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Effect of 3D-printed custom tray wall thickness on the dimensional accuracy of elastomeric impressions: an in vitro study

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Article

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Abstract

Accurate conventional impressions remain essential for indirect restorations. This in vitro study assessed whether the wall thickness of 3D-printed custom trays affects the dimensional accuracy of dental casts made with impressions in three elastomeric materials: a vinyl polysiloxane, a polyether, and a vinyl siloxanether. A metal reference maxillary arch with four 6-mm reference spheres was fabricated. Ten double-mix impressions were made using a standardized guidance and axial demolding device for each material and tray thickness. Casts were poured in dental stone and subsequently scanned. Linear distances between sphere centers were measured and compared with the reference. Non-parametric statistics were applied. Across materials, deviations for shorter distances were small, whereas the longest span showed the largest discrepancies. For the vinyl polysiloxane, the lowest summed mean deviation occurred with 3 mm trays; for the polyether with 2 mm; and for the vinyl siloxanether with 3 mm. Despite some statistically significant differences, all median percentage deviations remained well below the 1% threshold commonly cited for elastomeric materials, indicating limited clinical impact. Within the limitations of this in vitro setup, 3D-printed custom trays of 1–3 mm achieved clinically acceptable accuracy. A 3 mm wall appears significantly advantageous for longer spans and when using vinyl siloxanether.

Introduction

Despite the rapid adoption of digital intraoral scanning, conventional elastomeric impressions remain necessary in many restorative procedures due to their versatility, well-characterized materials science, and compatibility with both analog and digital workflows [1–9]. Clinical outcomes such as marginal integrity and occlusal relationships depend on the dimensional fidelity of the impression, which is influenced not only by the polymerization kinetics and rheology of the elastomer but also by the mechanical behavior of the impression tray during seating and removal.

Tray rigidity helps to maintain uniform material thickness and limits tray flexure under the hydraulic and shear stresses that develop during seating. Inadequate rigidity, particularly in thin-walled trays or in long-span impressions, can allow bending, edge lift, or torsion that translate into linear and angular errors on the definitive cast [10, 11]. Custom trays are therefore preferred when precision is essential: they allow controlled internal spacing, predictable adhesive application, and the integration of design features - such as stops and guidance elements - that standardize seating [12].

Additive manufacturing (AM) has transformed the production of custom trays. Vat-photopolymerization techniques (SLA, DLP, MSLA) enable tightly controlled geometries, smooth surfaces, and fast build times using dedicated custom-tray resins [11]. Compared with manual fabrication, AM reduces operator variability, supports batch production, and facilitates purpose-built fixtures that interface with standardized demolding frames [11, 12]. However, the optimal wall thickness for AM trays remains unclear, with practical choices often resting upon experience rather than comparative evidence [11].

This study investigates the effect of wall thickness on dimensional accuracy across three clinically established elastomer classes: vinyl polysiloxane (VPS), polyether (PE), and a vinyl siloxanether hybrid (VPES). VPS is valued for elastic recovery and tear strength, PE for intrinsic hydrophilicity and snap-set behavior, and VPES for combining favorable surface wetting with VPS-like recovery [8, 13]. We hypothesized that thicker trays would improve accuracy, particularly on long inter-spherical spans where cumulative deviations emerge, and that the magnitude of benefit would vary by material.

To minimize confounding technique factors, a standardized, purpose-built seating and axial demolding device that reduces peel forces was used; employed a rigid metal reference model [14]; adhered to manufacturer-specified working and setting times in accordance with DIN EN ISO 4823. This is the German adoption of a European and international standard for dentistry, specifically elastomeric impression materials. A robust metrology pipeline based on simple, reproducible linear metrics between precisely positioned reference spheres was applied [11, 13].

Methods

Study design and reference model

A maxillary reference model based on a KaVo study arch (KaVo, Biberach an der Riß, Germany) incorporated one three-unit bridge preparation (14–16) and one partial-coverage preparation (25). Preparations followed contemporary recommendations - cervical chamfer approximately 0.8–1.0 mm, occlusal reduction approximately 1.5–2.0 mm, and total occlusal convergence of approximately 3–6° - to reflect clinical geometries relevant for crown and bridge work.

To generate robust linear metrics, four 6-mm spheres were positioned at teeth 17, 13, 23, and 27. Sphere centers defined four distances: 1–2 (17 − 13), 2–3 (13–23), 3–4 (23–27), and 4 − 1 (27 − 17). These distances span short inter-segment paths and a long diagonal (4 − 1), providing sensitivity to both local and cumulative dimensional effects.

