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The accuracy of single implant scans with a healing abutment-scanpeg system compared with the scans of a scanbody and conventional impressions: An in vitro study

Burak Yilmaz [a,b,c], Diogo Gouveia [c], Vinicius Rizzo Marques [a], Emre Diker [d,e], Martin Schimmel [f,g], Samir Abou-Ayash [f,*]

[a] Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland
[b] Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland
[c] Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, OH, 43210, USA
[d] The Ohio State University, College of Dentistry, Division of Restorative and Prosthetic Dentistry, Columbus, OH, USA
[e] Ankara University, Faculty of Dentistry Department of Prosthodontics, Ankara, Turkey
[f] Department of Reconstructive Dentistry and Gerodontology, University of Bern, Freiburgstrasse 7, 3007 Bern, Switzerland
[g] Extra Muros, Division of Gerodontology and Removable Prosthodontics, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland

A R T I C L E I N F O

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A B S T R A C T

Purpose: To compare the accuracy of polyvinylsiloxane (PVS) impressions and intraoral scans when a healing abutment-scanpeg system (HASP) or a conventional scanbody (CSB) was used on a single implant.
Materials and methods: A maxillary model with an implant (4.0 × 11 mm) (Neoss) and a CSB or an HASP (Neoss) was scanned by using a laboratory scanner (Ceramill Map 600; Amann Girrbach) (reference scans) and an intraoral scanner (Trios 3) (n = 10). PVS open-tray impressions were also made and stone casts of the model with a CSB were digitized with the laboratory scanner. Intraoral scanner and cast scans were superimposed to their reference scans. On superimposed scans, points were selected on HASP and CSB to calculate distance deviations (at points 1–4) and angular deviations (at points 5 and 6 on CSB and PVS, and 5–8 on HASP) between scans (trueness), and their variation (precision). The deviation data was analyzed with ANOVA and pairwise comparisons (trueness) with Tukey's adjustment, and F-tests (precision).
Results: At point 1, PVS had lower trueness than CSB (difference in means (DIMs) = 0.184 mm, p = 0.006) and HASP (DIMs = 0.122 mm, p = 0.042). At point 3, CSB had higher trueness than HASP (DIMs = 0.134 mm, p = 0.001). Angular deviations with PVS were higher than with CSB (DIMs = 0.6°, p = 0.013) and HASP (DIMs = 0.7°, p = 0.005). CSB had higher precision than PVS ($p < 0.05$). HASP had higher precision than PVS for distance (Point 1)($p < 0.001$) and angular deviations ($p < 0.05$). Deviation differences within the HASP parts were not significant.
Conclusion: The accuracy of intraoral scans and PVS impressions of an implant was similar.
Clinical relevance: The combined healing abutment-scanpeg system and the conventional scanbody can be recommended for scans of anterior single implants with the intraoral scanner used.

1. Introduction

Since the early days of implant dentistry, conventional impressions with elastomeric materials, commonly polyvinylsiloxane (PVS), have been the standard of care to transfer the implant's intraoral position to the master cast [1–3]. The use of CAD-CAM technology to fabricate implant-supported crowns has become popular in the last decade and the workflow can be either direct or indirect depending on whether an intraoral scanner (IOS) and an intraoral scan body (ISB) or a laboratory scanner and a laboratory scan body (LSB) are used [4]. The CAD-CAM workflow is not error-free [5,6], and the scan accuracy is crucial to start the workflow with minimum errors. Accuracy is determined by

* Corresponding author.
E-mail addresses: burak.yilmaz@zmk.unibe.ch (B. Yilmaz), Gouveia.5@osu.edu (D. Gouveia), marqvr@gmail.com (V.R. Marques), emrediker@outlook.com (E. Diker), martin.schimmel@zmk.unibe.ch (M. Schimmel), samir.abou-ayash@zmk.unibe.ch (S. Abou-Ayash).

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trueness and precision (ISO-5725). Trueness describes how far the measurement deviates from the actual dimensions of the measured object. Precision describes how close repeated measurements are to each other [7]. Several factors influence the precision of an IOS, which can be subdivided into operator-related factors (e.g. the level of experience) [8], patient-related factors (e.g. distance between implants) [9], the environment (e.g. light conditions) [10], and the software- (e.g. software version [11] and hardware-related factors (e.g. type of intraoral scanner) [12]. Furthermore, recent studies have demonstrated statistically significant manufacturing tolerances with ISBs, which may have a major effect on the precision of intraoral scanning [13,14]. Commercially available ISBs have variety of shapes, sizes, surfaces, and connections [4]. While digital implant scanning has been well documented in the literature [9,15–19], studies are scarce on the effects of ISBs on the scan accuracy [16,19–23].

