Title Page

Original article

Title: Evaluation of the accuracy of coded healing abutments, scan body, and conventional impressions on implants with different angulations

Short title: Accuracy of coded healing abutments

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Abstract

Purpose: To evaluate the effect of implant angulation on the accuracy (trueness and precision) of analog (ANA) and digital impressions using coded healing abutment (CHA) and scan body (SB), in implant-supported fixed partial dentures (ISFPDs).

Methods: Two mandibular models with internal connection implants were fabricated: one with parallel implants (M1) and another with angulated implants (M2). Three impression techniques were tested: CHA, SB, and conventional open-tray (ANA) (n=10 each). Digital impressions were acquired with an intraoral scanner, whereas conventional impressions were made with splinted open-tray copings and polyvinylsiloxane, then digitized with a laboratory scanner. STL files were imported into CAD software and analyzed with metrological software (Geomagic) to assess accuracy by comparison with coordinate measuring machine (CMM) reference data. Data were analyzed using one-way analysis of variance with Tukey's HSD post hoc test, t-tests and Levene´s test.

Results: SB impressions showed the highest trueness for linear distance and implant positions. No differences were observed between CHA and SB for angulated implants. ANA exhibited greater deviations across most parameters. For precision, SB and CHA outperformed ANA, particularly in M2. Implant angulation reduced ANA accuracy but did not affect digital impressions.

Conclusions: Scan bodies provided the highest accuracy, especially in parallel implants. Coded healing abutments demonstrated acceptable accuracy across all variables and comparable performance to scan bodies in angulated implants, representing a viable alternative for digital impressions in ISFPDs.

WHAT IS ALREADY KNOWN ABOUT THIS TOPIC?

Scan bodies are the current standard for digital implant impressions. Coded healing abutments have been proposed as an alternative, simplifying the procedure, and potentially preserving soft tissue stability. However, existing evidence on their accuracy remains limited, and heterogeneous, with outcomes influenced by implant angulation and other clinical variables.

WHAT DOES THIS STUDY ADD?

This study demonstrates that coded healing abutments can achieve clinically acceptable accuracy, especially with angulated implants, although scan bodies remain the most reliable option overall. Implant angulation affected analog impressions more than digital techniques. Coded healing abutments may be a valid alternative to scan bodies in selected clinical scenarios, but further clinical trials are needed to confirm their performance under real conditions.

Key words: Implant-supported, digital impression, code abutment healing, scan body, accuracy

1. Introduction

Implant-supported prostheses have become a well-established treatment option for the replacement of missing teeth, providing predictable long-term outcomes in terms of survival, function, and patient satisfaction. Clinical evidence consistently reports high implant survival rates supporting their routine use in contemporary prosthodontics[1,2].

The continuous innovation in digital dentistry has redefined treatment workflows, shifting from conventional analog protocols to fully integrated digital systems. Conventional elastomeric impressions used to fabricate implant-supported fixed partial dentures (ISFPDs) have long been the standard, yet they involve multiple steps, material distortion risks, and patient discomfort, limitations that digital workflows seek to amend[3,4]. Digital impressions have emerged as a reliable alternative due to their reported efficiency and accuracy comparable to, or even exceeding, conventional impression techniques[5-10]. The digital workflow involves capturing the three-dimensional (3D) position of implants and peri-implant soft tissue using intraoral scanners (IOSs) and scan bodies (SBs), enabling computer-aided design and computer-aided manufacturing (CAD-CAM) of the definitive prosthesis[4,11]. Although SBs are widely accepted as the standard approach, their use entails certain clinical limitations. The clinical protocol requires removal of the healing abutments and placement of SBs, which prolongs clinical procedures and involves repeated peri-implant soft tissue manipulation, which may compromise the mucosal seal and increase the risk of inflammation and patient discomfort[12,13].