The reference was manufactured in a metal (NEM) alloy by selective laser melting (SLM) (Bego Bremer Goldschlaegerei GmbH, Bremen, Germany) from CAD (Fig. 1a) and digitized as a reference using a laboratory scanner (InEos X5, Dentsply Sirona, York, USA) prior to experimentation.

Design and fabrication of 3D-printed custom trays

Custom trays were designed in Geomagic Wrap (Geomagic Wrap X2024.2.0, 3D Systems Rock Hill, USA) with nominal wall thicknesses of 1, 2, or 3 mm and a uniform 4-mm internal spacing between model surface and tray intaglio to standardize the elastomer layer. One anterior and two posterior guidance loops were integrated to engage a standardized seating/demolding frame (Fig. 1b green custom tray).

Trays were printed on a Formlabs Form3B+ (Formlabs Inc., Sommerville, USA) using a dedicated custom-tray resin (Formlabs Custom Tray Resin, RS-F2-CTBL-01, Formlabs Inc., Sommerville, USA). After printing, all trays were washed in isopropanol (Form Wash, Formlabs Inc., Sommerville, USA), post-cured at 60°C (Form Cure, Formlabs Inc., Sommerville, USA) for 30 min, and internally air-abraded with 50 µm Al_2O_3 (Cemat-NT4, Wassermann, Hamburg, Germany) to enhance micromechanical retention. Tray adhesives were applied according to the impression material: a universal adhesive for VPS (Coltène, Langenau, Germany), a vinylsiloxanether adhesive for VPES (Kettenbach, Eschenburg, Germany), and a polyether adhesive for PE (3M ESPE, Seefeld, Germany).

Impression protocol and standardized axial demolding

Impression protocol and standardized axial demolding
For each material (VPS - Affinis; VPES - Identium; PE - Impregum Penta H DuoSoft) and each wall thickness (1/2/3 mm), n = 10 impressions were made (total n = 90). The double-mix technique was used: high-viscosity material placed in the tray and low-viscosity material syringed around preparations and spheres. Manufacturer-specified working and intraoral setting times were followed for all materials and viscosity pairings.

A purpose-built demounting frame system ensured guided seating by engaging the tray loops during impression making (Fig. 1b). After setting, the same frame enabled axial demolding through stepwise screw actuation, minimizing peel and bending that otherwise cause removal-induced distortion. This fixtured approach standardized both seating and removal across all specimens.

Cast fabrication and digitization

After placing a printed removal frame (Fig. 2a creamy white) on the custom tray, Impressions were poured after approximately three hours using a type IV dental stone (Fujirock EP, gold-brown, GC Europe, Leuven, Belgium) at a constant 100 g:20 mL powder-to-water ratio. Mixing consisted 15 s manual spatulation followed by 45 s vacuum mixing (Wamix classic, Wassermann, Hamburg, Germany). Casts were placed on a vibrator during pouring (D-R 644, Harnisch + Rieth, Winterbach, Germany) to release air and stored undisturbed for 30–40 min before frame-assisted axial demolding (Fig. 2b).

Casts were digitized on an inEos X5 laboratory scanner (Dentsply Sirona, York, USA). The STL meshes were exported for metric analysis alongside the reference STL.

Metrology and statistical analysis

In GOM Inspect (GOM Inspect 2018; GOM GmbH, Braunschweig, Germany), sphere centers were computed and the four linear distances

(1–2, 2–3, 3–4, 4 – 1) were measured for each cast (Fig. 3). Absolute deviations from the reference distances were calculated per metric. For descriptive statistics, we summarized medians, interquartile ranges, and ranges; results are also aggregated as the sum of mean absolute deviations across the four distances for each material and thickness.

Normality was screened with Kolmogorov-Smirnov and Shapiro-Wilk tests (n = 10 per cell). As several distributions deviated from normality, non-parametric methods were used: Kruskal-Wallis tests for omnibus comparisons and Dunn's post-hoc tests with Bonferroni correction for pairwise contrasts (α = 0.05). Analyses were performed in standard statistical software (SPSS and spreadsheet tools) (Microsoft Excel; Microsoft Corporation, Redmond, USA; IBM SPSS 25; IBM Corp, Armonk, USA), and the sample size mirrored prior in-vitro tray/material studies while remaining feasible for tightly controlled fabrication and scanning.