Coded healing abutments are a type of ISB and were first introduced to be used with conventional impressions [23,24]. Because the healing abutment also serves as an impression post/scanbody, it enables the reduction of the number of appointments and the times the healing abutment needs to be removed [21], which minimizes the irritation of peri-implant soft tissues [25]. The use of coded healing abutments with IOSs can be advantageous as the impression to fabrication workflow can become completely digital [20]. A common drawback for the use of coded healing abutments and current scan bodies is the fact that they commonly have a conical or cylindrical shape, which does not reflect the shape of a natural tooth [4]. Accordingly, an interim implant-supported restoration or a custom healing abutment is needed to form an optimal emergence profile, particularly in the anterior region or with wide span edentulous sites to be restored with single implants [26]. A recently introduced healing abutment-scanpeg system enables the scans of implants, shapes the soft tissues for an optimal emergence profile, and the healing abutment can be kept on the implant throughout healing and the crown fabrication process [20]. Therefore, this system not only enables digitization of the implant position, but also minimizes soft tissue trauma and expedites the prosthetic workflow [20]. Currently, there is no published studies on the accuracy of the healing abutment-scanpeg system and clinicians would benefit from a study investigating its accuracy.

The aim of the present study was to investigate the scan accuracy (trueness and precision) of a healing abutment-scanpeg system comparing with that of a conventional scanbody, and PVS impressions when used on an anterior implant. The scan accuracies of the healing abutment and the scanpeg, and when combined were also aimed to be investigated. The first null hypothesis was that the scan accuracy of the healing abutment-scanpeg system would not be different than the accuracy of a conventional scanbody or conventional PVS impressions. The second null hypothesis was that the scan trueness of the healing abutment and the scanpeg, and when they were combined would not be different.

2. Materials and methods

2.1. Data acquisition

An additively manufactured (Form 2; Formlabs Inc, Somerville, MA, USA) maxillary resin model with an implant (4.0 × 11 mm) (Proactive Straight Implant; Neoss, Woodland Hills, CA, USA) at maxillary left central incisor was used. A conventional intraoral scanbody (CSB) (Neoss, Woodland Hills, CA, USA) was tightened on the implant by using a digital torque meter to 10 Ncm (Fig. 1A). The model was scanned by using a laboratory scanner (Ceramill Map 600; Amann Girrbach AG, Koblach, Austria)(CSB reference) to obtain a reference scan. An operator who has experience in digital scanning (at least 10 pilot scans and 2-year experience with scanning) scanned the model with the intraoral scanner (Trios 3; 3Shape, Copenhagen, Denmark) including all teeth and the scanbody (n = 10). Then, the scanbody was removed and a healing abutment-scanpeg system (HASP) was placed (Fig. 1B) tightening the healing abutment to 10 Ncm and securing the scanpeg on the healing abutment which has a friction fit mechanism with a key way (Fig. 2). The model was again scanned with the same laboratory scanner (HASP reference) and then by using the same intraoral scanner by the same operator (n = 10). After the HASP was removed, a conventional open-tray impression post was placed on the implant and tightened to 10 Ncm. Polyvnylsiloxane impressions (Panasil; Kettenbach GmbH & Co. KG, Eschenburg, Germany) were made by using light and heavy-body consistency and open-tray technique (n = 10). Then, the analogs were tightened to impression posts and the impressions were poured in Type IV dental stone (Silky-Rock, Whipmix Corp.). Then, the CSB scanbodies were tightened on the analogs (10 Ncm) and each cast with CSB was scanned by using the same laboratory scanner to record the positions of the analogs in casts (Fig. 1C). Then, the CSB scan and the PVS impression

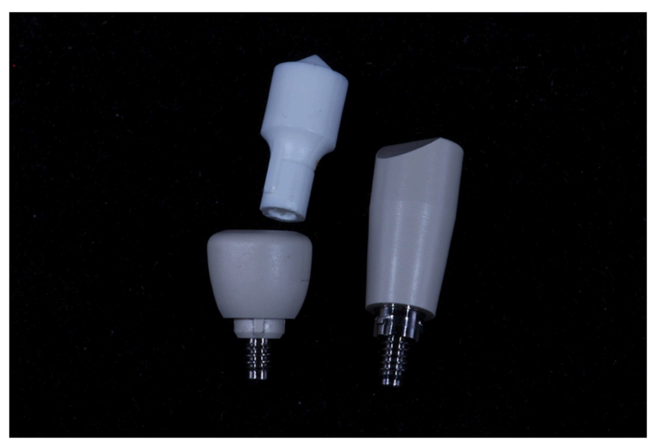

Fig. 2. Applied scanbodies: Individual parts of the healing abutment-scanpeg system (HASP; left) and the conventional scanbody (CSB; right).

