the impact of trueness with varying degrees of crowding arches. In this study, three different crowded dental models simulated oral posture and scanned images via the use of IOS, and the trueness of three dental arches was compared. The study aimed to investigate whether the severity of dental arch-crowding affects the trueness of scanning.

Materials and methods

Models set up

Three crowding models (mild, moderate, and severe) were designed and printed as study models. Then, the model was scanned by a desktop scanner (E4 Dental Scanner; 3Shape, Copenhagen, Denmark) to obtain the initial STL file. The printing models were fixed at Nissin Simple Manikin II (Nissin Dental Products Inc., Kyoto, Japan) and set on a dental chair to simulate the clinical posture. The study's intraoral scanner (IOS) system was VIRTUO VIVO (Dentalwings, Montreal, Canada).

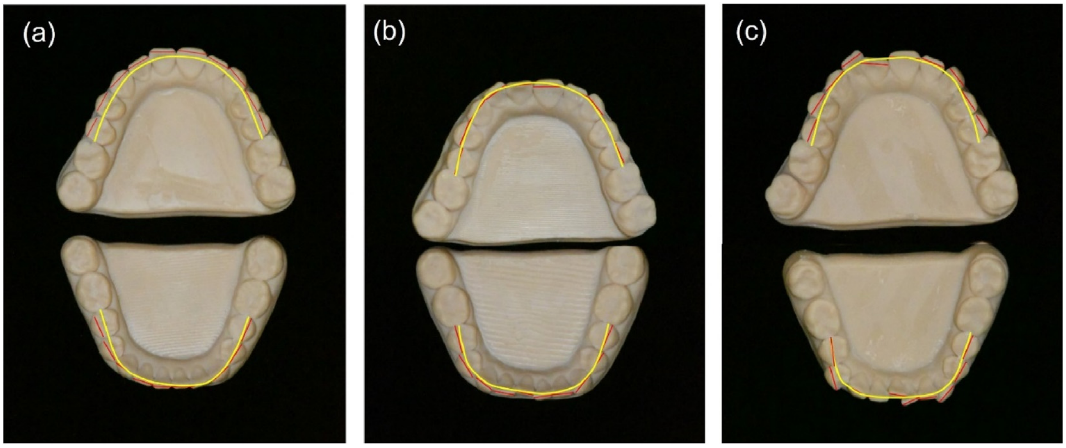

Figure 1 Three different crowding arches: (a) model MI, (b) model MO, (c) model SE (red line represents mesiodistal width; yellow line indicates sectional arch length; model MI: mild, model MO: moderate, and model SE: severe).

Crowded models definition

Fig. 1 shows three dental models, model MI (mild), model MO (moderate), and model SE (severe) respectively. One operator used a Vernier Scale to measure the degree of crowding. In this study, crowding was defined as: the sum of the mesiodistal width of the second premolar to the opposite second premolar minus the sum of the sectional arch length; mild crowding was defined as a discrepancy less than 4 mm with a discrepancy between 4 mm and 8 mm was determined as moderate crowding, and severe crowding determined when the discrepancy was more than 8 mm. The scans had to use the same scanning sequence and method in Fig. 2.

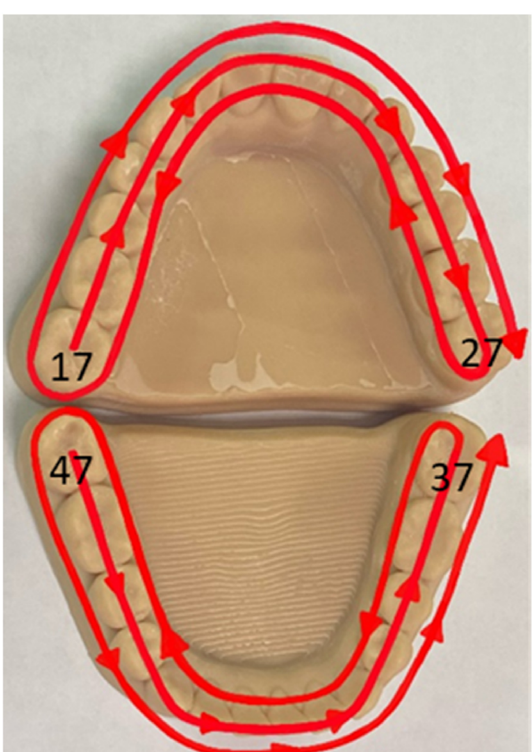

Figure 2 Scanning sequence.

