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RESEARCH AND EDUCATION

Influence of scan body design on accuracy of the implant position as transferred to a virtual definitive implant cast

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ABSTRACT

Statement of problem. Previous studies have analyzed factors influencing intraoral scanner accuracy; however, how the intraoral scan body design affects the implant position on the virtual definitive cast is unclear.

Purpose. The purpose of this in vitro study was to measure the discrepancies of the implant replica positions of the virtual definitive implant cast obtained by using 3 different scan body designs when performing a digital scan.

Material and methods. A partially edentulous typodont with 3 implant replicas (Implant Replica RP Branemark system; Nobel Biocare Services AG) was prepared. Three groups were determined based on the scan body system evaluated: SB-1 (Elos Accurate Nobel Biocare), SB-2 (NT Digital Implant Technology), and SB-3 (Dynamic Abutment). Each scan body was positioned on each implant replica of the typodont, and was digitized by using an intraoral scanner (iTero Element; Cadent) as per the manufacturer's scanning protocol at 1000 lux illuminance. A standard tessellation language (STL) file was obtained. Before the scan bodies were removed from the typodont, a coordinate measuring machine (CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Messtechnik GmbH) was used to measure the scan body positions on the x-, y-, and z-axis. The linear and angular discrepancies between the position of the scan bodies on the typodont and STL file were calculated by using the best fit technique with a specific program (Calypso; Carl Zeiss Industrielle Messtechnik GmbH). The procedure was repeated until 10 STL files were obtained per group. The Shapiro-Wilk test revealed that the data were not normally distributed. The data were analyzed by using the Mann-Whitney U test (α=.05).

Results. The coordinate measuring machine was unable to measure the scan body positions of the magnetically retained SB-3 group because of its mobility when palpating at the smallest pressure possible. Therefore, this group was excluded. No significant differences were found in the linear discrepancies between the SB-1 and SB-2 groups (P>.05). The most accurate scan body position was obtained on the z-axis. However, the SB-1 group revealed a significantly higher XZ angular discrepancy than the SB-2 group (P<.001).

Conclusions. The scan body systems tested (SB-1 and SB-2 groups) accurately transferred the linear implant positions to the virtual definitive implant cast. However, significant differences were observed in the XZ angular implant positions between the scan body systems analyzed. (J Prosthet Dent 2020;■:■-■)

A definitive implant cast should accurately represent the three-dimensional (3D) implant positions of the implants in relation to the surrounding intraoral tissues.[1] Conventionally, an implant impression is made with an elastomeric impression material in a custom tray after attaching an implant impression abutment to each implant.[1-3] When an intraoral scanner (IOS) is used, it should obtain an accurate representation of the clinical situation, including the 3D position of implants using an intraoral scan body placed on each implant.[4-8]

The accuracy of IOSs when performing implant digital scans has been evaluated.[5-7,9-17] Intraoral scanning has

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Clinical Implications

The selection of an intraoral scan body may impact the accuracy of an intraoral digital scan; therefore, the clinician should carefully select the scan body system for an implant digital scan.

Table 1. Scan body systems evaluated

Group	Scan Body System	Scan Body Material
SB-1: Nobel Biocare Services AG	Elos Accurate Intraoral Scan Body	Titanium base with coronal PEEK component
SB-2: NT Digital implant technology	Scan body 3D Guide K Series	Titanium base with coronal PEEK component
SB-3: Dynamic Abutment Solutions	Intraoral scan body system with intraoral adaptor.	Intraoral adaptor: Titanium Intraoral scan body: PEEK 2 pieces connected with magnet

PEEK, polyetheretherketone; SB, scan body.

been reported to be a clinically acceptable alternative to conventional impression methods in the fabrication of implant-supported crowns and short-span fixed dental prostheses.[10,11,16-19] However, the published data that evaluated the accuracy of implant digital scans provided an inconclusive level of clinical evidence for a predictable application compared with conventional techniques.[13-15] In addition, the relationship between the design features of different intraoral scan body designs and the accuracy of implant position digitalization is unclear.[19-22]