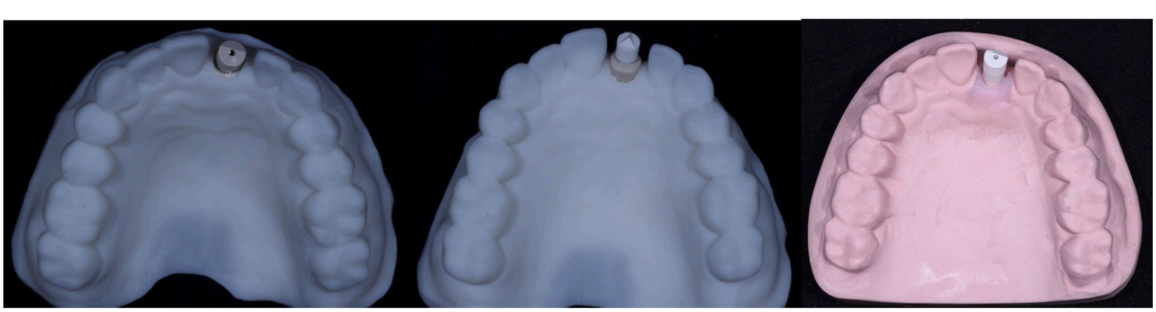

Fig. 1. A–C **Study Models**: Study models with (A) the conventional scanbody (CSB), (B) the healing abutment-scanpeg system (HASP), (C) and the stone cast with the CSB in the left central incisor position.

scans were superimposed with the CSB reference scan and the HASP scans were superimposed with the HASP reference scan. All intraoral scans were done by using the same scan path, which was recommended by the manufacturer of the scanner; the scans started on the occlusal of left second molars, continued on occlusals/incisals of remaining teeth followed by their linguals and buccals. The scan files were converted to standard tessellation language (STL) format.

2.2. Evaluation of accuracy

The intraoral scanner scans were exported to a 3-dimensional metrology software (GOM GmbH; Braunschweig, Germany–version 2018 Hotfix 7, Rev. 120738, Build 2019-08-23) for superimpositions with the reference scans. On the reference scan of each group analyzed, two planes (buccopalatal (x plane) and mesio-distal (y plane)) were created crossing the center of the scanbody (Fig. 3). On x plane, four points were selected at different locations of the scanbody (1 - implant-abutment-connection, 2- most buccal-coronal, 3 - middle point on buccal coronal slope, 4 - most palatal coronal point) to measure distance deviations. On mesiodistal plane (y plane): point 5 was at the implant-abutment connection and point 6 was at the most mesial coronal point angle, which would be used only for angular deviations (Fig. 4). Because the HASP design was different than that of CSB and PVS groups, corresponding similar points were selected on HASP and additional points were selected for angular deviation calculations within HASP parts: on x plane: 1 - implant-abutment-connection, 2 - most buccal-coronal, 3 – middle point on buccal coronal slope, 4 – most palatal point on top of scanpeg, 5 - healing abutment-scanpeg connection; and on y plane: 6 – implant-abutment connection, 7 – healing abutment-scanpeg connection and 8 - most distal coronal point (Fig. 5).

The scanned models were initially aligned by using software's pre-alignment feature. Then, all teeth except for the scanbody site were selected for further alignment by using the "local best-fit" tool. The coordinates for the predefined points on the CSB/ HASP were then added and program's algorithm generated the deviations between the specified points on the reference and the tests scans in respective planes. By using the coordinates, it was ensured that same points were always selected on scanbodies for subsequent comparisons.

For PVS and CSB angular deviations, points 1 and 2 were used to draw a line on buccopalatal plane and points 5 and 6 were used for a line on mesiodistal plane (Fig. 4). Then, the angles between the lines on the reference and the test scan models were calculated.

Angular deviations for HASP were analyzed between the lines drawn from point 1 to point 2 on buccopalatal plane, and a line was drawn between point 6 at implant-abutment connection and point 8 on mesiodistal plane (Fig. 5).

To compare the angular deviations within the HASP parts, additional lines were drawn between the healing abutment and the scanpeg. For buccopalatal angle of only the healing abutment (BPHA), points 1 and 5 were used to draw a line and for buccopalatal angle of only the scanpeg (BPSP), points 2 and 5 were used. For the mesiodistal angle of only the healing abutment (MDHA), points 6 and 7, and for the mesiodistal angle of only the scanpeg (MDSP), points 7 and 8 were used to draw the lines (Fig. 5).

For the evaluation of trueness, distance- and angular deviations between the corresponding points and lines in test and reference datasets were calculated. For the evaluation of precision, the variance of deviations of each point and angle within each test group was calculated.

