RESEARCH PAPER

Comparative Evaluation of the 3-Dimensional Implant Impression Accuracy between Conventional and Digital Impression Using Two Different Intraoral Scanners: An In Vivo Study

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ABSTRACT

Background: Accurate three-dimensional (3D) recording of implant positions is fundamental to achieving passive fit and long-term success of implant-supported prostheses. The growing adoption of digital intraoral scanners (IOS) necessitates rigorous clinical evaluation of their accuracy relative to established conventional methods.

Purpose: To compare the 3D accuracy of implant impressions obtained with a conventional open-tray technique, the Primescan (Dentsply Sirona), and the Aoralscan 3 (Shining 3D) intraoral scanners under in vivo conditions.

Materials and Methods: A standardised splinted open-tray reference model was fabricated for each patient and served as the control, scanned with a high-precision Zeiss ATOS 5 industrial scanner. Each patient additionally underwent one conventional polyvinyl siloxane (PVS) impression and two digital scans. All datasets were exported as STL files and superimposed using Zeiss Inspect 2025 reverse-engineering software. Inter-implant distance deviation, angular deviation, and 3D linear displacement were measured and compared using one-way ANOVA followed by Tukey post hoc tests ($p < 0.05$).

Results: Statistically significant differences were observed for inter-implant distance ($F = 18.776$, $p < 0.001$) and angular deviation ($F = 45.144$, $p < 0.001$) among the three techniques. Primescan demonstrated the lowest mean deviations (inter-implant: 0.40 mm; angular: 0.68°), followed by Aoralscan 3 (0.67 mm; 1.07°), while conventional impressions showed the highest values (1.15 mm; 2.11°). Linear displacement did not differ significantly across groups ($p > 0.05$). Both digital systems performed within clinically acceptable thresholds.

Conclusions: Digital impression techniques — particularly Primescan — produced superior accuracy compared with conventional impressions for inter-implant distance and angular parameters under clinical conditions. Both IOS systems offered clinically acceptable accuracy, supporting their selective use in implant prosthodontic workflows.

Keywords: Conventional impression, Digital impression, Intraoral scanner, Implant impression accuracy, Three-dimensional analysis, Trueness, Precision

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INTRODUCTION

Precise transfer of the three-dimensional spatial position of dental implants from the oral environment to the working model or virtual dataset is a prerequisite for achieving passive fit of implant-supported prostheses. Dimensional inaccuracies at the impression stage propagate through every subsequent fabrication step and may ultimately manifest as biological or mechanical complications, including marginal bone loss, screw fracture, and prosthetic component failure. Although a universally accepted threshold for clinically acceptable passive fit remains elusive, discrepancies below 60 µm are widely considered challenging to detect clinically, while misfit values ranging from approximately 38 to 345 µm have been reported in the literature as conditionally acceptable, depending on clinical parameters and the number of implants involved.[1]

Conventional elastomeric impression techniques — using polyvinyl siloxane (PVS) or polyether materials in conjunction with open-tray (direct) or closed-tray (indirect) impression copings — have long constituted the clinical standard. Nevertheless, these approaches carry technique-sensitive variables including impression material distortion, coping displacement during removal, die stone expansion, and patient-related factors such as gag reflex and limited mouth opening.[2,3] The emergence of intraoral scanning (IOS) technology has introduced a digitally-mediated alternative that directly captures peri-implant anatomy and implant position via scan bodies, subsequently generating STL datasets compatible with computer-aided design and manufacturing (CAD/CAM) platforms.[4]

Reported benefits of digital workflows include enhanced chairside efficiency, improved patient acceptance, direct electronic communication with dental laboratories, and elimination of errors attributable to impression materials.[3,4] However, clinical evidence concerning IOS accuracy for multi-implant cases — particularly under in vivo conditions — remains heterogeneous. Factors such as saliva, limited access, tongue mobility, and the optical characteristics of different scanning algorithms may substantially influence the quality of digitally acquired data.[5] Moreover, the accuracy parameters evaluated — trueness (systematic deviation from a reference) and precision (repeatability of the measurement) — differ across studies, rendering direct comparisons difficult.[4]

Several contemporary IOS systems have been evaluated in vitro, yet only a limited body of evidence addresses their performance under genuine clinical conditions using industrial-grade reference measurements. The Primescan (Dentsply Sirona) employs an active triangulation principle with a dynamic depth scan field extending up to 20 mm, while the Aoralscan 3 (Shining 3D) uses structured-light active triangulation with advanced software stitching algorithms; both represent widely adopted systems across different market segments.[5,6] Comparative clinical data between these two systems, validated against an industrial reference scanner, are currently lacking.

