Original article

In vitro analysis of intraoral digital impression of inlay preparation according to tooth location and cavity type

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Abstract  

Purpose: This study aimed to evaluate the influence of tooth location and inlay cavity type on the accuracy of intraoral digital impressions.  
Methods: Class II inlay preparation was performed on anatomical models of the maxillary first molar (16) and mandibular first molar (46). Mesio-occlusal and disto-occlusal cavities were prepared, such that the axial wall of the proximal box measured 1 mm or 2 mm in height. Thus, four types of inlay cavities were prepared in 16 and 46, respectively. Ten digital impressions of each cavity were obtained using Cerec Primescan (Sirona). Reference scans were obtained with a laboratory scanner (E3, 3Shape). All scan data were exported for comparative analysis of the three-dimensional models. Mean absolute deviation values were calculated to evaluate the trueness and precision of the digital models. Color-coded maps were used for the qualitative analysis of deviations.  
Results: The overall results showed that the trueness for 16 (10.43 ± 0.39 μm) was higher than that for 46 (12.42 ± 0.59 μm) (p < 0.05), while the precision was similar between 16 (3.08 ± 0.92 μm) and 46 (3.08 ± 0.76 μm). The cavity type affected the accuracy of the digital impressions. The highest deviation was observed in positive directions at the margins of the proximal boxes regardless of the cavity type.  
Conclusions: Tooth location and cavity type affected the accuracy of intraoral digital impressions. Positive deviations were observed at the margins of the proximal boxes.  

Keywords: Digital workflow, Inlay cavity, Mean absolute deviation, Virtual model

1. Introduction

The use of digital workflows for the fabrication of indirect restorations has increased, owing to the evolution of computer-aided design and computer-aided manufacturing-based processes in dentistry [1]. A complete digital workflow can be created chairside, using intraoral scanning without physical models. Digital intraoral impressions are superior to conventional impression techniques with elastomeric materials, since they are perceived to be more comfortable by patients, time-saving, have fewer chances of cross-contamination, require only data storage, and can be transferred digitally to the dental laboratory [2, 3]. Indirect restorative workflow, whether conventional or digital, endeavors to prevent errors at each step and minimize the cumulative error through the whole process [2, 4]. Conventional impression procedures and gypsum models are substituted by intraoral scanning procedures and virtual digital models in the digital workflow. Intraoral scanning serves as the basis for the digital workflow and thus, its accuracy is crucial to successful restorative practice [5].

The first digital intraoral impression system was brought to market in 1987 knows as Cerec 1 system [6]. Recently, the newest Cerec system, Primescan AC (Sirona, Bensheim, Germany), was launched in 2019 [7]. Despite the progress in hardware and software for the newest system, little information is available about the performance of the Primescan AC, especially regarding intracoronal restorations.

Researchers have demonstrated the validity of the digital intraoral impression technique for fabricating single-tooth restorations and short-span fixed dental prostheses [8-10]. The accuracy of digital impressions has been commonly evaluated by the marginal and/or internal fit of final restorations [8-11]. However, evaluating the fit of restorations does not reveal the performance of the intraoral digital impression itself, because errors can occur at any step and accumulate through the fabrication workflow [5]. Previous studies have reported the performance of intraoral scanning for the complete arch [12-14], multiunit models [15-17], and single-crown models [18, 19]. In contrast, only a few studies have assessed the accuracy of intraoral digital
impressions for inlay restorations [20-22]. The introduction of errors into the digital intraoral impression before inlay fabrication can lead to an ill-fitting restoration which cannot be seated completely in the tooth, resulting in marginal discrepancy, occlusal interferences, loss of retention, biofilm accumulation, and secondary caries [23, 24]. More chairside time may be needed to adjust the discrepancy between the restoration and prepared cavity. Moreover, excessive adjustment can weaken the restoration itself [25].

Comparative analysis of three-dimensional (3D) models, a method widely used in engineering and adapted for dentistry, involves the superimposition of two surfaces after best-fit alignment [12-14, 20-22]. This superimposition of digital datasets is useful for evaluating the accuracy of digital impressions. The accuracy of measurements and results is described in terms of trueness and precision [26]. Trueness denotes the ability of a measurement to match the actual value, while precision indicates the ability of a measurement to ensure consistent reproduction.