2.3. Statistical analysis

The data generated (3D distance deviation at all points and buccopalatal and mesiodistal angles) were tabulated (Excel, Microsoft Corp.) for statistical analysis. Corresponding points in PVS and CSB (1–4) and HASP (1, 3, 4, 6) were compared for distance deviations. To compare the deviations amongst three groups, ANOVA was used to find overall differences between the groups and the pairwise comparison was made with Tukey's adjustment. Similar analyses were performed in the comparison of angles in the HASP group. For precision analysis, the F-test was used to compare the variance of deviation in two groups and the ratio of variance, and Bonferroni-corrected p-values were reported (alpha = .05).

3. Results

Significant differences in distance deviations were found amongst groups at point 1 ($p = 0.008$) and 3 ($p = 0.002$). At point 1, PVS had more deviations than CSB (estimated difference in means: 0.184 mm; $p = 0.006$) and HASP (estimated difference in means: 0.122 mm; $p = 0.042$), and deviations calculated with CSB and HASP were not significantly different (estimated difference in means: 0.062 mm; $p = 0.262$). At point 3, CSB had lower deviations compared with HASP (estimated difference in means: 0.134 mm; $p = 0.001$). No further significant differences in distance deviations amongst the groups were found at point 3, 2, and 4. An overview of distance deviations for all evaluated points in all groups are displayed in Fig. 6.

For angular deviations, significant difference amongst groups was only seen in mesiodistal direction ($p = 0.002$). Deviations with PVS were higher than the deviations with CSB (estimated difference in means: 0.64°; $p = 0.013$) and HASP (estimated difference in means: 0.73°; $p = 0.005$), and deviations with CSB and HASP were not significantly different (Fig. 7). When the angular deviations within the parts of HASP were considered, no significant differences were found for buccopalatal ($p = 0.311$) and mesiodistal deviations ($p = 0.527$) (Fig. 8). Table 1 summarizes the distance and angular deviations in each group.

The CSB had higher precision than PVS at all points and angles ($p < 0.05$). HASP had higher precision than PVS at point 1 ($p < 0.001$) and for both angular deviations ($p < 0.05$). HASP and CSB did not have

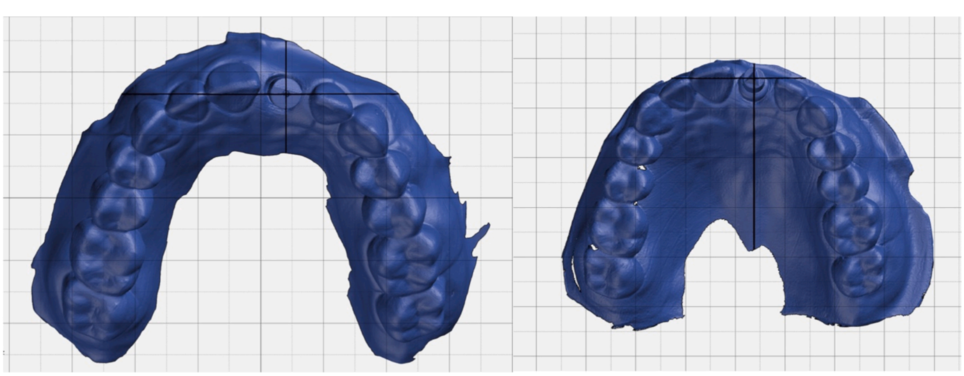

Fig. 3. A and B **Definition of planes:** Mesiodistal (y plane) and buccopalatal (x-plane) planes for the models with (A) the conventional scanbody (CSB), (B) and the healing abutment-scanpeg system (HASP).