To address these drawbacks, coded healing abutments (CHAs) have been introduced. CHAs combine the biological role of healing abutments with the digital transfer function of SBs[5,14]. Their surfaces contain identifiable geometric or coded features that allow IOSs to recognize and register implant position, without abutment replacement. This approach simplifies the impression procedure, reduce the number of clinical steps, and preserve peri-implant soft tissue stability by minimizing abutment manipulation[12,14-19]. Previous studies suggest that CHA-based workflows may reduce chairside time while maintaining acceptable accuracy levels for clinical use[16,20,21]. However, the evidence remains heterogeneous, with reported outcomes influenced by variables such as implant angulation, interimplant distance, prosthesis span, and scanner technology[15,19,21-23]. Some studies have reported deviations in accuracy compared to SBs that may compromise prosthesis fit in more complex scenarios. Furthermore, most available studies are laboratory-based, with limited clinical validation[12,14,15,21,22,24]. Consequently, the actual reliability of CHAs in daily prosthodontic practice remains controversial.

Accuracy is crucial in ISFPDs, since passive framework fit is required to avoid biological and mechanical complications; even slight deviations in digital impressions may result in misfit, screw loosening, or adverse bone–implant stress[4,15,19,25]. Thus, it remains necessary to clarify whether CHAs represents a viable alternative to SBs, particularly in situations involving angulated implants. Therefore, this in vitro study aimed to evaluate the accuracy (trueness and precision) of digital impressions using CHAs and SBs, compared with conventional impressions for ISFPDs, and to assess the effect of implant angulation. The null hypothesis stated that impression accuracy would not differ among techniques, regardless of implant angulation.

2. Materials and Methods

Two mandibular master models were designed in CAD software (DentalCAD v2.4, Plovdiv 7290, Exocad GmbH, Darmstadt, Germany) and fabricated in polymethyl methacrylate (PMMA), with missing teeth 3.5–3.7. Implant analogs (TSV, ZimVie) with 3.5-mm platforms were placed at sites 3.5 and 3.7, 1 mm subcrestally. Model 1 (M1) had parallel implants, while Model 2 (M2) was designed with the anterior implant angulated 10° buccally and the posterior implant 20° lingually. The implant angulations were chosen based on previous studies[23,26-29]. Both models included removable gingiva (Fig. 1). Each model was measured 10 times with a coordinate measuring machine (CMM) (Global EVO 9-15-8, Hexagon Manufacturing Intelligence, North Kingstown, RI, USA) using a tactile probe to generate reference datasets.

The sample size was determined based on previous studies[18,24,26,27], and through an a priori power analysis using data from previous study[28] with statistical software (G*Power 3.1.9.4, Samsøvej, Denmark) applying a significance level = 0.05, power = 0.8, and effect size = 0.78 (large). This calculation indicated a minimum requirement of 54 specimens, and a total of 60 specimens (30 per group) were included in the study. Two groups were established (n = 30 each) based on implant angulation: Group 1 (M1) with parallel implants, and Group 2 (M2) with implants angulated. Within each group, 3 subgroups (n = 10 each) were defined according to the impression technique used: CHA, SB, or conventional analog technique (ANA) (Table 1).

A custom methacrylate fixture was fabricated to standardize the digital scanning sequence. It consisted of 4 parts: a base for support, a model platform with 3 positioning stops and 360° rotation, an articulated scanning arm with a ball joint, and a stabilization area for IOS head positioning (Fig. 2). An IOS (Primescan, Dentsply Sirona, North Carolina, USA) was calibrated before use, and each model was scanned 10 times with CHA and SB by the same experienced operator using the methacrylate fixture, following the manufacturer's protocol. Scanning was performed sequentially from the occlusal, lingual, and labial sides. A total of 40 STL files were generated and subsequently imported into dental design software (DentalCAD 3.0 Galway, Exocad GmbH) to align each STL with its corresponding virtual analog, yielding 40 digital casts.

Conventional impressions were performed last to preserve the master models. Ten impressions per model were obtained using open-tray and splinted copings, which were stabilized with acrylic resin (Pattern resin; GC, Tokyo, Japan), sectioned, and re-luted to minimize shrinkage. Impressions were made with polyvinylsiloxane impression (Ellite HD Putty and Light body, Zhermak, Badia Polesine, Italy) and poured in Type IV dental stone (Fujirock, GC, Tokyo, Japan). The casts were then digitized with a laboratory scanner (T710, Medit, Seoul, South Korea), and the resulting STL files were imported into CAD software (Exocad Dental CAD, Exocad GmbH) for alignment with virtual implant analogs.