Factors that influence the accuracy of a digital scan include implant angulation,[9] distance between the implants,[12] scanning protocol,[23,24] calibration of the intraoral digitizing device,[25] handling and learning,[26,27] and ambient scanning light conditions.[28-30] Furthermore, scanning accuracy differences should be expected when considering the different scanning technologies that are available.[31-40]

The accuracy of a scanner is defined by trueness and precision. Trueness relates to the ability of the scanner to reproduce a dental arch as close to its true form as possible without deformation or distortion, whereas precision indicates the difference among images acquired by repeated scanning under the same conditions.[41]

The purpose of this in vitro study was to measure and compare the linear and angular discrepancies of the implant replica positions obtained by using 3 different scan body designs when performing a digital scan. The null hypotheses were that no significant differences in linear and angular discrepancies would be found between the 3 scan body designs with regard to the typodont implant replica positions and virtual definitive cast implant replica positions.

MATERIAL AND METHODS

A dental simulator mannequin (Nissin Type 2; Nissin) with a partially maxillary dentate typodont (Hard Gingiva Jaw Model MIS2009-U-HD-M-32; Nissin) was used. The right third and second molar, right first premolar, and left first and second premolar denture teeth were present. In the edentulous areas, 3 implant replicas (Implant replica RP Brånemark system; Nobel Biocare Services AG) in the positions of right and left canines and second left molar were placed and secured with acrylic resin (Pattern Resin; GC America). The coronal 3 mm of implant replicas were covered with tissue moulage (Softissue Moulage; Kerr Corp) to simulate the clinical conditions and facilitate posterior measurements.

A prosthodontist (M.R.L.) with 8 years of experience using IOSs recorded different digital scans of the maxillary typodont with 3 different intraoral scan body systems (Table 1): SB-1 (ELOS Medtech), SB-2 group (NT Digital Implant technology), and SB-3 (Dynamic Abutment) (Fig. 1). All the digital scans were performed in a room with a dental chair (A-dec 500; Adec) and no windows. The unit light was turned off. The ceiling light (GE F54W-T5-841-ECO; Ecolux High Output) comprised six 54-W fluorescent tubes registering 5000 lumens and 4100 K white spectrum color temperature. The luminosity at the typodont was 1000 lux measured by using a light meter (LX1330B Light Meter; Dr. Meter Digital Illuminance).

For the SB-1 specimens, an intraoral scan body (Elos accurate IO scanbody Bränemark system RP; Nobel Biocare Services AG) was hand tightened until stable on each implant replica positioned on the maxillary typodont, as recommended by the manufacturer. Then, without removing or changing the scan body positions, a digital scan was obtained by using an IOS (iTero Element; Cadent) following the scanning protocol recommended by the manufacturer. A standard tessellation language (STL_{SB1}) file was created.

Before the scan bodies were removed from the typodont, a coordinate measuring machine (CMM) (CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Messtechnik GmbH) was used to measure the scan body positions on the x-, y-, and z-axis by using a 0.5-mm stylus (SensorVast XXT 0.5 mm; Carl Zeiss Industrielle Messtechnik GmbH) at a 0.1-N tactile load (Fig. 2). The data for each scan body were condensed to the center point of the implant replica in the x- (buccolingual), y- (mesiodistal), and z-(apicocoronal) axis. 3D linear (x-, y-, and z-axis) directions of the center point displacement were calculated in micrometers (μm).

For the angular discrepancy calculations, the axis of each implant replica of the master cast was calculated. Each axis had 2 projections, one on the x-axis (XZ angle) and another on the y-axis (YZ angle). The nominal linear