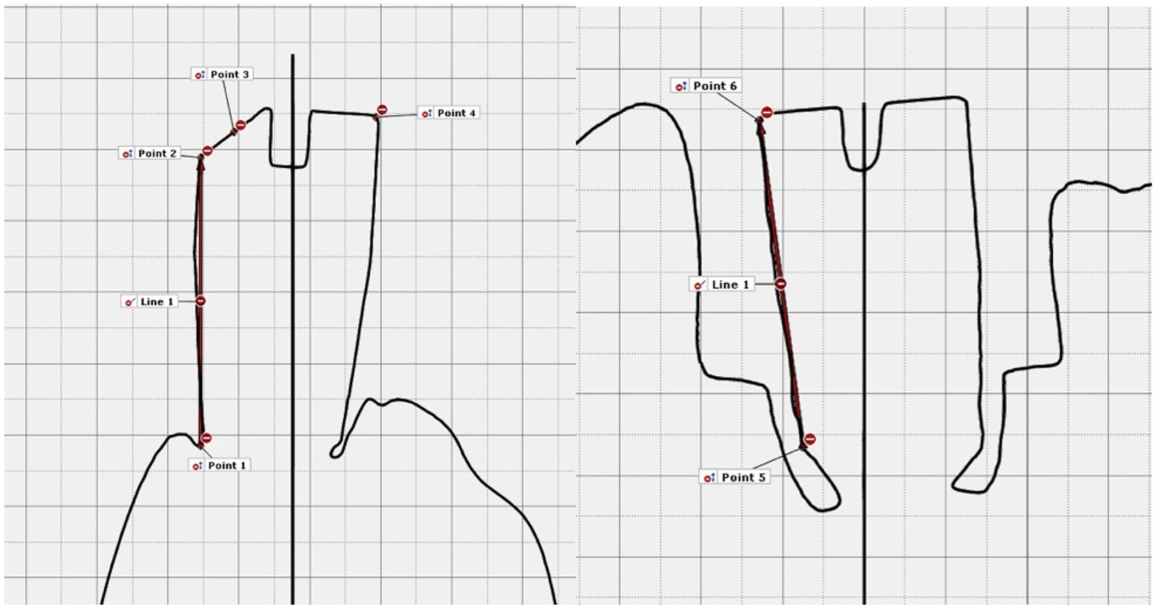

Fig. 4. A and B **Points and angles on the conventional scanbody (CSB):** Overview of selected points and angles in (A) the buccopalatal, (B) and mesiodistal planes.

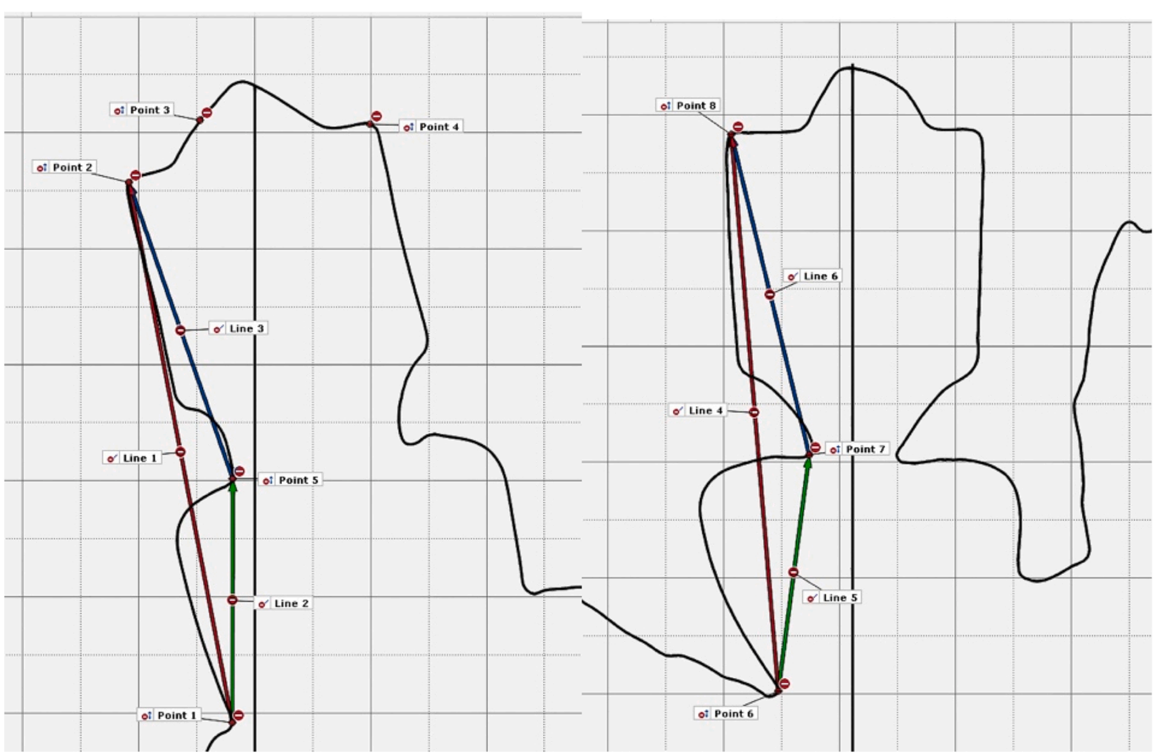

Fig. 5. A and B **Points and angles on the healing abutment-scanpeg system (HASP):** Overview of selected points and angles in (A) the buccopalatal, (B) and mesiodistal planes.

significantly different precision at any points or angles.

4. Discussion

The trueness and precision of CSB and HASP were different than those of PVS, and accordingly the first null hypothesis was rejected. The second null hypothesis was accepted as the trueness of scans of the healing abutment and the scanpeg was not different.