Scanning strategy

For scanning the maxilla, the following path was used: beginning with the right second molar on the occlusal surface, continuing along the occlusal surface until reaching the right second molar again, then returning via the palatal surface, and finally sweeping once over the buccal surfaces. For the mandible, the scanning path started at the occlusal side of the second molar in the fourth quarter of the arch, proceeding longitudinally along the arch until reaching the left second molar and then continuing along the lingual side before ending on the buccal side.

To ensure the consistency and reliability of the experiment, a single experienced right-handed dentist was responsible for conducting all scans. Before operating the experiment, the experienced dentist has practiced scanning the maxilla and mandible each for 10 times to reach the plateau of the learning curve.

To control for variability, each arch scan was performed within a strict time limit of less than 250 s. Additionally, the distance between the IOS scanning tip and the surface being scanned was maintained at a constant of approximately 10 mm throughout the scanning process. To minimize potential sources of variation, all scans were conducted in the same room, with the same room temperature (22 °C), relative humidity (60%), and lighting conditions. To eliminate any additional sources of variability, the same dentist also performed all test scans using AI scanning technology.

The data obtained from the scans was analyzed using the "best fit matching" and "cut view" tools available in the CAD software program (Exocad DentalCAD; Exocad GmbH, Align Technology Inc., Santa Clara, CA, USA). These tools were used to calculate the differences between each measuring point on the model and the table scan file.

Finally, all the STL files were imported into three-dimensional analyzing software (DentalCAD 3.0 Galway,

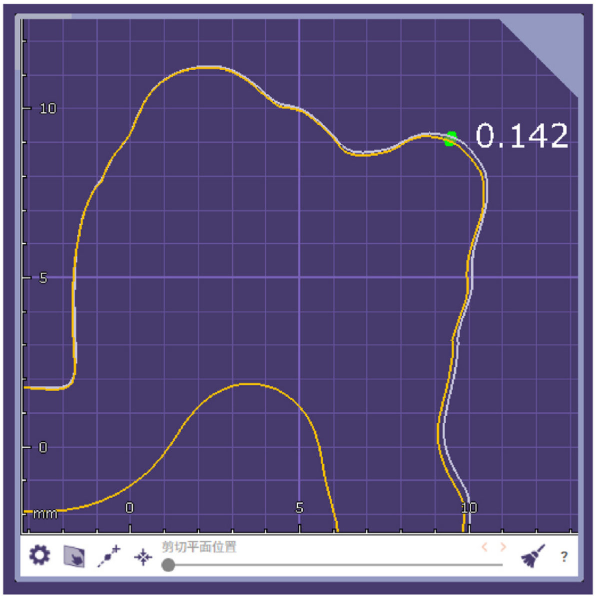

Figure 3 Operational interface of analyzing software, the maximum deviation was 0.142 mm.

exocad GmbH, DE Hessen, Darmstadt, Germany) to evaluate the trueness of different crowding arches. Each of the meshes generated by the intraoral scanner was superimposed onto the reference model captured with the desktop scanner to measure the mean distance (± standard deviation, SD). Fig. 3 illustrated the interface of the operating software, the superimposed deviation in this case was 0.142 mm.

Statistical analysis

Comparisons between the groups were statistically analyzed using one-way variance analysis (ANOVA) and *post hoc* comparisons with Tukey test via IBM SPSS (SPSS Statistics for Windows, v20; IBM Corp., Armonk, NY, USA). A statistical significance value of $P < 0.05$ was used in all tests.