Accordingly, this in vivo study was designed to comparatively evaluate the 3D implant impression accuracy achievable with a conventional PVS open-tray technique and two contemporary intraoral scanners in partially edentulous patients. Outcome measures included inter-implant distance deviation, angular displacement, and 3D linear displacement, assessed with reference to an industrial-grade Zeiss ATOS 5 scanner.

MATERIALS AND METHODS

Study design and ethical approval

This single-centre, in vivo, three-arm comparative study was conducted at the Department of Prosthodontics, Crown and Bridge, Maxillofacial Prosthodontics and Oral Implantology, I.T.S. Dental College, Hospital and Research Centre, Greater Noida, Uttar Pradesh, India. Ethical clearance was obtained from the Institutional Ethics Committee prior to commencement (IEC/Prostho/01/24). All participants provided written informed consent. The study adhered to the principles of the Declaration of Helsinki.

Sample size and participant selection

Sample size was calculated using G*Power (version 3.0.1; Franz Faul, Universität Kiel, Germany) for one-way ANOVA with three groups, specifying an effect size of $f = 0.40$, alpha error probability of 0.05, and a power of 0.80. The computation indicated a minimum of nine observations per group; ten participants were recruited to provide a conservative buffer and enhance statistical power (actual power = 0.81).

Inclusion criteria comprised: (i) adults aged 18 years or older; (ii) partial edentulism with two adjacent, well-osseointegrated implants in either the anterior or posterior region; (iii) completion of second-stage surgery; and (iv) clinically healthy peri-implant tissues with adequate mouth opening. Participants were excluded if they had a history of smoking or tobacco use, systemic conditions affecting healing, limited mouth opening, or were unwilling to participate.

Reference model fabrication

A standardised reference model was constructed for each participant to serve as the control dataset. Following removal of healing abutments, two open-tray impression copings compatible with the implant system (Adin RS) were hand-tightened and their seating verified radiographically. The copings were splinted with autopolymerising pattern resin (Pattern Resin LS, GC Corporation) using the brush-bead technique to a standardised dimension of 4 mm height and 2 mm width. The splinted assembly was subsequently sectioned, rejoined to minimise polymerisation stress, and attached to corresponding implant analogs before immersion in Type IV gypsum (Zhermack Elite Rock; powder-to-water ratio standardised throughout). After complete setting, the reference model was retrieved and stored under controlled conditions. Each reference model was digitised with a Zeiss ATOS 5 industrial scanner, and the resulting STL file was designated (Figure 4) the control dataset for all superimposition analyses.

Conventional impression technique
One conventional impression was recorded per participant using the splinted open-tray technique. Open-tray impression copings were connected to the implants, verified radiographically, and splinted with pattern resin following the same sectioning and rejoining protocol described for reference model fabrication. A perforated stainless steel tray was modified to provide coping screw access and coated with a compatible adhesive (allowed to dry for 3 minutes). Addition silicone material (Zhermack Hydrorise; heavy body/putty in the tray, light body syringe-applied to the peri-implant region) was used in a one-step technique. After complete setting, the coping screw was released, the impression retrieved, and the coping was verified to remain embedded. A resilient gingival mask material (Esthetic Mask, Detax) was applied around the coping-analog junction. The impression was disinfected and poured with Type IV gypsum (Zhermack Elite Rock) under standardised water-to-powder ratios. The resultant master cast was subsequently digitised with an InEos X5 laboratory scanner (Dentsply Sirona), and the STL file was used for comparative superimposition (Figure 1).

Digital impression technique
Two digital impressions were recorded per participant using the Primescan (Dentsply Sirona) and the Aoralscan 3 (Shining 3D) (Figure 2 and Figure 3) intraoral scanners, in randomised order. Healing abutments were removed and compatible scan bodies (Adin RS) for each implant system were connected and hand-tightened; seating was confirmed visually. Each operator followed the manufacturer-recommended scanning path, capturing the scan body, surrounding peri-implant soft tissues, adjacent dentition, and the opposing arch. A bite registration scan was performed for arch articulation. Stitching errors or zones of missing data were identified during the acquisition phase and rescanned as required. The final STL file was exported directly from the IOS software for analysis.