The accuracy (trueness and precision) of CSB and HASP in terms of distance and angular deviations was higher than the accuracy of PVS at some selected points and angles. The fact that PVS was associated with more errors may be considered expectable as it involves more steps and materials; each step and material have their own limitations and errors associated with them. Previous studies have shown that scans of single implants with intraoral scanners are at least as accurate as indirect digitization by using conventional impressions and subsequent scanning of the stone cast [27]. However, it was also shown that the scanbody type may have an influence on the accuracy of intraoral scans [4]. CSB

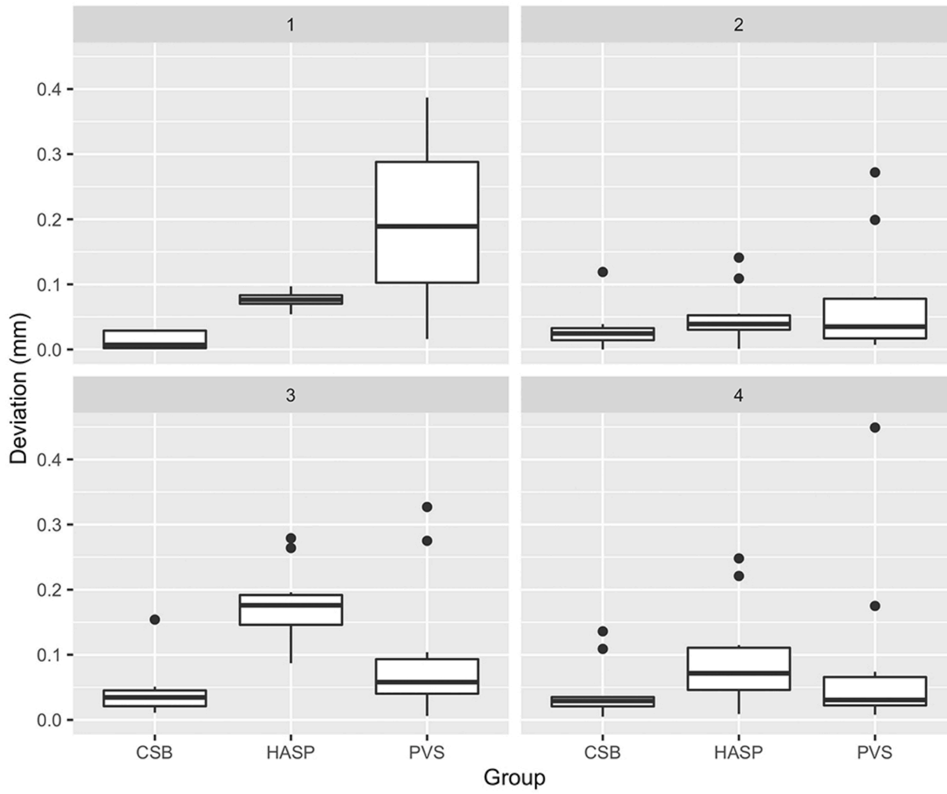

Fig. 6. Distance deviations: Distance deviations at points 1-4 (buccopalatal plane) in the healing abutment-scanpeg system (HASP), the polyvinylsiloxane impression (PVS), and the conventional scanbody (CSB) group.

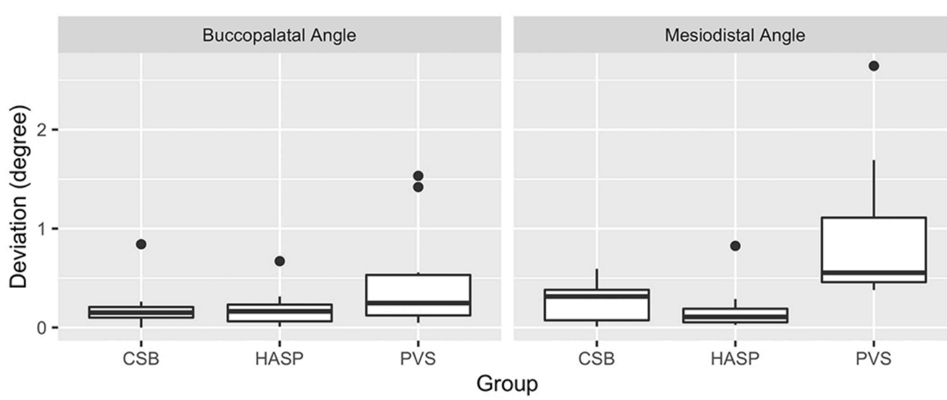

Fig. 7. Angular deviations: Angular deviations in buccopalatal and mesiodistal plane for the healing abutment-scanpeg system (HASP), the polyvinylsiloxane impression (PVS), and the conventional (CSB) group.

and HASP performed similarly at all points and angles, except for point 3, where CSB had favorable trueness compared with HASP. Nevertheless, it may be interpreted that CSB and HASP had similar scan accuracy.