Results

Table 1 lists the space analysis and discrepancy of the three models, and the mean deviations of the three models in the maxilla and mandible are presented in Table 2. The deviation value between intraoral scans and desktop scans of model SE was the maximum (0.144 ± 0.049 mm), followed by models MI (0.099 ± 0.030 mm), and MO (0.095 ± 0.032 mm) in the maxillary arch. In the mandibular arch, ordering the deviation from greatest to least was model SE (0.108 ± 0.051 mm), model MO (0.107 ± 0.061 mm), and model MI (0.103 ± 0.003 mm).

In the maxilla, the values demonstrated the difference among the three models ($P < 0.05$), but there was no significant difference between models in the mandible. Fig. 4 represents the superimpositions between digital reference and intraoral scan models. Model SE showed high deviations (high percentages of the pink color showed on the occlusal side).

Fig. 5 shows the deviation of different tooth positions among three models in the maxilla. The three models had similar deviations in tooth positions 13 to 22, and the statistical results showed a significant difference at tooth positions 15,16,17,24,25,26. Fig. 6 shows the deviation of different tooth positions among the models in the mandible. The figure shows that the scanning deviations had similar trends in different tooth positions, but the statistical results showed that there are significant differences at tooth positions 37, 45, 46, and 47.

Discussion

The principal findings of this study indicate that the trueness between intraoral and desktop scanning systems for

Table 1 Space analysis and discrepancy for the three models. (Unit: mm).

	5-5 Total mesiodistal width		Arch length		Space discrepancy[b]	
	Maxillary arch	Mandibular arch	Maxillary arch	Mandibular arch	Maxillary arch	Mandibular arch
[a]Model MI	71.5	66.9	70.3	64.0	−1.2	−2.9
[a]Model MO	71.5	66.9	66.5	61.0	−5.0	−5.9
[a]Model SE	71.5	66.9	63.0	56.7	−8.5	−8.9

[a] Definition of degree of crowding dentition: mild <4 mm, moderate 4–6 mm, severe >6 mm; MI: mild; MO: moderate; SE: severe.
[b] Space deficiency is space required (5-5 Total mesiodistal width) minus space available (arch length).

Table 2 The mean deviations of three models in the maxilla and mandible (Unit: mm).

	Maxillary arch			Mandibular arch		
	Mean ± SD	95% CI	*P*-value	Mean ± SD	95% CI	*P*-value
Model MI	0.099 ± 0.030[a]	(0.094,0.104)		0.103 ± 0.003	(0.096,0.109)	
Model MO	0.095 ± 0.032[a]	(0.089,0.100)	<0.001	0.107 ± 0.061	(0.097,0.117)	0.669
Model SE	0.144 ± 0.049[b]	(0.135,0.152)		0.108 ± 0.051	(0.099,0.116)	

*One-way ANOVA (three independent groups); *Multiple comparisons with *post hoc* Tukey test; different superscript letters in a column indicate statistical significance among groups ($P < 0.05$); MI: mild; MO: moderate; SE: severe.