A metrological analysis software (Geomagic Control X v 2022.1.0, 3D Systems, Rock Hill, SC, USA) was used to assess the accuracy of 3D manufactured dental components[4,7,18]. All STL files were imported into the software, and a dimensional analysis was performed. The first step was to identify the center of each implant and to measure its Cartesian coordinates (X, Y, Z) to define its 3D position. Subsequently, the linear distance between the centers of the implants and their angulation in both the frontal and sagittal planes were measured (Fig. 3). A metric report was generated for each STL and subsequently used to quantify deviations from the CMM data.

Trueness was calculated as the mean difference of discrepancies between the test group values and those of the CMM, while precision was assessed in terms of standard deviation (SD)[28,29]. The independent variables evaluated were the impression technique and implant angulation. The dependent variables were the linear distance between implants, the angles formed by implants in the frontal and sagittal planes, and the 3-D positions of the implants. The data were analyzed using a statistical software (IBM SPSS Statistics v28, IBM Corp, Armonk, NY, USA), with the significance level set at $\alpha = 0.05$. The Shapiro-Wilk test confirmed that the data were normally distributed. Trueness was assessed using one-way ANOVA followed by Tukey´s HSD post hoc test to identify differences among the impression groups. A t-test was conducted to compare groups M1 and M2. Precision was evaluated using Levene´s test.

3. Results

The means, SDs, and statistical significance are presented in Table 2. For model with parallel implants (M1**)**, precision**,** assessed with Levene's test, revealed differences for the anterior implant at the Y2 and Z2 coordinates. The SB and ANA groups exhibited significantly higher precision than the CHA group at Y2, while the ANA group showed the greatest variability at Z2. No differences were found for the linear or angular variables. Regarding trueness**,** one-way ANOVA demonstrated differences among groups. For the linear distance between implants, the SB group showed the highest trueness (19.7 ± 0.02 mm), whereas the ANA group displayed the greatest discrepancies. For angular deviation in the frontal plane, the ANA group achieved the highest trueness (2.98 ± 0.24°), being the only group not significantly different from the CMM reference values. In the sagittal plane, CHA showed the highest trueness (0.19 ± 0.1°), with no differences among groups (Figs. 4-6). Across all groups, the posterior implant exhibited the highest trueness, while the SB group consistently demonstrated the highest trueness for the anterior implant coordinates.

In the model with angulated implants (M2), for precision Levene's test identified differences at the anterior implant. The SB group showed the highest precision for linear distance and angular deviations, although no difference was detected compared with CHA. For trueness**,** ANOVA indicated group differences. SB achieved the highest trueness for the linear distance between implants (20.1 ± 0.01 mm), although not significantly different from CHA. CHA showed the highest trueness for angular deviation in the frontal plane (23.66 ± 0.32°), with no difference compared to SB. For the sagittal plane, SB obtained the highest trueness (0.48 ± 0.25°), again without differences among groups (Figs. 4-6). As in M1, the posterior implant consistently demonstrated the highest trueness across groups, whereas the SB group achieved the best trueness for the anterior implant coordinates.

When comparing the accuracy between M1 and M2, t-test showed no differences between M1 and M2 for the CHA and SB groups. In contrast, the ANA group exhibited significantly higher accuracy in M1, both for linear distance ($p = 0.03$) and for angular deviations in the frontal ($P < 0.001$) and sagittal planes ($P < 0.001$) (Figs. 4-6).

4. Discussion

This study compared the accuracy of digital impressions obtained with CHAs and SBs, as well as ANA impressions in ISFPDs across implant angulations. The results obtained support the partial rejection of the null hypothesis, as significant differences were identified in the accuracy of the impression systems depending on the specific variable analyzed.