Measurements and analysis
All STL datasets — reference model (control), conventional impression cast scan, and both digital impression scans — were imported into Zeiss Inspect 2025 reverse-engineering software and superimposed (Figure 5). Each dataset was registered to the reference model STL using a best-fit alignment algorithm with defined reference regions. Three outcome variables were quantified:

1. **Inter-implant distance deviation (mm):** Linear distance between the centres of the mesial and distal implant analogs, compared with the reference value.
2. **Angular deviation (°):** Rotational discrepancy of the scan body flat reference surface relative to the inter-implant axis (Z-axis).
3. **Three-dimensional linear displacement (Δr):** Calculated as $\Delta r = \sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}$, where Δx, Δy, and Δz represent the coordinate deviations along the three Cartesian axes.

Each measurement was repeated three times per dataset; mean values were used for statistical analysis. Data were analysed with SPSS version 24. Continuous variables are expressed as mean ± standard deviation. One-way ANOVA was employed to identify significant differences among the three impression techniques, and pairwise comparisons were conducted using Tukey's honestly significant difference (HSD) post hoc test. Statistical significance was set at $p < 0.05$.

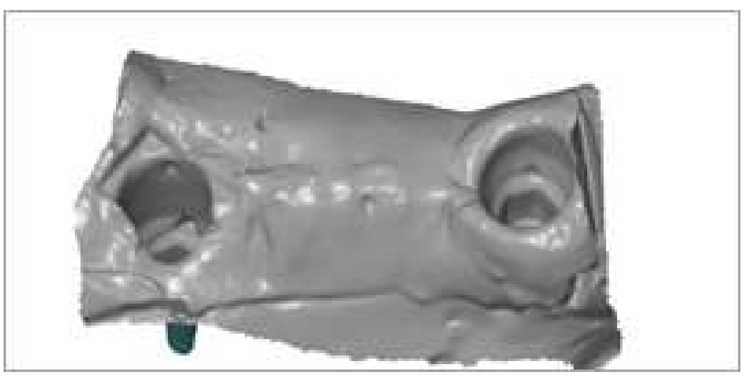

Figure 1- STL File of Conventional Impression Scan (Laboratory Scanner)

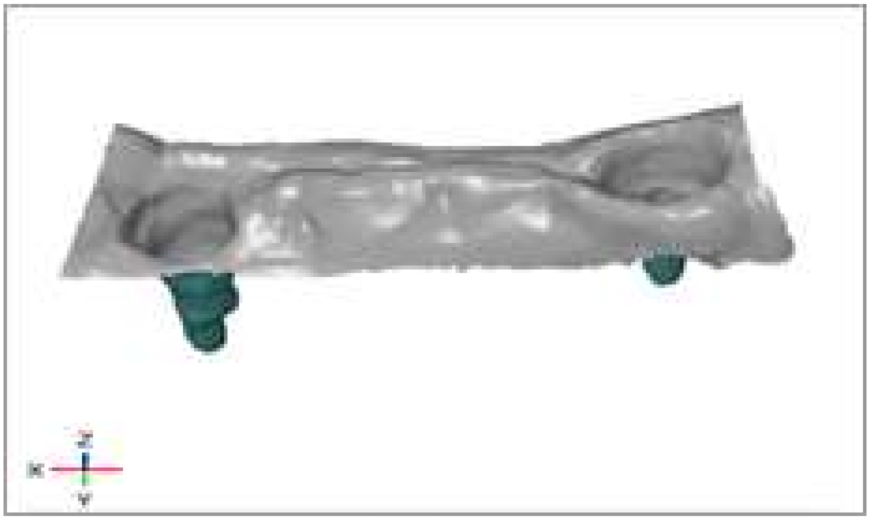

Figure 2 - STL File of Shining 3D (Aoralscan 3)