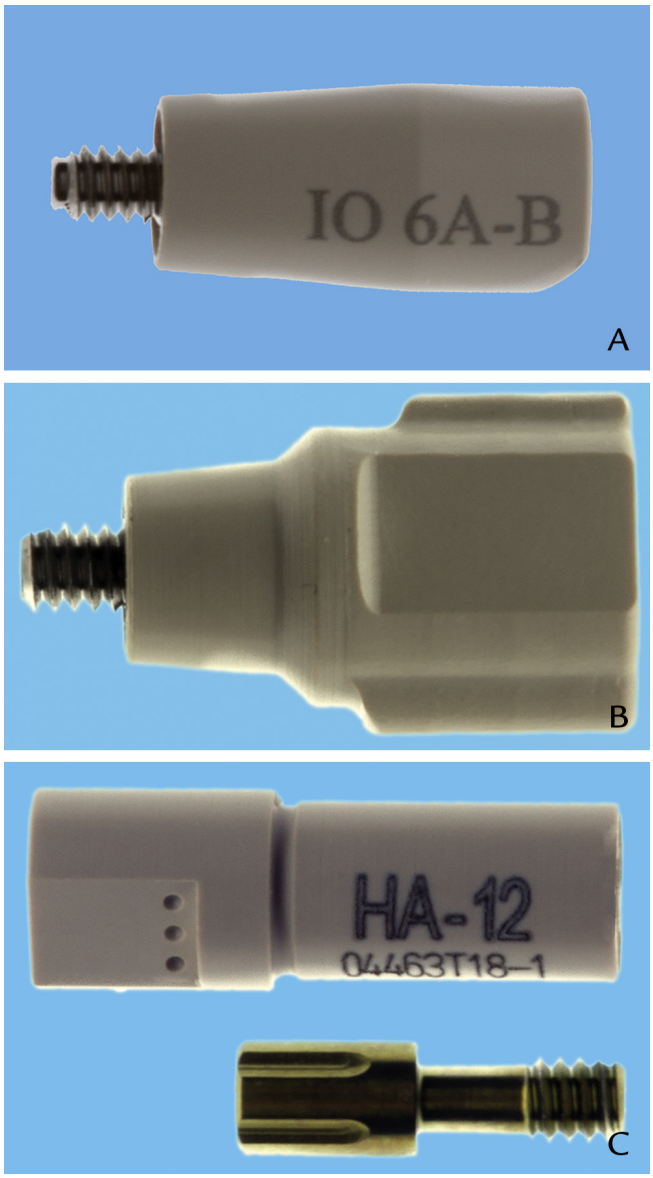

Figure 1. A, One-piece intraoral scan body from SB-1 group (Elos accurate IO scanbody Brånemark system RP; Nobel Biocare Services AG). B, One-piece intraoral scan body from SB-2 group (Scan Body 3D Guide K Series; NT Digital Implant Technology). C, Two-piece intraoral scan body system from SB-3 group (Dynamic Abutment Intraoral Scanner; Dynamic Abutment Solutions).

accuracy of the machine was described by the manufacturer to be within 1 μm on all axes. The 3D position of scan bodies on the typodont was calculated and used as a reference to calculate the scan body discrepancies within different STL files obtained in the SB-1 group using the best fit technique in a specific CAD software program (Calypso; Carl Zeiss Industrielle Messtechnik GmbH). The 3D discrepancy was calculated by using the formula $3D = \sqrt{x^2+y^2+z^2}$.[2,42] The same procedure was repeated with a new set of intraoral scan bodies until 10 STL files were obtained on the SB-1 group.

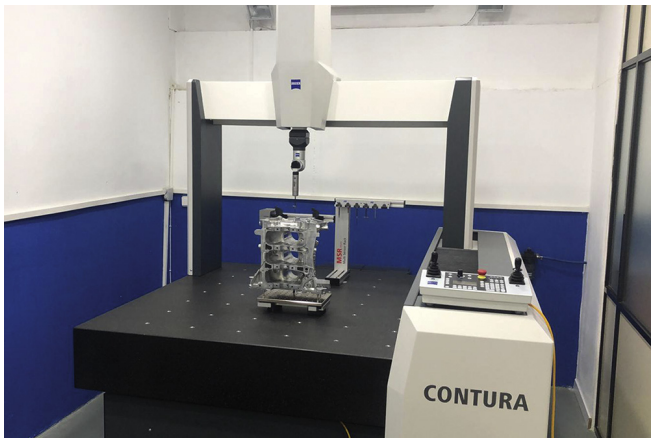

Figure 2. Coordinate measuring machine (CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Messtechnik GmbH) analysis.