The purpose of this study was to evaluate the influence of tooth location and inlay cavity type on the accuracy of the digital intraoral impression using comparative 3D analysis. The null hypothesis was that there would be no difference in the accuracy of the digital intraoral impression with respect to tooth location and inlay cavity type.

2. Materials and methods

Class II inlays were prepared in anatomical tooth models (A5AN-500, Nissin Dental, Kyoto, Japan) of the maxillary right first molar (16) and mandibular right first molar (46) using a flat-end tapered diamond bur (845KR.314.018, Komet Dental, Lemgo, Germany). Meso-occlusal (MO) and disto-occlusal (DO) cavities were prepared with an occlusal-thismus width of 2.5 mm, 1.5-mm occlusal depth at the central pit, and 1 mm (short) or 2 mm (long) axial wall height for the proximal box. Eventually, four types of inlay cavities (MO-short, MO-long, DO-short, and DO-long) were prepared in 16 and 46, respectively (Fig. 1). The teeth with inlay cavities were screw-retained onto four typodont sets (D85SDP-TRM.451(GSF)-MF, Nissin Dental), which were mounted on a dental phantom head during the scanning procedure, in order to replicate the clinical environment (Fig. 2). The interincisal opening was maintained at 45 mm. Ten digital impressions of each prepared tooth were obtained by an experienced operator using Cerec Primescan AC (v.5.1.0), according to the manufacturer’s instruction. The operator was positioned on the right side of the phantom and scanned the corresponding region including the prepared and adjacent teeth. The scanner was started from the distal adjacent tooth in the occlusal view and moved over the prepared tooth in the mesial direction. Next, the buccal and lingual surfaces were consecutively scanned. Lastly, the scanner was on the prepared tooth to acquire the proximal surfaces in the distal and mesial direction. The reference scan data was obtained by scanning each prepared tooth model with a laboratory scanner (E3, 3Shape, Copenhagen, Denmark) using the die scan mode. All scan data were exported as binary standard tessellation language files for comparative 3D analysis.

The digital models were processed and analyzed with a 3D analysis software (GOM Inspect 2018, GOM GmbH, Braunschweig, Germany). The digital models were trimmed such that only the crown portion of 16 or 46 remained. An initial alignment was done using the function “3-point alignment” and followed by the function “local best-fit” in order to set the scan datasets in the same position. Three nominal planes were created on the mesial, distal, and gingival aspects of the prepared tooth. Irrelevant areas were deleted by the nominal planes to leave only the crown portion of the prepared tooth and obtain a same field of interest. The accuracy of the digital models was assessed as per the trueness and precision, according to definition 5725-1 of the International Organization for Standardization [26]. Trueness is defined as the closeness of agreement between the experimental dataset and reference dataset, while precision is defined as the closeness of agreement among the different scans obtained under the same condition. The prealigned and trimmed digital models were superimposed onto the corresponding reference model using the best-fit alignment method to evaluate the trueness of each cavity group ($n = 10$). The precision was evaluated by superimposing each scan onto the other in the respective test groups ($n = 45$). The mean absolute deviation (average deviation) was used to quantify the 3D difference between the scanned data sets [14, 15]. A low average deviation indicated high trueness or precision. Moreover, the mean maximum positive deviation and mean maximum negative deviation were obtained to observe the local magnitude of deviation with respect to trueness. Color-coded maps were obtained by superimposing all intraoral digital models of a group on the corresponding reference model for the qualitative evaluation of the pattern of deviation.

Data were analyzed using a statistical program (IBM SPSS v.25, IBM Corp., Armonk, NY). The Kolmogorov-Smirnov test was used to determine the normality of data distribution, and Levene’s test was performed to test the equality of variances. The independent two-sample t-test was used to compare variables for the overall trueness and precision between 16 and 46. Bonferroni correction was used for pairwise comparisons. A one-way analysis of variance was conducted to test the statistical significance of the differences among the four types of inlay cavities within each tooth group. Dunnett’s T3 test was used for post-hoc pairwise comparisons. The correlation between trueness and precision was assessed using Spearman’s rank correlation test. Analyses were performed at a significance level of $\alpha = 0.05$.