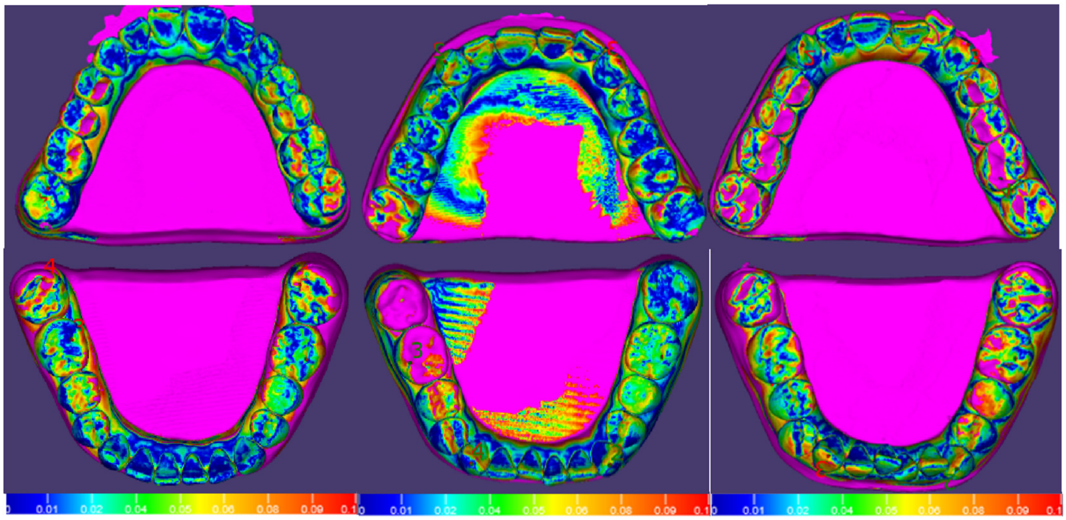

Figure 4 The superimpositions between digital reference models and digital intraoral scan models, (a) model MI, (b) model MO, (c) model SE. (model MI: mild, model MO: moderate, and model SE: severe).

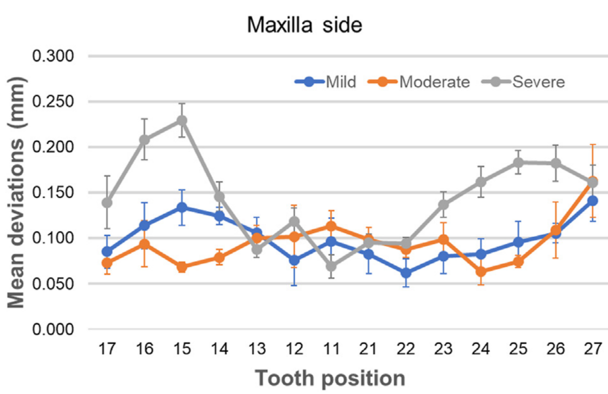

Figure 5 Deviations at different tooth positions among three models in the maxilla.

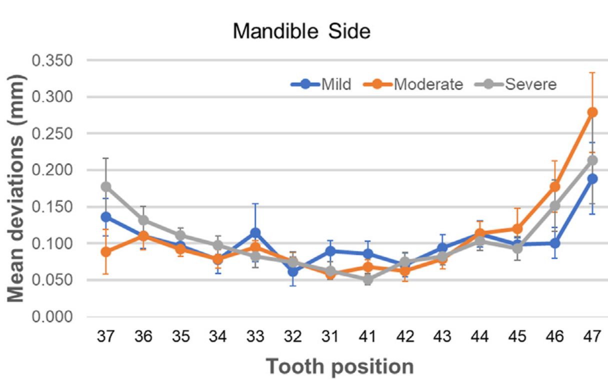

Figure 6 Deviations at different tooth positions among three models in the mandible.

dental arches varies depending on the different tooth-size arch-length deficiency. In maxillary arch, model SE showed the highest deviation values, while models MO and model MI showed similar deviations in maxilla ($P < 0.001$). The mandible revealed no significant differences in the three models ($P = 0.662$). These results suggest that caution should be exercised when relying on scanning technology for certain dental crowding models, as accuracy can vary significantly depending on the model being scanned. Although there is no tolerance range for the deviation value of intraoral scanning for the crowded dental arch currently, it is speculated that shortening the orthodontic treatment time would be beneficial if the deviation value can be reduced. While the study provides valuable insight into the accuracy of scanning technology, the findings are limited to the specific models and scanning methods used in this study and might not be generalizable to other scenarios. Overall, the study highlights the importance of carefully considering the limitations of scanning technology when using it in clinical practice.

The scanning time of the mild, moderate, and severe crowding models (maxilla and mandible) was 299, 300, and 407 s, respectively. The results showed that the model with requiring longer scanning time had lower trueness. Medina-Sotomayor[18] demonstrated the low-scan deviation in a single crown, which requires shorter scanning time than a full arch scan. For different crowding conditions, it might be that the scanning time is too long and the machine overheats, resulting in an increase in error. Furthermore, a more crowded arch might necessitate repeated imaging. Capturing images is a key factor for trueness of intraoral scanners, so severe crowding in the oral cavity might create difficulty in the scanning embrasure; additionally, excess movement of scanner would affect the accuracy of capturing images[14] while also extending the scanning time.