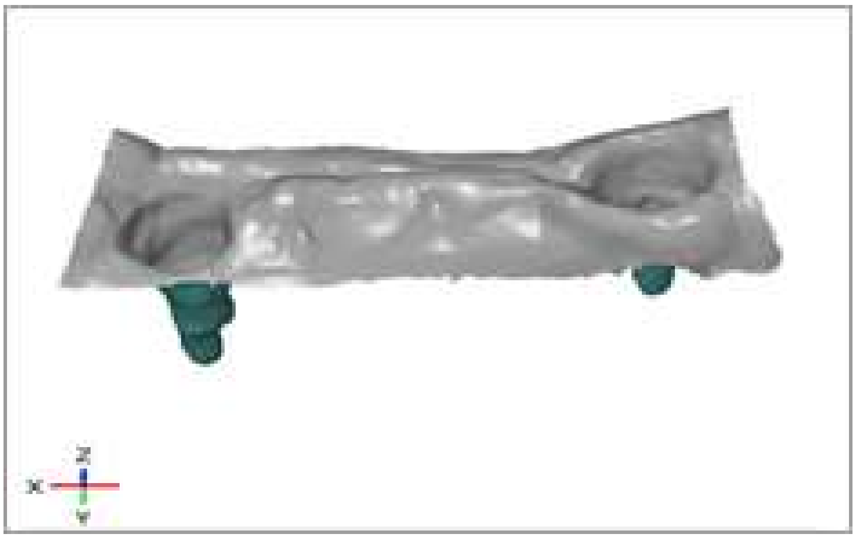

Figure 3 - STL File of Primescan Scan (Dentsply Sirona)

Figure 4 - STL File of Control Scan Data (Zeiss Scanner)

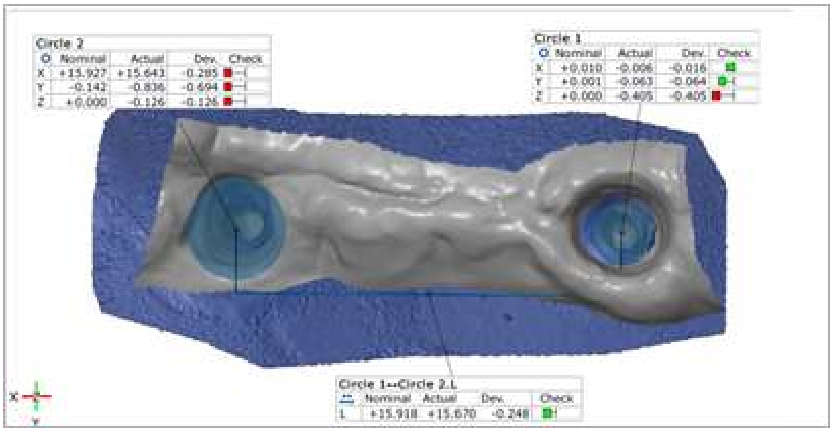

Figure 5 - Superimposistion of STL Files

RESULTS

Ten patients (mean age 38.4 ± 11.2 years; 6 males, 4 females) with a total of 20 osseointegrated implants (14 in the posterior region, 6 in the anterior region) were included. No adverse events were recorded during data collection.

Inter-implant distance deviation

One-way ANOVA revealed a highly significant difference in inter-implant distance deviation among the three groups ($F = 18.776$; $p < 0.001$) [Table 1]. Primescan demonstrated the smallest mean deviation (0.40 ± 0.20 mm), followed by Aoralscan 3 (0.67 ± 0.21 mm), while the conventional impression technique showed the largest deviation (1.15 ± 0.38 mm). Tukey post hoc analysis indicated that both digital systems differed significantly from the conventional technique (Primescan vs. conventional: mean difference 0.75 mm, $p < 0.001$; Aoralscan 3 vs. conventional: mean difference 0.48 mm, $p = 0.002$). The difference between the two digital systems did not reach statistical significance (mean difference 0.27 mm, $p = 0.097$) [Table 2].