Post hoc power analysis

A post hoc sensitivity analysis was conducted for the overall comparison of the nine groups (total sample size: n = 90, α = 0.05, power = 80%). The analysis indicated that the study was sufficiently powered to detect effects of at least f = 0.43, corresponding to a large effect size. Therefore, while large group differences could be identified with adequate statistical power, smaller effects may have remained undetected due to limited sensitivity of the study design. Consequently, non-significant findings should be interpreted with caution, particularly when small or moderate effects cannot be excluded

Quality control and bias mitigation

All trays were built with identical orientation and support strategies to avoid confounding related to printing direction; wash and post-cure cycles followed manufacturer guidelines. Adhesive types were matched to materials and allowed to dry according to instructions before impression making.

The frame constrained seating and removal to a repeatable path; the same operator executed all steps following a written SOP. Stones were batched to minimize lot-to-lot variation; environmental conditions were stable in the laboratory. Scanner calibration was verified before batches of scans.

Results

Ninety casts (3 materials × 3 wall thicknesses × 10 each) were analyzable with no exclusion. To evaluate overall linear dimensional stability, the total distance parameter *S* (sum of individual measurement distances according to DIN EN ISO 4823) was analyzed as a single primary outcome metric. Across all tray wall thicknesses combined (n = 90 per material), median absolute dimensional deviations (*S*) were 0.152 mm (IQR: 0.091 mm) for Affinis, 0.155mm (IQR: 0.095 mm) for Identium, and 0.201 mm (IQR: 0.101 mm) for Impregum (Table 1). The Kruskal-Wallis-test revealed no statistically significant differences in global dimensional accuracy among the three impression materials ($H(2) = 2.237$, $p =$

0.327; Table 1). Bonferroni-adjusted post-hoc pairwise comparisons confirmed the absence of significant inter-material differences (p > 0.50 for all pairs)

Influence of Tray Wall Thickness Within Impression Materials

Intra-material analysis demonstrated a statistically significant impact of tray wall thickness (1 mm, 2 mm and 3 mm) on dimensional accuracy for all tested materials (p < 0.05; Table 1, Fig. 4).

Affinis (A1–A3): Tray wall thickness significantly influenced dimensional deviation (H(2) = 8.859, p = 0.012; Table 1). Post-hoc analysis showed significantly lower deviations in the 3-mm-group (A3: 0.138 mm, IQR: 0,038 mm) compared to the 2-mm-group (A2: 0,203 mm, IQR: 0.089 mm; p = 0.015; Table 1, Fig. 4).

Identium (ID1–ID3): A highly significant thickness-dependent effect was observed (H(2) = 19.534, p < 0.001; Table 1). Dimensional deviation decreased continuously with increasing tray wall thickness. Pairwise comparisons revealed significant differences between 1mm (ID1: 0.323 mm, IQR: 0.146 mm) vs. 2 mm (ID2: 0,155 mm, IQR: 0.050 mm; p = 0.038) and $1\backslash:\mathrm{mm}$ vs. $3\backslash:\mathrm{mm}$ (ID3: 0.099 mm; IQR: 0.104 mm; p < 0.001; Table 1, Fig. 4).

Impregum (IM1–IM3): Tray thickness significantly affected accuracy (H(2) = 8.125, p = 0.017; Table 1). The 2- mm-group exhibited the lowest deviation (IM2: 0.144 mm, IQR: 0.109 mm), which was significantly lower than that of the 1- mm-group (IM1: 0.219 mm, IQR: 0.056 mm; p = 0.019; Table 1, Fig. 4).

Material Comparison Within Identical Tray Wall Thicknesses

Inter-material comparisons stratified by tray wall thickness revealed distinct performance patterns across materials (Table 1, Fig. 4):

Table 1
Descriptive statistics and statistical comparison of linear dimensional deviation S [mm] across impression materials and tray wall thicknesses.