For the SB-2 specimens, an intraoral scan body (K Series, Scan Body 3D-Guide for intraoral scanning Ref. K 9.S3D4.100; NT Digital Implant Technology) was hand tightened until stable on each implant replica on the maxillary typodont, as recommended by the manufacturer. Then, a digital scan was obtained using the same IOS, and the same scanning protocol as performed on SB-1 group. An STL_{SB2} file was created. Before the scan bodies were removed from the typodont by using the same CMM machine, an identical protocol was used to analyze the linear and angular discrepancies in each scan body position of the typodont within each STL file obtained in the SB-2 group. The same procedure was repeated with a new set of intraoral scan bodies until 10 STL files were obtained for the SB-2 group.

For the SB-3 specimens, an intraoral adaptor (Dynamic Scanbody System Adaptor 12 mm length for Brånemark RP connection; Dynamic Abutment Solutions) was hand tightened until stable on each implant replica on the maxillary typodont. Subsequently, the scan body (Intraoral Scan body for Brånemark RP connection; Dynamic Abutment Solutions) was positioned on each intraoral adaptor. Then, a digital scan was obtained by using the same IOS and scanning protocol as performed on the SB-1 and SB-2 groups. An STL_{SB3} file was obtained. Before the scan bodies were removed from the typodont by using the same CMM machine, an identical protocol was used to analyze the linear and angular discrepancies on each scan body position of the typodont within each STL file obtained in the SB-3 group. The same procedure was repeated with a new set of intraoral scan bodies until 10 STL files were obtained on the SB-2 group.

The definition of trueness in the experiment was the average absolute distance between the reference model and the scanned model. Precision was defined as the distances between points of the reference model and the scanned model.[40]

Table 2. Linear (x-, y-, and z-axis) and angular (XZ and YZ angles) discrepancies between implant replica positions of maxillary typodont and virtual definitive implant casts of SB-1 and SB-2 groups

Group	x-Axis (μm) Median ±IQR	y-Axis (μm) Median ±IQR	z-Axis (μm) Median ±IQR	XZ Angle (degrees) Median ±IQR	YZ Angle (degrees) Median ±IQR
SB-1	-18.8 ±95.2[a]	2.6 ±95.3[b]	0 ±0[c]	0.5 ±0.2[d]	0.0 ±0.5[f]
SB-2	11.4 ±66.9[a]	1.9 ±79.5[b]	0 ±0[c]	-0.0 ±0.4[e]	0.0 ±0.2[f]

IQR, interquartile range; SB, scan body; SB-1 group, Elos accurate IO scanbody Brånemark system RP (Nobel Biocare Services AG); SB-2 group, Scan Body 3D Guide K Series (NT Digital Implant Technology). Table designed to be read column wise and letters unique to each element. No statistically significant differences (*P*>.05) between groups with same superscript letter. Median values represent trueness while interquartile range values represent precision of digitizing procedures tested

Table 3. 3D discrepancy between implant replica positions of maxillary typodont and virtual definitive implant casts of SB-1 and SB-2 groups

Group	Trueness (μm)	Precision (μm)
SB-1	18.9[a]	134.7[b]
SB-2	11.5[a]	103.9[b]

IQR, interquartile range; SB, scan bodyl; SB-1 group, Elos accurate IO scanbody Brånemark system RP (Nobel Biocare Services AG); SB-2 group, Scan Body 3D Guide K Series (NT Digital Implant Technology). Table designed to be read column wise and letters unique to each element. No statistically significant differences (*P*>.05) between groups with same superscript letter.

The Shapiro-Wilk test revealed that the data were not normally distributed. The data for linear (μm) and angular (degrees) discrepancies were analyzed using the Mann-Whitney U test. Statistical analysis was performed by using a statistical software program (IBM SPSS Statistics for Windows, v25; IBM Corp) (α=.05).

RESULTS

The CMM machine was unable to measure the scan body positions of specimens in the magnetically retained SB-3 group because of the mobility of scan bodies when contacted by the 0.5-mm stylus at the smallest load possible (0.1 N). Therefore, this group was excluded from the statistical analysis.

Linear (x-, y-, and z-axis), angular (XZ and YZ angles), and 3D discrepancies are presented in Tables 2 and 3. The boxplots of linear and angular discrepancies are presented in Figure 3. The Mann-Whitney U test revealed no significant differences in the linear x-, y-, and z-axis distortion between the SB-1 and SB-2 groups (*P*>.05). The most accurate scan body positions were obtained on the z-axis (*P*<.05). Furthermore, no significant differences were observed in the YZ angular discrepancy between the groups. However, the SB-1 group demonstrated a significantly higher XZ angular discrepancy than the SB-2 group (*P*<.001).