3. Results

The overall results of average deviation of trueness, mean maximum positive deviation, mean maximum negative deviation, and average deviation of precision are summarized in Table 1. Tooth number 16 showed a significantly higher trueness (average deviation: 10.43 ± 0.39 μm) than that for 46 (12.42 ± 0.59 μm) ($p < 0.05$). In contrast, there was no significant difference in the overall precision between 16 and 46. The mean maximum positive and negative deviations did not differ significantly between the teeth, while the mean maximum positive deviation was significantly larger than the mean maximum negative deviation for both the teeth ($p < 0.05$).

Tables 2 and 3 summarize the variables according to the cavity type (MO-short, MO-long, DO-short, and DO-long) for each tooth group. Fig. 3 and Fig. 4 provide a graphical overview of the results for trueness and precision, respectively. In tooth number 16, MO-long showed significantly lower trueness (10.81 ± 0.23 μm) than that for MO-short (10.03 ± 0.25 μm) and DO-long (10.32 ± 0.23 μm) ($p < 0.05$). In contrast, MO-long showed significantly higher precision (2.81 ± 0.42 μm) than that with DO-short (3.37 ± 1.29 μm) and DO-long (3.34 ± 1.06 μm) ($p < 0.05$). The mean maximum positive deviation ranged from 62.47 μm to 108.80 μm, while the mean maximum negative deviation ranged from 47.72 μm to 56.57 μm. MO-long showed the highest maximum positive deviation (108.80 ± 3.46 μm) among the different cavity types in 16.

In tooth number 46, MO-short showed significantly lower trueness (12.71 ± 0.30 μm) than that for DO-long (12.05 ± 0.32 μm) ($p < 0.05$). MO-short showed significantly lower precision (3.18 ± 0.65 μm) than that with DO-long (2.68 ± 0.43 μm) ($p < 0.05$). The mean maximum positive deviation ranged from 58.42 μm to 108.79 μm, while the mean maximum negative deviation ranged from 48.10 μm to 58.46 μm. MO-short and MO-long showed significantly higher maximum positive deviations than those with DO-short and DO-long ($p < 0.05$). There was no significant correlation between trueness and precision for all the cavity groups.

Fig. 5 shows color-coded maps that were created for assessing deviation patterns with respect to trueness. All intraoral digital models of each cavity group were superimposed on the corresponding reference model in order to demonstrate the cumulative deviation pattern. The majority of deviations occurred in positive directions at the margins of the proximal boxes in all groups. Maximum positive deviations higher than 80 μm were observed frequently at the gingival margins of the proximal boxes.

Local positive deviations were observed at the gingival and palatal margins of the proximal boxes of MO cavities in 16. Large positive deviations were observed at the buccal margins besides at the palatal margins of DO cavities in 16. On the other hand, local positive deviations were observed at the gingival and lingual margins of the proximal box of MO-short in 46. Positive deviations were observed along all margins of the proximal box of MO-long in 46, and were prominent at the bucco-gingival area of the margin.
Negative deviations were observed commonly at the pulpo-distal/mesial line angles of the occlusal cavities and the axio-gingival line angles of the proximal boxes, but with lower magnitudes compared with those of the positive deviations.

4. Discussion

The null hypothesis that there would be no difference in the accuracy of intraoral digital impressions depending on tooth location and inlay cavity type was rejected by the findings of this study. The overall results showed that the trueness for 16 was higher than that for 46, while the precision was similar between the teeth. The cavity type affected the trueness and precision of the digital impressions. There was no significant correlation between trueness and precision.

This in vitro study was designed to simulate clinical conditions as closely as possible. The inlay cavities were prepared in anatomical tooth models according to the Cerec guidelines. Some researchers have reported that restoration type, tooth geometry, and tooth location affected the accuracy of digital impressions [21, 27, 28]. Proximal areas are most challenging for adequate digital impressions [21, 29, 30]. MO and DO cavities are commonly encountered in clinical practice, and have different accessibility and visual interference in the oral cavity. With regard to tooth geometry, cavity depth can be associated with the accuracy of digital impressions [21, 28]. In the present study, short and long axial wall heights simulated inlay cavities that were extended just below the proximal contact point and extended gingivally into the interproximal area, respectively.