Impression Material	1 mm Median (IQR) [mm]	2 mm Median (IQR) [mm]	3 mm Median (IQR) [mm]	Overall Material Median (IQR) [mm]	p-value (within material)
Affinis	0.156 (0.153)	0.203 (0.089)[a]	0.138 (0.038)[a,c]	0.152 (0.091)	**p = 0.012***
Identium	0.323 (0.146)[a,b]	0.155 (0.050)[a]	0.099 (0.104)[b,c]	0.155 (0.095)	**p < 0.001***
Impregum	0.219 (0.056)[a]	0.144 (0.109)[a]	0.210 (0.115)[c]	0.201 (0.101)	**p = 0.017***
Overall Thickness	p = 0.054	**p = 0.047***	**p < 0.001***	p = 0.327	-

* Statistically significant difference ($p < 0.05$)

, Statistically significant intra-material pairwise differences after Bonferroni correction ($p < 0.05$)

Statistically significant inter-material differences at 3 mm wall thickness ($p < 0.05$); Impregum vs. Affinis: $p = 0.016$, Impregum vs. Identium: $p < 0.001$)

1-mm Tray Thickness (A1, ID1, IM1): No statistically significant differences were observed among materials ($H(2) = 5.828$, $p = 0.054$), although Identium displayed the highest median deviation (ID1: 0.323 mm, Table 1, Fig. 4).

2-mm Tray Thickness (A2, ID2, IM2): The overall omnibus test indicated significant variance ($H(2) = 6.100$, $p = 0.047$), but post-hoc pairwise comparisons failed to reach statistical significance after Bonferroni correction ($p > 0.05$; Table 1, Fig. 4).

3-mmTray Thickness (A3, ID3, IM3): A highly significant difference was identified ($H(2) = 15.550$, $p < 0.001$, Table 1, Fig. 4). Post-hoc analyses demonstrated that Impregum (IM3: 0.210 mm, IQR: 0,115 mm) produced significantly higher dimensional deviations compared to both Affinis (A3: 0,138 mm, IQR: 0.038 mm; $p = 0.016$) and Identium (ID3: 0.099 mm, IQR: 0,104 mm; $p < 0.001$; Table 1, Fig. 4). No significant difference was detected between Affinis and Identium at 3 mm thickness.

Discussion

The present in-vitro comparison demonstrates that increasing the wall thickness of 3D-printed custom trays generally improves dimensional fidelity on long spans, with smaller or negligible changes on short spans [11, 12]. Mechanistically, thicker walls raise tray stiffness, mitigating bending during seating and resisting removal-induced deformation - particularly when demolding is constrained to an axial path [11].

The standardized frame likely minimized inter-specimen variability and helped reveal the underlying tray-rigidity effect rather than operator-dependent artifacts [9, 13].

Material-specific interpretation

VPS (Affinis) showed clear improvement at 3 mm, aligning with expectations for an elastic, surfactant-modified hydrophobic material supported by a stiffer substrate [8]. VPES (Identium) displayed the strongest and significant benefit at 3 mm, consistent with hybrid rheology that couples favorable surface wetting with VPS-like elastic recovery [8, 15]. PE (Impregum) reached its optimum at 2 mm; at 3 mm, performance did not further improve in this setup, which may reflect a balance between tray stiffness and the material's snap-set dynamics and handling in narrow channels [8].

Clinical implications

For routine crown and bridge impressions, a 3 mm wall is a good choice for VPS and VPES when long-span accuracy is prioritized, whereas 2 mm may efficiently serve for PE in moderate spans. Independent of material, employing a guided, near-axial removal trajectory (e.g., via palatal handles or external assistance) is advisable to limit peel forces. Uniform internal spacing around 4 mm and consistent adhesive selection/drying further standardized outcomes.

Strengths and limitations

Strengths include the controlled AM workflow (uniform CAD, build orientation, post-processing), a rigid NEM reference, fixture-guided seating and demolding, and a metrology pipeline built on robust linear metrics between large spheres -minimizing landmarking subjectivity. Limitations are inherent to the in-vitro design: absence of soft-tissue displacement, saliva, and patient-specific removal vectors; a focus on linear distances rather than surface RMS (root-mean-square) maps; and no exploration of alternative lattice-reinforced tray designs or different build orientations [9, 13]. Sensitivity analysis revealed that the present study was powered to detect only large effects ($f = 0.43$) across the nine groups. Therefore, the absence of statistical significance does not necessarily indicate the absence of smaller underlying effects, which may have remained undetected due to limited statistical power. In contrast, the sample size was in line with the standard practice commonly used in materials science studies [11, 16]. In clinical practice, a rejected impression rate of 10% is a realistic and relevant benchmark for a dentist. Also, only one printer model and material were used here.