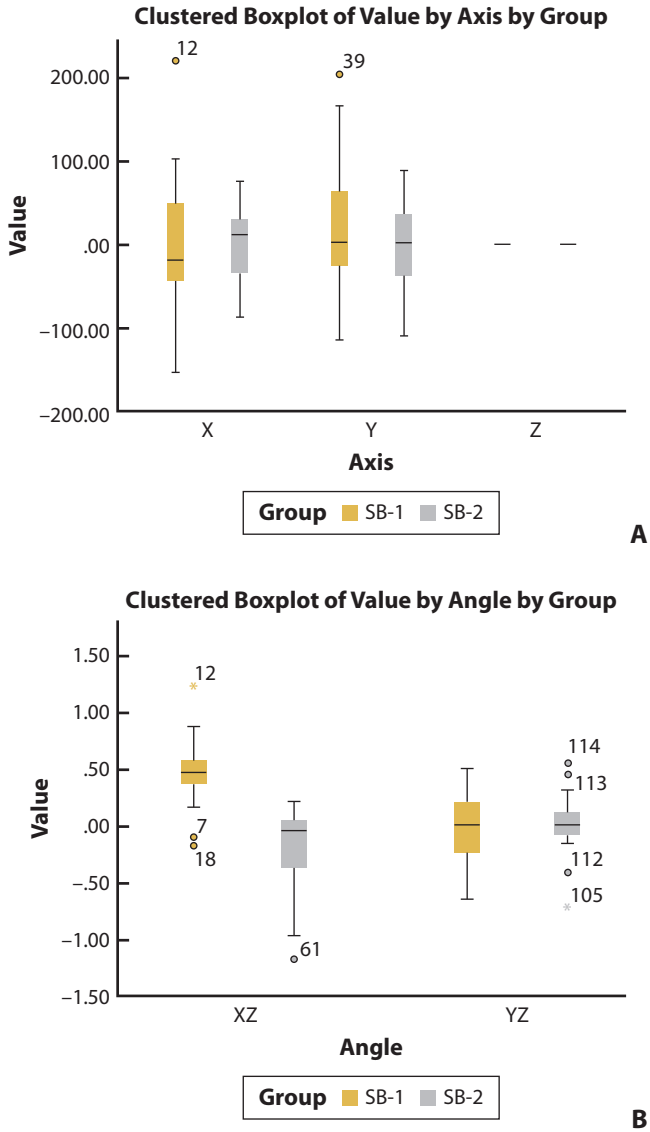

Figure 3. A, Boxplot of linear (x-, y-, and z-axes) discrepancies (μm). B, Boxplot of the angular (XZ and YZ angles) discrepancies in degrees. SB, scan body; SB-1 group, Elos accurate IO scanbody Brånemark system RP (Nobel Biocare Services AG); SB-2 group, Scan Body 3D Guide K Series (NT Digital Implant Technology).

DISCUSSION

The purpose of the present in vitro study was to measure and compare the linear and angular discrepancies in the scan body positions on the typodont and their corresponding virtual definitive implant casts obtained by using 3 different scan body systems when performing a digital scan. No significant differences were found in the linear x-, y-, and z-axis distortion between the SB-1 and SB-2 groups; however, the SB-1 group revealed a significantly higher XZ angular discrepancy than the SB-2 group. Therefore, the null hypothesis was rejected.

Because of mobility when palpated with a 0.5-mm stylus, the CMM machine was unable to measure the scan body positions of the specimens in the SB-3 group. Therefore, this group was excluded from the statistical analysis. This product connects a metal intraoral adaptor

to the coronal polyetheretherketone (PEEK) scan body with a magnet. Most likely, the magnet was unable to maintain the PEEK scan body in place during the scanning procedure. In a clinical situation, contact with the patient's tongue or scanning tip could result in unrecognized inaccuracies of the intraoral scan. Clinical studies are recommended to analyze the performance of 2-piece intraoral scan bodies and their accuracy in transferring the implant position to the virtual definitive implant cast.