Table 1: Inter-implant distance deviation across impression techniques relative to Zeiss reference scanner

Group	Mean Deviation (mm)	Standard Deviation (mm)	ANOVA (F / p)
Group 1: Primescan (Dentsply Sirona)	0.40	0.20	F = 18.776
Group 2: Aoralscan 3 (Shining 3D)	0.67	0.21	p < 0.001**
Group 3: Conventional (PVS/open-tray)	1.15	0.38	

*** p < 0.001 — highly significant; PVS = polyvinyl siloxane*

Table 2: Pairwise comparisons of inter-implant distance deviation (Tukey HSD post hoc)

Comparison	Mean Difference (mm)	p value
Primescan vs. Aoralscan 3	0.27	0.097 (NS)
Primescan vs. Conventional	0.75	< 0.001**
Aoralscan 3 vs. Conventional	0.48	0.002*

*NS = not significant; * p < 0.05; ** p < 0.001*

Angular deviation

Angular deviation demonstrated the strongest discrimination between techniques ($F = 45.144$; $p < 0.001$) [Table 3]. Primescan yielded the lowest angular error (0.68 ± 0.21°), followed by Aoralscan 3 (1.07 ± 0.29°), with conventional impressions recording the highest deviation (2.11 ± 0.48°). Post hoc analysis revealed a statistically significant difference even between the two digital systems (mean difference 0.39°, $p = 0.046$). Both digital systems differed significantly from the conventional technique (Primescan vs. conventional: 1.43°, $p < 0.001$; Aoralscan 3 vs. conventional: 1.04°, $p < 0.001$) [Table 4]. Angular discrepancy was the parameter most strongly associated with the choice of impression technique, underscoring its clinical relevance for prosthetic passive fit.

Table 3: Angular deviation across impression techniques relative to Zeiss reference scanner

Group	Mean Deviation (°)	Standard Deviation (°)	ANOVA (F / p)
Group 1: Primescan	0.68	0.21	F = 45.144
Group 2: Aoralscan 3	1.07	0.29	p < 0.001**
Group 3: Conventional	2.11	0.48	

*** p < 0.001 — highly significant*

Table 4: Pairwise comparisons of angular deviation (Tukey HSD post hoc)

Comparison	Mean Difference (°)	p value
Primescan vs. Aoralscan 3	0.39	0.046*
Primescan vs. Conventional	1.43	< 0.001**
Aoralscan 3 vs. Conventional	1.04	< 0.001**

** p < 0.05; ** p < 0.001*

Three-dimensional linear displacement

No statistically significant differences were observed among the three techniques for 3D linear displacement (Δr) when each was compared with the Zeiss reference [Table 5 and 6]. Primescan and Aoralscan 3 showed high agreement with the reference scanner ($p = 0.995$ and $p = 1.000$, respectively). Although the conventional impression group registered a numerically higher mean Δr (9.93 µm), pairwise comparisons with both digital systems also failed to reach significance ($p > 0.05$). These findings suggest that under the relatively favourable conditions of this study — involving parallel or near-parallel adjacent implants over a limited span — all three techniques maintain comparable positional accuracy in the translational domain.

Table 5: Three-dimensional linear displacement (Δr) relative to Zeiss reference scanner

Group	Mean Δr (µm)	One-way ANOVA p	Significance
Group 1: Primescan	1.22	0.995	NS
Group 2: Aoralscan 3	0.17	1.000	NS
Group 3: Conventional	9.93	0.241	NS

NS = not significant (p > 0.05)

Table 6: Pairwise comparisons of 3D linear displacement (Tukey HSD post hoc)

Comparison	Mean Difference (µm)	p value
Primescan vs. Aoralscan 3	1.39	0.993 (NS)
Primescan vs. Conventional	8.71	0.350 (NS)
Aoralscan 3 vs. Conventional	10.10	0.228 (NS)

NS = not significant (p > 0.05)

DISCUSSION

This in vivo study evaluated 3D implant impression accuracy using an industrial-grade reference scanner to establish a robust control, a methodological approach that adds credibility beyond conventional laboratory-scanner references. The principal findings indicate that digital impression techniques — particularly Primescan — yield significantly lower inter-implant distance deviations and angular errors than the conventional PVS open-tray technique, while 3D linear displacement remains comparable across all methods under the study conditions.