Future work

Future investigations should incorporate full-field 3D surface deviation analyses (RMS, local error histograms), evaluate lattice reinforcement and handle geometry, and study build-orientation effects on stiffness. Clinically oriented trials or simulated intraoral models could quantify the interaction of tray rigidity with soft-tissue compliance, moisture control strategies, and different removal vectors. Economic analyses comparing time, material use, and reprint rates across thicknesses would further support guideline development.

Conclusions

- • Tray wall thickness modulates dimensional fidelity primarily over long spans; short spans are less affected.
- • Across materials, a 3 mm wall improved accuracy for VPS and VPES; PE performed best at 2 mm in this setup.
- • All median percentage deviations for linear metrics remained below 1%, suggesting limited clinical impact under standardized conditions.
- • Consistent internal spacing (≈ 4 mm), correct adhesive selection, and near-axial demolding are recommended.
- • Extending evaluation to full-field 3D metrics and clinical scenarios will refine thickness recommendations and tray design guidelines.

Declarations

Ethics approval

This was an in-vitro material study without human participants or animals; formal approval by an ethics committee and informed consent were not required.

Competing Interests

Christian Hoehne is an Editorial Board Member of Scientific Reports and a Guest Editor for the collection Digital Dentistry.

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Author Contribution

Nico Rosenberger: Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing; Johannes Schrenker: Data curation, Formal analysis, Validation, Visualization, Writing – review & editing; Christoph Wassermann: Data curation, Investigation, Validation, Visualization, Writing – review & editing; Marcel Gerhardt: Data curation, Formal analysis, Investigation,

Validation; Marc Schmitter: Resources, Supervision, Writing - review & editing; Christian Hoehne: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing

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Data Availability

The datasets generated and analyzed during the present study are available from the corresponding author on reasonable request.

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Figures



Figure 1

SLM printed NEM reference model (a). Standardized impression system put on the NEM reference (b). The custom tray is visible in green and the demounting frame system in grey.

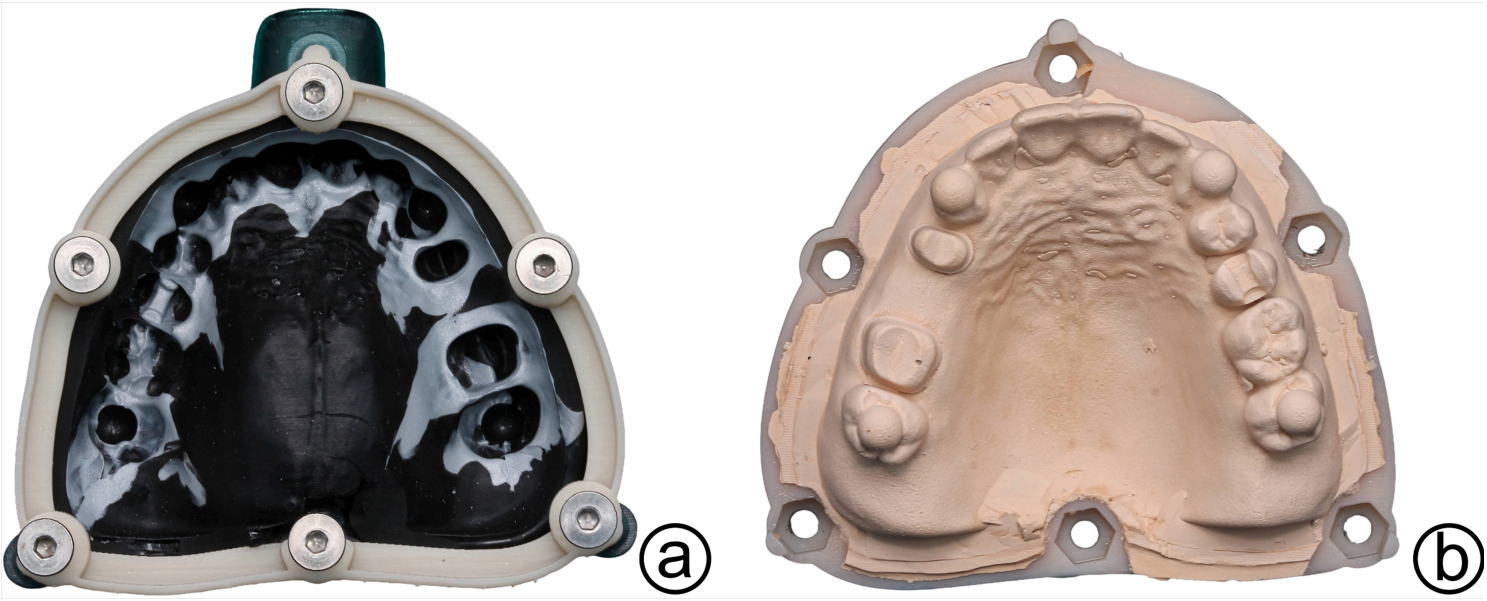


Figure 2

Impression with removable frame (a); after pouring out with dental stone and removal from the impression (b).