The degree of crowding in the dentition will show the arrangement and overlap of the teeth. The experimental design of this study selected three degrees of crowding ranging from mild to obvious, ranging from 4 mm to 8 mm. The degree of crowding in this range moderately reflects the general disorder of the dentition. Computer simulation is used to simulate the overlapping of evenly arranged teeth. The position and angle of individual teeth will not be too buccal or lingual. Errors caused by extreme tooth positions or angles will be eliminated. Dentition crowding of more than 8 mm may also result in a small dental arch, or the position and angle of the teeth are too buccal or lingually inclined, but it is a special situation of the dentition, which can be used as an extension of the oral scan study. Although the selection criteria of the three different crowding levels in the model are subjective, and the results cannot reflect all crowded dental arch situations, it can qualitatively demonstrate the impact of the crowding level on the oral scan.

On the other hand, mild and moderate crowded arch did not show significant deviation; therefore, it is reasonable to suppose that the amount of crowding arch had a specific effect on trueness. Yoon et al.[17] found the difference in crowding does not appear to depend on the severity of crowding, concluding that the digital model can also be used for crowding beyond 4.5 mm. Different crowding models in the upper and lower jaws also have different trueness, while Feng et al. showed the similar results.[14]

In the upper jaw, there were significant differences among the three models. The severe model has the lowest accuracy, followed by moderate and mild. It is speculated that the reason for the difference in the upper row of teeth may be caused by the machine itself, scanning sequence as well as scanning gestures. In the lower jaw, differences were visible directly and more easily located and scanned than in the upper jaw. There was no obvious difference among the three models, the error value trend lines were similar, and there appear cases where the error value was relatively large in the posterior teeth with the statistical results showing significant differences at the tooth positions 15, 16, 17, 24, 25, 26 in the maxilla and significant differences at the tooth positions 37, 45, 46, 47 in the mandible.

Posterior teeth reflected higher differences than the other positions, presumably related to the errors caused by the machine and gestures. These deviations could be attributed to the inevitable shaking and movement when holding the IOS. The 3D model reconstruction would cause larger deviations in the curved areas of the dental arch, such as premolars, canines and the distal surface of the molars, which require more angles to be flipped during shooting.

Many papers have proposed relevant research on the clinical application of oral scanners such as in comparing the accuracy of traditional impressions and oral scanners, pointing out that oral scanners are more detailed and less error-prone in short-span areas. For clinical orthodontic treatment, a definite diagnosis and combining further digital material, *ex aligner*, would accelerate the treatment efficiency and accuracy. The results showed that the severe crowding case using optical impression should control the scan time or use a hybrid method to obtain proper study or working models. On the other hand, when the crowding level is mild or moderate, optical impressions could be suggested in clinical use. After confirming the level of different tooth-size arch-length deficiency, the digital method can be used as a tool for clinical diagnosis and practice. Although Christopoulou et al.[24] indicated it is unclear as to whether digital methods are more accurate than traditional methods in moderate or severe crowding, with further research being required to determine the reliability of digital measurements. In addition to the latest IOS technological advancements improving the accuracy and repeatability of recorded measurements, different scanning strategies are being explored to facilitate diagnosis and treatment planning.

There are some limitations in this study. Only one mouth scanner and one scan strategy were used; however, despite the dental model via a Nissin holder being set on a dental chair to simulate the posture, environmental influences such as saliva, blood and soft tissue changes would pose unforeseen limitations in this study. Furthermore, different scanners may have different technical specifications and operations, comparing different IOS and environments would benefit in future research.

Within the limitations of the present study, the accuracy of optical impression for full arch via one path in the full arch differed between maxilla and mandible and was dependent on crowding levels. In the maxilla, the discrepancy increased when the degree of crowding was higher ($P < 0.001$), with this discrepancy increasing in scanning the posterior teeth. In the mandible, there were no significant deviations ($P = 0.662$) among the three different levels. Excellent diagnosis paired with digital tools could improve the efficiency of treatment.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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