All groups had mean distance deviations less than 80 microns almost at all selected points. Previous studies on digital and conventional single implant impressions demonstrated similar deviations [28]. PVS had mean distance deviations close to 200 microns at only point 1. The reason for high deviations and low precision may be due to the fact that point 1 is at the gingival level and the laboratory scanner might have had difficulty capturing point 1. Although laboratory scanner technologies have significantly improved in recent years, their scan mechanism may lead to acquisition problems [29]. A laboratory scanner automatically moves the object to be scanned into different positions to achieve the best possible illumination for optimal acquisition of all areas [30]. Targeted acquisition of specific sites, as can be done with an intraoral scanner, is only possible with certain laboratory scanners [31]. The restricted mobility of the object plate can prevent optimal capturing of sites, which are difficult for the light to reach. Therefore, higher deviations seen with the PVS group at Point 1 may be due to its location on the cast and possible difficulty the laboratory scanner had to capture this point [32]. For the test groups intraoral scanner captured the images (HASP and CSB), deviations were small at Point 1. Considering the distance and angular deviations in the present study and comparing them with those in previous studies, it can be interpreted that intraoral scans with CSB and HASP are suitable to fabricate implant crowns with adequate fit [12]. The application of a completely digital workflow to fabricate a monolithic implant crown is possible [33]. With the advents in ceramic technologies, the optical properties of monolithic crowns currently enable their use also in the anterior region [34,35]. A systematic review with meta-analysis has reported that patients generally

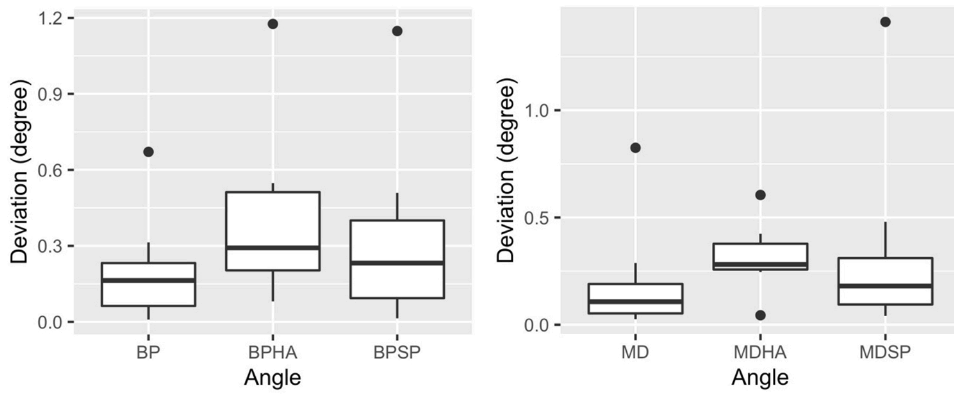

Fig. 8. A and B **Angular deviations within the different parts of the healing abutment-scanpeg system (HASP):** (A) Deviation in buccopalatal plane (overall (BP), only of the healing abutment (BPHA), and only of the scanpeg (BPSP)), (B) deviation in mesiodistal plane (overall (MD), only of the healing abutment (MDHA), and only of the scanpeg (MDSP)).

Table 1
Mean (±SD) distance and angular deviations.

Group	Point 1	Point 2	Point 3	Point 4	buccopalatal	mesiodistal
CSB	0.014 (±0.015)	0.031 (±0.033)	0.043 (±0.041)	0.043 (±0.044)	0.208 (±0.237)	0.273 (±0.205)
HASP	0.076 (±0.013)	0.05 (±0.044)	0.178 (±0.059)	0.094 (±0.081)	0.195 (±0.193)	0.186 (±0.239)
PVS	0.197 (±0.186)	0.075 (0.09)	0.101 (0.109)	0.087 (0.136)	0.486 (±0.547)	0.913 (±0.742)

Mean distance [mm] and angular [degree] ± standard deviations (SD) at the evaluated points and planes relative to the corresponding reference; CSB = conventional scanbody, HASP = healing abutment-scanpeg system, PVS = polyvinylsiloxane impression.

perceive the esthetic outcome of implant crowns as “very good” regardless of the crown materials used [36]. Nevertheless, definitive crowns were not fabricated in the present study and only the scans were compared. The accuracy of definitive crowns fabricated by using intraoral scans and conventional impressions should be investigated to completely understand the effect of deviations in scans/impressions on the positional accuracy of definitive crowns.