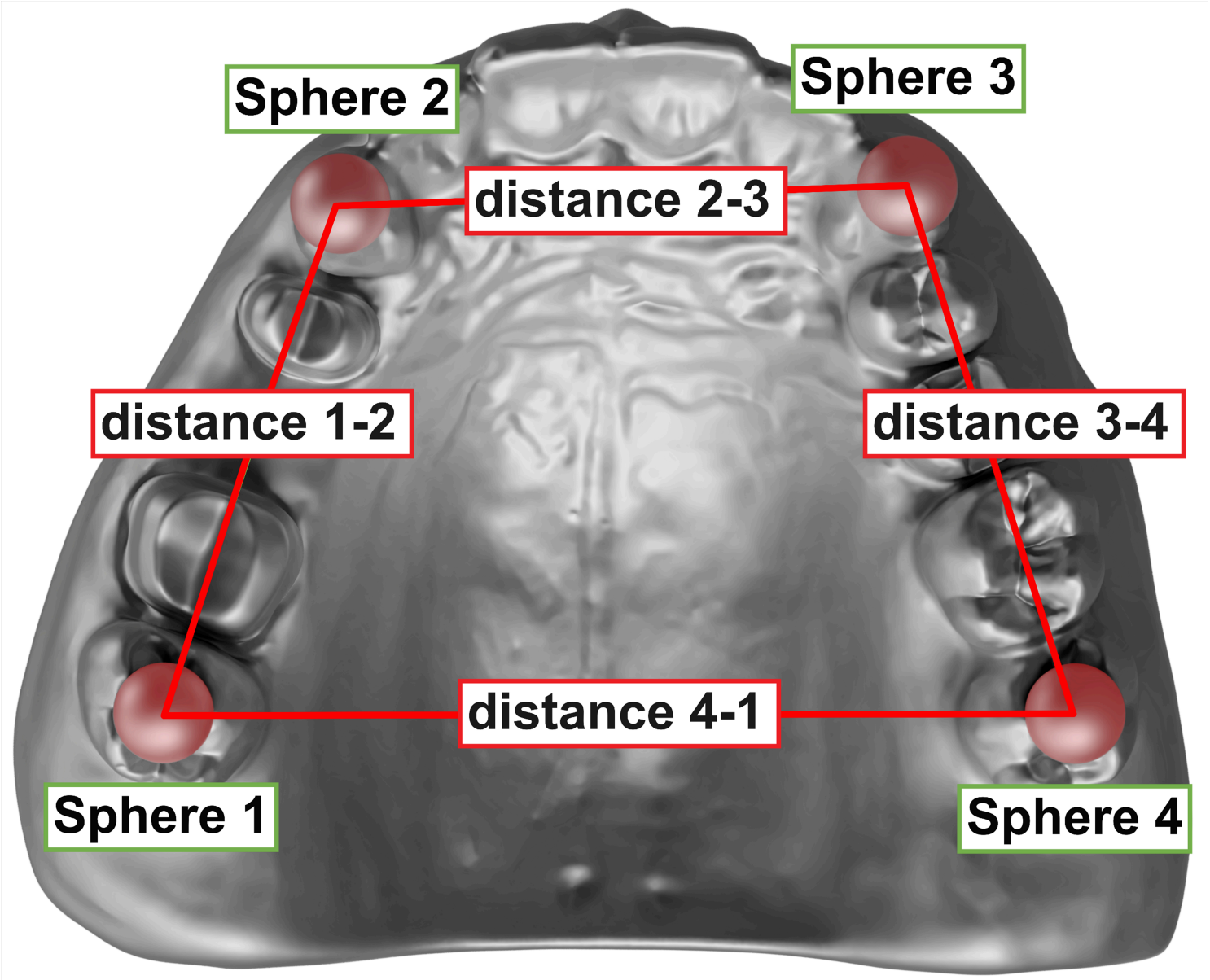


Figure 3

Digitized reference model with marked spheres (green frames) and distances (red frames).