Current dental CAD software programs do not allow a direct comparison of implant replica positions between the partially dentate typodont and the virtual definitive implant casts obtained from the different digital scans. When the STL file of a virtual definitive implant cast is exported from the dental CAD software program (Model builder, Dental System; 3Shape), the program automatically generates the space for implant analogs on the virtual cast. This is performed because the STL file is used to additively manufacture the definitive implant cast. This means that after the additively manufacture of the polymer cast, the digital implant replicas are positioned in the cast. For that reason, it was not possible to obtain the STL file with implant replicas. Therefore, the scan body positions were analyzed instead.

Although the geometries of scan bodies differed significantly among the groups evaluated, a significant difference was only encountered in the XZ angular discrepancy between the scan body positions on the partially dentate typodont and the scan bodies of the virtual definitive implant casts obtained using an IOS. Furthermore, CMM analysis not only provided information pertaining to linear and angular position discrepancies but also to different positions on the x-, y-, and z-axes. For example, a negative value on the z-axis discrepancy represents a more apical position of the scan body than to the position of the typodont. The standard deviations of the x- and y-axis discrepancies indicated large variability in the obtained data.

Manufacturing tolerances and variation in material construction differences among the scan body system evaluated may have introduced uncontrolled discrepancies into the measurements performed. In the present study, each scan body was hand tightened on each implant replica of the typodont, as the manufacturer recommended; however, this may have led to a difference in scan body seating among the groups. In addition, each scan body group was positioned on the implant replica of the typodont and was not removed until the digital scan and measurements with the CMM machine were completed. Therefore, the damage to the PEEK scan bodies was minimized.[21,37] The IOS selected (iTero Element; Cadent) has been reported to accurately reproduce scan body geometries under room light scanning conditions when following the scanning protocol recommended by the manufacturer.[28,29] However, generalizations of the results obtained in the present study should be avoided as variations in the IOS technology and system may lead to different results.

Stimmelmayr et al[20] analyzed in vitro the accuracy of the scan bodies both on implants and laboratory implant replicas by using a laboratory white-light scanner. A completely edentulous arch with 4 implants was used. On each scan, the scan bodies were detached from the implants or implant replicas and reattached on the same implant clockwise at a torque of 5 Ncm. The first scan of each group (control) was used as a reference and compared with the remaining digital scans. The mean discrepancy of the scan bodies was 39 ±58 μm on the original implants and 11 ±17 μm on the laboratory implant replicas.

Mizumoto et al[21] evaluated the effects of 4 scanning techniques and 5 intraoral scan bodies on the trueness, precision, and scan time in a completely edentulous arch with 4 implants. Significant differences were reported in the trueness and precision of the resulting scans when 4 different scanning strategies and 5 scan bodies were tested. All scan bodies and scan techniques resulted in a distance deviation greater than 170 μm and an angular deviation greater than 0.5 degrees.

Different research protocols make a comparison between studies on implant digital scan accuracy difficult. Specifically, the complexity and area of the geometry analyzed (number of implants present in a partially dentate or completely edentulous arch), superimposition method selected (best fit algorithm or iterative closest point algorithm), and reference model used (STL file with known dimensions or an STL file obtained from a reference scanner such as a laboratory scanner).

Limitations of the present study include the in vitro conditions for digital scans, limited number of IOS systems evaluated, limited number of different scan body designs tested, and partially edentulous environment compared with a completely edentulous clinical situation. Further in vitro and clinical studies are recommended to assess the ability to transfer the implant position with scan bodies made of different materials and with different geometries, different implant connections, different implant positions and angulations, different intraoral scanning technologies, and partially dentate and completely edentulous conditions.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The CMM machine was unable to measure the scan body of the magnetically retained SB-3 group specimens because of the mobility of the scan body when palpating with the smallest load possible. Therefore, this group was excluded from the statistical analysis.

2. The scan body systems tested (SB-1 and SB-2 groups) were able to accurately transfer the linear implant positions on the x-, y-, and z-axes on the virtual implant working cast of a partially dentate digital scan, with the z-axis being the most accurate scan body position obtained.
3. Significant differences were obtained in the XZ angular implant position among the scan body systems analyzed.

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