In recent years, digital impression techniques employing SBs have increasingly replaced conventional methods, providing improved accuracy and reliability in implant prosthodontics[8,9]. The results of this study underscore the continuing transition toward digital workflows in the fabrication of ISFPDs. SBs consistently achieved the highest accuracy, whereas CHAs demonstrated clinically acceptable trueness, particularly in angulated implants. Conversely, analog impressions showed greater variability. Consistent with these findings, clinical and in vitro studies have demonstrated that SBs remain the most precise and dependable approach for capturing digital impressions of implants[30,31].

CHAs, initially introduced by Grossman et al. (2006)**,** were developed to streamline the digital workflow for implant-supported restorations[32].These abutments feature occlusal markings that can be detected by IOSs, enabling the accurate digital capture of essential implant-related parameters, including the connection type, abutment geometry, emergence profile, peri-implant soft tissue position, and abutment height[15,33]. Several in vitro studies have evaluated the accuracy of CHAs in comparison with conventional and SB impression techniques[12,14,15,18,21,24]. These investigations have often reported comparable performance between CHA and SB systems[12,21,24], consistent with the findings of the present study, particularly for models with angulated implants. Conversely, Ng et al. observed greater deviations for CHA impressions under similar angulated conditions[22]. Such discrepancies may arise from differences in scanning protocols, software alignment algorithms, and the generation of STL files, all of which can vary considerably among different intraoral scanner systems[33,34].

One relevant point is the superior performance of posterior implant sites in the study, whereas previous investigations have often described greater distortions in distal regions due to increased scan length and cumulative stitching errors[17,19]. The present findings may reflect the use of a controlled device, with rigid stabilization of the models and absence of intraoral variables such as saliva, soft tissue movement, or restricted access. Clinically, such confounding factors may reduce CHA reliability in posterior sites, especially in partially edentulous arches[26]. [26]

Regarding implant angulation, in the study no differences were observed between CHA and SB groups when compared under angulated conditions, which is consistent with systematic reviews reporting that moderate angulations (<30°) do not substantially impair digital accuracy[8,26,27,35]. Nevertheless, evidence from full-arch rehabilitations suggests that deviations accumulate as the number of implants and the degree of divergence increase, potentially affecting passive fit[28,34]. This underlines the need for further clinical trials to confirm whether CHA-based workflows can reliably replace SBs in more complex prosthetic scenarios.

The clinical implications of these findings are noteworthy. By eliminating repeated abutment manipulation, CHAs may help preserve peri-implant soft tissue stability and reduce chairside time, which is particularly advantageous in patients with thin biotypes or high esthetic demands[33]. At the same time, the slightly lower accuracy observed with CHAs in parallel implants suggests that clinicians should exercise caution in cases where prosthesis fit tolerance is minimal, such as long-span or screw-retained frameworks. In such situations, SBs may remain the more predictable option until CHA protocols and IOS technologies undergo further refinement[30].

Several limitations should be acknowledged in the study. First, this was an in vitro study using a single operator and one IOS, which restricts generalizability. Operator experience, scanning strategies or IOS system have been shown to significantly influence outcomes[10,33,36,37]. Therefore, the present results cannot be directly extrapolated to clinical conditions or to other IOS systems. Second, implant position accuracy was assessed as the primary outcome, whereas the ultimate clinical endpoint, the fit and performance of the definitive prosthesis, was not tested. Finally, while the CMM ensured high precision for reference measurements, in vivo variables such as saliva, patient movement, and limited intraoral access may alter real-world performance[9,15,23,26].

In summary, the present study confirms that CHAs provide clinically acceptable accuracy, particularly under angulated implant conditions, but SBs continue to offer superior reliability across most scenarios. Future research should validate CHA performance under real clinical conditions with multiple IOS systems and operators.

5. Conclusions

Within the limitations of this in vitro study, both coded healing abutments and scan bodies demonstrated higher accuracy than conventional analog impressions, particularly with angulated implants. Scan bodies achieved the highest trueness, although no differences were observed between scan bodies and coded healing abutments in angulated implants. Implant angulation negatively affected the accuracy of analog impressions. Overall, scan bodies remain the most reliable approach for digital impressions in implant-supported fixed partial prostheses, while coded healing abutments may serve as a valid alternative in selected clinical situations.

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Conflict of interest statement.

The authors reported no conflicts of interest related to this study.

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Tables

Table 1. Technical characteristics of implant scanning systems.