The superior angular accuracy of both IOS systems relative to the conventional approach is among the most clinically consequential findings of this study. Angular deviations are known to exert a disproportionate influence on the passive fit of multi-unit implant frameworks, since rotational misfits amplify geometric error across the prosthetic span.[7] The conventional impression technique, despite utilising a standardised splinted open-tray protocol, accumulated a mean angular deviation of 2.11°, which was statistically and clinically distinct from the 0.68° and 1.07° recorded for Primescan and Aoralscan 3, respectively. This pattern aligns with findings by Alikhasi and colleagues[8], who demonstrated that digital workflows maintain consistent angular accuracy irrespective of implant connection type and angulation in vitro, and with the conclusions of a clinical investigation by Alsharbaty et al.[1], wherein the digital technique showed the lowest angular distortion among the evaluated methods.

Primescan outperformed Aoralscan 3 for angular deviation (mean difference 0.39°; p = 0.046), a distinction that, while statistically significant, remains within a range that may or may not translate into clinically detectable misfit for short-span restorations. The technological basis for this difference likely relates to Primescan's active triangulation engine and extended depth-of-field characteristics, which provide more stable scan body geometry recognition under intraoral conditions. Aoralscan 3, employing structured-light triangulation with software-based mesh refinement, demonstrated comparable — though marginally inferior — angular performance. The practical implication for clinicians is that both systems represent viable alternatives to conventional impressions; however, scanner selection may matter more as prosthetic complexity or implant span increases.

The absence of significant differences in 3D linear displacement across techniques is consistent with observations reported by Ma and colleagues[5] and Elashry et al.[9], who noted that translational accuracy is relatively robust in short-span, near-parallel implant configurations. Inter-implant distance deviation, in contrast, was significantly affected by technique, with the conventional approach producing values more than twice those of Primescan. This finding reinforces concerns previously raised regarding dimensional changes in conventional impression workflows — including impression material distortion during removal, polymerisation shrinkage of pattern resin splints, and die stone expansion — errors that accumulate sequentially and may exceed clinically acceptable thresholds when prosthetic demands are high.[2,3]

The results of the present study partially corroborate the systematic body of evidence supporting digital impressions for partially edentulous, short-span implant cases. Amin et al.[10] and Albayrak et al.[11] demonstrated clear IOS superiority in full-arch in vitro scenarios, findings echoed in clinical settings by Chochlidakis et al.[12] for maxillary fixed complete prostheses. Conversely, studies involving full-arch edentulous rehabilitations with angulated implants — notably Jasim et al.[13] and Borshanu et al.[14] — have cautioned that digital systems may still underperform relative to splinted conventional techniques in demanding geometric configurations. The current study, involving only two adjacent implants in partially edentulous patients, represents a clinically simpler scenario where the advantages of IOS can be more fully realised without the cumulative stitching errors known to degrade digital accuracy at greater scanning spans.[4,6]

A notable methodological strength of this study is the use of the Zeiss ATOS 5 industrial scanner as the reference standard. Industrial scanners offer sub-micrometre accuracy, providing a more faithful reference than conventional laboratory scanners typically employed in dental research. This approach, conceptually similar to that of Nedelcu et al.[15], strengthens the validity of the comparative assessment. Additionally, each participant's reference model was fabricated under standardised conditions before any experimental impression was recorded, ensuring that the control was free from the technique-related variables inherent to the experimental groups.

Limitations of this study include its relatively small sample size, restriction to two adjacent implants per patient, and the fact that all implants were placed in near-parallel orientations to standardise conditions. Consequently, the findings cannot be directly extrapolated to more complex scenarios involving severely angled implants, longer-span rehabilitations, or fully edentulous arches. Operator experience with IOS was held constant in this study, which may not reflect variability in clinical practice. Furthermore, the study assessed impression accuracy rather than the clinical fit of the final prosthesis, which remains the most clinically meaningful outcome.

CONCLUSIONS

Within the limitations of this in vivo study, the following conclusions are drawn:

1. Digital impression techniques produced significantly lower inter-implant distance deviations and angular errors compared with the conventional PVS splinted open-tray impression technique.
2. Primescan demonstrated significantly superior angular accuracy compared with Aoralscan 3; however, both digital systems performed within clinically acceptable thresholds.
3. No statistically significant differences were observed among the three techniques for 3D linear displacement, suggesting comparable translational accuracy under favourable clinical conditions.
4. Digital intraoral scanning may be considered a clinically reliable and efficient alternative to conventional impression techniques for partially edentulous patients with two adjacent implants, with Primescan offering an advantage in angular precision.

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