In this study, we acquired intraoral digital impressions on the phantom head. One of the most distinctive features of the intraoral digital impression is that scan data acquisition is accomplished within the oral cavity in real clinical situations. In contrast, some in vitro studies on intraoral scanning were performed under free-space conditions, i.e., the model was held in the hand during scanning, which permitted greater freedom while placing the scanning wands [12-19]. A greater degree of freedom (than that which is actually available in the oral cavity) ensures a direct line-of-sight, favorable angle of incidence, which can affect the quality of the scan [30, 31]. An in vivo study found that the precision for extraoral scanning was higher than that for intraoral scanning with the same intraoral scanner [31]. An in vitro study by Keeling et al. [30] demonstrated that the sharpness of the distal margin of a crown preparation on the lower molar was significantly decreased in scans obtained from a phantom head. Studies comparing intraoral scanners and laboratory scanners showed that laboratory scanners produced a more precise outcome than intraoral scanners [27, 31]. The superior accuracy of laboratory scanners may be attributed to conditions that favor a direct line-of-sight. Therefore, scanning conditions can affect the results of studies on digital impressions. The findings of our study may be clinical relevant since the models were place on a phantom head during the intraoral digital impression procedure, which simulated the oral conditions to a certain degree.

A desktop laser scanner (E3, 3Shape) was used to acquire reference scans. The E3 scanner has an accuracy of 7 μm, as reported by the manufacturer, and has shown higher accuracy compared with some other desktop scanners [32]. The reference scans were obtained by scanning each prepared tooth like a single-die model in order to eliminate interferences of the adjacent teeth and gingival structure.

The overall trueness was higher for 16 than that for 46. A direct line-of-sight is the first prerequisite for a digital impression of good quality [30, 31]. A proper angle of incidence is also required for optimal scanner performance [30]. Even if a direct line-of-sight is available, a restricted viewing angle or unfavorable wand orientation can lead to a deviation in the acquired scan. While scanning the upper molar, the palatal vault provided space for favorable orientation of the scanner head on the palatal side, and the smaller arch of the lower dentition (than that of the upper dentition) gave more freedom for placing the scanner wand on the buccal side. A favorable condition for scanning the proximal areas may improve the trueness of the digital impression of the upper molar, since the deviations were observed mostly at the proximal areas.

Some studies evaluated the effect of tooth location and shape on digital impressions [21, 27, 28]. Rudolph et al. [28] observed a greater deviation with a crown preparation on an incisor than that on a molar. Since their results were obtained by scanning single dies in a laboratory condition, the difference between the deviations of the incisors and molars cannot be attributed to tooth location but to the convergence angle and length of the prepared teeth. They reported that steep tooth surfaces negatively affected the quality of the digital impression. Su and Sun [27] found that the precision of digital impressions for single crown preparations was similar for incisors and molars. However, their findings did not demonstrate the effect of tooth location, because the scanning procedure was performed in a free space. Several in vivo studies on full-arch digital impressions with
Table 1. Overall comparisons between the teeth for average deviation for trueness, mean maximum deviations, and average deviation for precision (μm).

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Average deviation for trueness*</th>
<th>Mean maximum positive deviation**</th>
<th>Mean maximum negative deviation**</th>
<th>Average deviation for precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 16</td>
<td>10.43 ± 0.39</td>
<td>82.02 ± 19.59Aa</td>
<td>52.04 ± 4.63Ab</td>
<td>3.08 ± 0.92</td>
</tr>
<tr>
<td>No. 46</td>
<td>12.42 ± 0.59</td>
<td>86.28 ± 28.31Aa</td>
<td>55.66 ± 5.45Ab</td>
<td>3.08 ± 0.76</td>
</tr>
</tbody>
</table>

* There is a significant difference in the average deviation for trueness of the teeth (p < 0.05).

** The same uppercase superscript letters indicate the absence of a statistically significant difference in the same column, with respect to mean maximum deviations. Different lowercase superscript letters indicate significant differences in the same row (p < 0.05).

Table 2. Comparisons of parameters between inlay cavities for tooth No. 16 (μm).