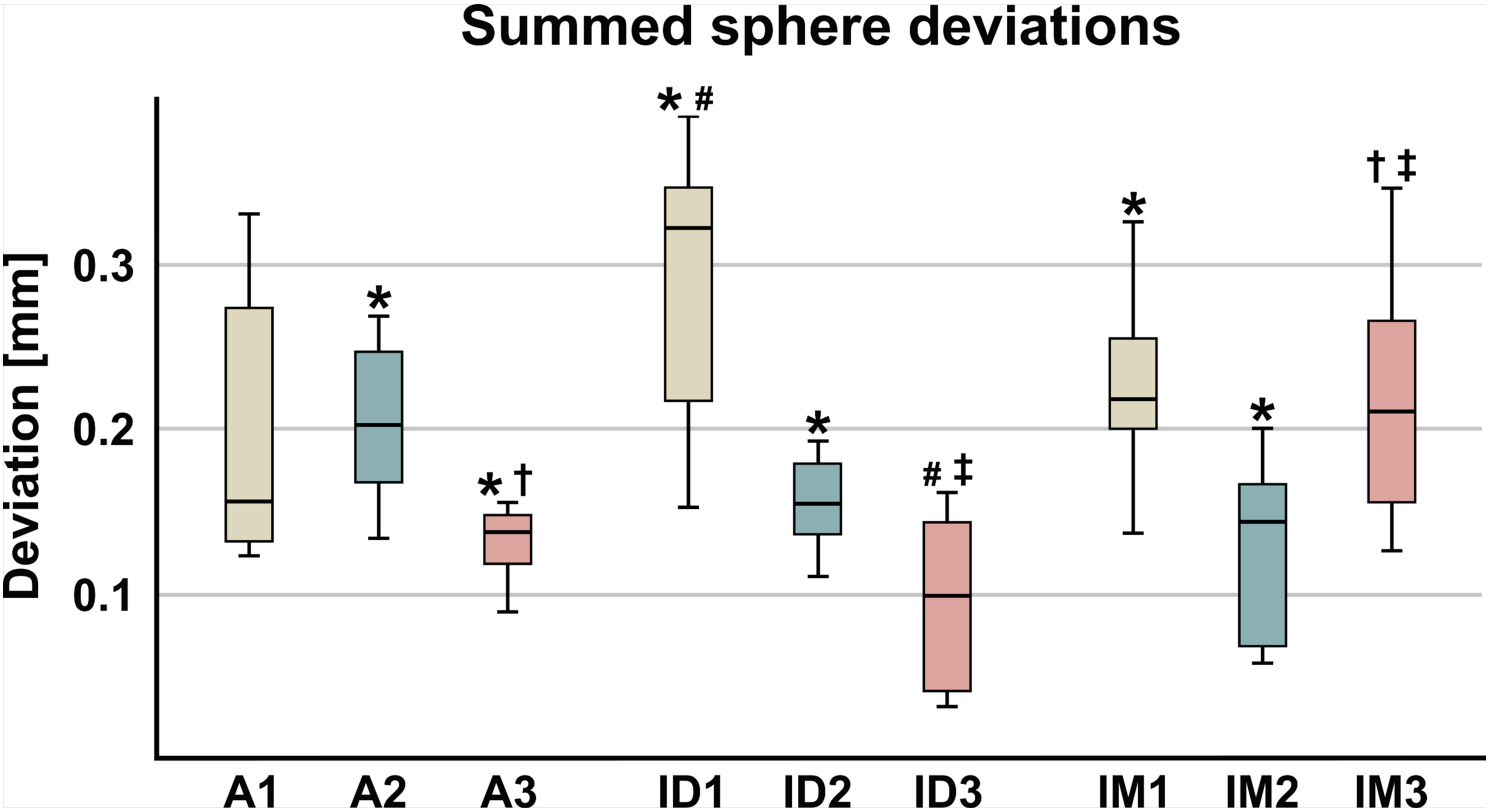


Figure 4

Boxplot of summed mean absolute deviations between spheres. Wall thicknesses are numbered from one to three millimeters. The materials are abbreviated as (A) VPS - Affinis, (ID) VPES - Identium and (IM) PE - Impregum. Inter and inside material significant different values are marked with symbols ($\alpha < 0.05$). Intra-material pairwise differences marked as an asterisk and hash. Inter-material differences marked as a dagger and double dagger.