Scan system	**Scan systems dimensions (Diameter, length)**	**Core material**
CHA (Encode; ZimVie)	3.5 mm, 3 mm	Titanium
SB (ZimVie)	3.5 mm, 10 mm	GenTek® (PEEK) and Titanium base

CHA: coded healing abutment; SB: scan body; PEEK: polyetheretherketone.

Table 2. Means and standard deviations (SD) of implant coordinates, inter-implant linear distances, and angular deviations.

Model	Impression system	X1	Y1	Z1	X2	Y2	Z2	Linear distance (mm)	Angle frontal plane (degrees)	Angle sagittal plane (degrees)
M1	CHA	0	0	0	19.66 ±0.22^{a}	0^{a}	0.62 ±0.04^{a}	19.67 ±0.02^{a}	2.82 ±0.26^{a}	0.19 ±0.1^{a}
	SB	0	0	0	19.70 ±0.01^{b}	0^{b}	0.44 ±0.03^{a}	19.7 ±0.02^{b}	2.94 ±0.01^{a}	0.21 ±0.07^{a}
	ANA	0	0	0	19.66 ±0.25^{a}	0^{b}	0.64 ±0.08^{b}	19.67 ±0.03^{a}	2.98 ±0.24^{a,b}	0.29 ±0.15^{a}
	CMM (reference)	0	0	0	19.7^{b}	0^{a,b}	0.5^{c}	19.7^{b}	3.2^{b}	0.03^{b}
M2	CHA	0	0	0	20.07 ±0.02^{a}	0^{a}	0.52 ±0.07^{a}	20.08 ±0.02^{a}	23.66 ±0.32^{a}	0.82 ±0.2^{a}
	SB	0	0	0	20.10 ±0.01^{a}	0^{b,c}	0.31 ±0.02^{b}	20.10 ±0.01^{a}	23.58 ±0.23^{a}	0.49 ±0.25^{a,c}
	ANA	0	0	0	20.04 ±0.04^{b}	0^{a,c}	0.62 ±0.18^{a}	20.05 ±0.04^{b}	21.94 ±1.8^{b}	1.02 ±0.55^{b}
	CMM (reference)	0	0	0	20.12^{c}	0^{c}	0.33^{b}	20.12^{c}	24.11^{c}	0.33^{c}

Means labeled with different letters indicate significant differences according to the Tukey test; means sharing the same letter do not differ significantly from each other. Significances at $P < 0.05$. M1: model 1; M2: model 2; CHA: coded healing abutment; SB: scan body; ANA: analog impression; CMM: coordinate measuring machine

Legend to Figures

Fig. 1. Master models. A) Model 1. B) Model 2.

Fig. 2. Custom metacrylate fixture detail

Fig. 3. Geomagic Control X software images: A) Spatial coordinates. B) Linear distance between implants. C) Angle in the frontal plane. D) Angle in the sagittal plane.

Fig. 4. Linear distance between implants according to impression systems and master models.

CHA-1: coded healing abutment, model M1; CHA-2: coded healing abutment, model M2; SB-1: scan body, model M1; SB-2: scan body, model M2; ANA-1: analog impression, model M1; ANA-2: analog impression, model M2; CMM-1: coordinate measuring machine, model M1; CMM-2: coordinate measuring machine, model M2.

Fig. 5. Angle in the frontal plane according to impression systems and master models.

CHA-1: coded healing abutment, model M1; CHA-2: coded healing abutment, model M2; SB-1: scan body, model M1; SB-2: scan body, model M2; ANA-1: analog impression, model M1; ANA-2: analog impression, model M2; CMM-1: coordinate measuring machine, model M1; CMM-2: coordinate measuring machine, model M2.

Fig. 6. Angle in the sagittal plane according to impression systems and master models.

CHA-1: coded healing abutment, model M1; CHA-2: coded healing abutment, model M2; SB-1: scan body, model M1; SB-2: scan body, model M2; ANA-1: analog impression, model M1; ANA-2: analog impression, model M2; CMM-1: coordinate measuring machine, model M1; CMM-2: coordinate measuring machine, model M2.