<table>
<thead>
<tr>
<th>Cavity</th>
<th>Average deviation for trueness</th>
<th>Mean maximum positive deviation</th>
<th>Mean maximum negative deviation</th>
<th>Average deviation for precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-short</td>
<td>10.03 ± 0.25A</td>
<td>73.19 ± 12.06AB</td>
<td>56.57 ± 2.42B</td>
<td>2.78 ± 0.38A</td>
</tr>
<tr>
<td>MO-long</td>
<td>10.81 ± 0.23C</td>
<td>108.80 ± 3.46C</td>
<td>54.17 ± 2.66B</td>
<td>2.81 ± 0.42A</td>
</tr>
<tr>
<td>DO-short</td>
<td>10.57 ± 0.31B</td>
<td>62.47 ± 12.55A</td>
<td>49.69 ± 3.54A</td>
<td>3.37 ± 1.29B</td>
</tr>
<tr>
<td>DO-long</td>
<td>10.32 ± 0.23AB</td>
<td>83.63 ± 6.04B</td>
<td>47.72 ± 3.57A</td>
<td>3.34 ± 1.06B</td>
</tr>
</tbody>
</table>

Different superscript letters indicate significant differences in the same column (p < 0.05).

Table 3. Comparisons of parameters between inlay cavities for tooth No. 46 (μm).

<table>
<thead>
<tr>
<th>Cavity</th>
<th>Average deviation for trueness</th>
<th>Mean maximum positive deviation</th>
<th>Mean maximum negative deviation</th>
<th>Average deviation for precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-short</td>
<td>12.71 ± 0.30B</td>
<td>108.79 ± 35.17B</td>
<td>57.62 ± 2.09B</td>
<td>3.18 ± 0.65B</td>
</tr>
<tr>
<td>MO-long</td>
<td>12.62 ± 0.84AB</td>
<td>105.12 ± 11.13B</td>
<td>58.44 ± 2.42B</td>
<td>2.99 ± 0.65AB</td>
</tr>
<tr>
<td>DO-short</td>
<td>12.28 ± 0.54AB</td>
<td>58.42 ± 8.15A</td>
<td>48.10 ± 4.47A</td>
<td>3.45 ± 0.99B</td>
</tr>
<tr>
<td>DO-long</td>
<td>12.05 ± 0.32A</td>
<td>72.77 ± 4.86A</td>
<td>58.46 ± 3.64B</td>
<td>2.68 ± 0.43A</td>
</tr>
</tbody>
</table>

Different superscript letters indicate significant differences in the same column (p < 0.05).

Fig. 3. Illustration of overall average deviation for trueness. Tooth No. 16 significantly better overall trueness than tooth No. 46 (p < 0.05).

Fig. 4. Illustration of overall average deviation for precision. There was no significantly difference in overall precision between tooth No. 16 and tooth No. 46.

Intraoral scanners have reported that the posterior region showed a greater deviation than that in the anterior region [31, 33]. The deviation in the posterior region increased when an intraoral scanner was used in the oral cavity, compared to when it was used in a free space [31]. The findings of our study and previous studies indicate that patient and tooth-related factors, such as anatomic restrictions associated with the placement of intraoral scanners, tooth location, and morphology, can affect the quality of digital impressions.

The most prominent deviations occurred at the margins of the proximal boxes, irrespective of the cavity type. Studies on intraoral digital impressions have reported that local deviations were frequently observed at the proximal areas [31, 33]. Deviations in the proximal areas can be caused by limited visibility, unfavorable viewing angle, tooth morphology [28-30, 34]. First, the neighboring teeth hinder a direct line-of-sight over the
proximal areas. A study on a tooth prepared to receive a crown prosthesis reported that the presence of adjacent teeth resulted in less sharply defined margins at the proximal areas on the scanned image compared to the absence of neighboring teeth [30]. In contrast, the same study reported that the scan images of buccal and lingual margins were not affected by the presence of neighboring teeth. Moreover, even if a line-of-sight is available, limited visibility and an unfavorable viewing angle can result in a distorted scan image [30, 34]. Deviations in scan images could be decreased by ensuring that the scanning ray is as perpendicular as possible to the surface being scanned [34, 35]. In our study, although all margins of the proximal boxes were uninterrupted on the scanned images, local deviations in some areas reached up to 100 μm. The proximal margins were visible through the scan camera but frequent changes were needed in the positioning and orientation of the scan wand during the scanning procedure. Sometimes, the scan ray had to be directed nearly parallel to the proximal surfaces being scanned in order to obtain a direct line-of-sight. Tooth morphology is another factor that can affect the accuracy of digital impressions [28, 31]. Changes in the curvature and steepness of the proximal areas can negatively affect the accuracy of digital impressions [28]. Moreover, the visibility of undercut areas below the height of contour is restricted and they appear as shadow regions, which are difficult to scan correctly.

The deviations in the proximal areas occurred in positive directions with respect to trueness (Fig. 5). Besides restricted visibility, proximity to the adjacent teeth can cause local deviations in the proximal areas [30, 36]. The surface algorithm of the scanning software tends to fill and smooth flaws on the scan image by interpolating over missing data. This system algorithm often incorporates artificial bulges on the preparation margins or bridges between approximal regions on the scanned image [29, 30, 36]. These bulges and bridges are associated with large positive deviations. In this study, the proximal margins of all inlay cavities were clearly visible to the naked eye with distinct clearances from the neighboring teeth. However, the bulges on the digital models were observed most frequently at the gingival margins (Fig. 6). Thus, the positive deviations observed at the proximal margins can be attributed to the artificial bulges associated with the proximity to the adjacent teeth. Ferrari et al. [36] assessed horizontal distances needed to obtain a clearly defined margin in digital intraoral impressions. They concluded that a clearance of greater than 0.5 mm was required to record a clear and undistorted digital impression in the marginal areas. On the other hand, the bulges of the proximal margins frequently occurred, even though we prepared the inlay cavities with a clearance exceeding 0.5 mm. Therefore, clinicians need to try to provide distinct clearance from the neighboring tooth during cavity preparation for inlay restorations fabricated using a digital workflow. Conventional impression techniques should be considered if the individual tooth anatomy does not permit the provision of a distinct proximal clearance.

There was no significant correlation between trueness and precision. For instance, although MO-long in 16 showed a relatively low trueness (a high deviation value), it showed a similar or even better precision compared with the other cavities (Fig. 3, Fig. 4, and Fig. 7). Park et al. [21] reported that the cavity type affected the trueness of digital intraoral impressions but not the precision, which is consistent with our findings. This implies that even though an intraoral scanning has good reproducibility, the measurements of a digital model can deviate considerably from those of the actual cavity. In other words, repeat scanning will not reveal the possible deviations introduced in the digital impression step. The errors in the digital model that cannot be easily be recognized by a practitioner can result in an ill-fitting restoration, which can require more time for adjustments or result in a consequent failure of the restorative workflow. Therefore, confounding factors, such as placing margins in areas with restricted visibility and proximity to the neighboring teeth, should be avoided in the cavity preparation step to obtain an accurate digital intraoral impression.

This study evaluated the accuracy of intraoral digital impression for inlay preparations. The clinical implication of a discrepancy in the digital impression step has not been elucidated well [37]. Nevertheless, it seems obvious that further errors can be introduced in the subsequent steps, including virtual model processing, restoration design, and restoration milling [5]. Therefore, the discrepancy of digital impressions should be minimized to obtain restorations with a good fit. A review reported that marginal misfits for single-tooth ceramic restorations derived from digital intraoral impressions and conventional impressions were 63.3 μm and 58.9 μm, respectively [11]. These discrepancies are below the maximum clinically acceptable marginal discrepancy of 120 μm [38]. The average trueness values ranging from 10.03 μm to 12.71 μm in our study, support the validity of using the digital intraoral impression technique.

The results of this study were obtained by performing a digital scan in an in vitro environment. Performing the assessment in other clinical situations may yield different findings, because various factors can affect the results of intraoral scanning [29, 31]. Another limitation of the present study was that only one intraoral scan system was used. Further studies are needed to fully comprehend the features of intraoral scanning with various intraoral
scan systems in clinical settings.

5. Conclusion
Within the limitations of this study, tooth location and inlay cavity type affected the accuracy of the intraoral digital impression. The overall accuracy of digital impressions for inlay preparations was clinically acceptable, but positive deviations were observed at the margins of the proximal boxes.

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Conflicts of interest
The authors declare to have no conflict of interest.

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