The angular deviation was seen in the mesiodistal direction and both HASP and RSP had low deviations compared with the PVS. The mean angular deviations were smaller than 0.3 degrees for both HASP and CSB at both directions. PVS had more than 0.5-degree mean deviation mesiodistally. Clinically, monolithic crowns fabricated by using HASP and CSB may have less interproximal contact issues compared with crowns fabricated by using PVS potentially decreasing the time for chairside adjustments. A decrease in chairside crown adjustment and delivery time using a direct digital workflow for single implant crowns was demonstrated in earlier studies [37]. Because the HASP consists of two pieces, a separate trueness analysis of each piece and when pieces were combined was performed. The results revealed that the scan trueness of both the healing abutment and the scanpeg, and their combination was similar, which ensured the adequate seating of the scanpeg on the healing abutment during scans. Some recent studies have shown significant tolerances in the manufacturing of scanbodies both when different scanbodies of the same type were compared to each other [13,14], and when compared to their library file in the CAD software [38]. This may be particularly important with the HASP system, since it consists of two parts. The fit of the two parts may be affected from the tolerances, which could influence the scan accuracy. In addition, it was demonstrated that the scanbody material and design had a significant effect on the scan accuracy [28,39]. The CSB is a made of PEEK and its implant connection is in Ti, and HASP’s healing abutment is completely made of PEEK, and its scanpeg is made of medical grade acrylic-based polymer. The fact that CSB and HASP’s scanpeg are made of different materials might have affected the scans, however, no significant differences between these two systems were seen in findings. In future studies, whether seating precision of the two pieces in the HASP system affect the accuracy should be investigated. When other comparable HASP systems are available, it would also be interesting to analyze the effect of scanpeg geometry and material.

The utilized metrology software to perform the scan superimpositions has been commonly used to evaluate the accuracy of intraoral scanners. Although the best fit-algorithm is frequently used for accuracy analyses, it has some limitations; the software attempts to find the ideal superimposition of two surface scans with the minimum difference between all surface points. This may lead to an underestimation of the distance of two corresponding points [40]. Therefore, the present study used a local instead of an overall best-fit algorithm excluding the surface points on the scanbodies. Subsequently, after local best-fit alignment, corresponding points on the scanbodies were selected for the comparisons to minimize the underestimation. However, results obtained with different metrology software, alignment techniques, or point selections could vary from the current results.

The sample size in the present study enabled the detection of statistical differences for trueness and precision. The number of scans used are equal the number of scans in previous studies which also reported significant differences [5,7,9,12]. One experienced operator did the scans in the present study and varied results may be achieved with different operators [41,42]. Also, even though a commonly used scanner was used to perform the scans, results may vary when different intraoral scanners are used [12,42]. The tested HASP is limited to a specific implant system. When the HASP system is used, it may be difficult to reintegrate an existing removable interim prosthesis after screwing on the healing abutment and performing the intraoral scan. A possible strategy to overcome this problem would be to shorten the healing abutment to the mucosa level after the scan. The emergence profile could still be contoured with the form of the healing abutment without compromising the fit of the existing interim prosthesis. However, the scanpeg may not be reused as its slot in the healing abutment would be removed with such a clinical adjustment. The use of a laboratory scanner to obtain the reference dataset is a limitation of the present study. Although the accuracy of laboratory scanners has increased over years [29], future studies should be performed by using an industrial high-accuracy scanner to obtain an optimal reference dataset. The model used in the present study does not completely simulate intraoral conditions; teeth, soft tissues, their optical properties and the light source of the environment may significantly affect the findings. Therefore, clinical outcomes should be evaluated with in vivo studies and the performance of healing abutment-scanpeg system to contour the soft tissues should also be investigated.

5. Conclusion

The scan accuracy of combined healing abutment-scan peg system and the conventional scanbody was higher at some selected points compared with the conventional impression accuracy. However, the effect of the difference in accuracy on definitive crown's positional accuracy should be further investigated. The use of combined healing abutment-scanpeg system and the conventional scanbody can be recommended with the utilized intraoral scanner.

Author contributions

The authors of the manuscript contributed in the following ways to the submitted manuscript:

Burak Yilmaz: Conceptualization, Data curation, Formal analysis; Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Drafting initial manuscript, reviewing and confirming final version

Diogo Gouveia Data curation, Formal analysis, Drafting initial manuscript, Reviewing and confirming final version

Vinicius Rizzo-Marques Investigation, Methodology, Validation, Visualization, Drafting initial manuscript Reviewing and confirming final version

Emre Diker: Data curation, Methodology, Reviewing and confirming final version

Martin Schimmel: Formal analysis, Methodology, Reviewing and confirming final version

Samir Abou-Ayash Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Drafting initial manuscript, reviewing and confirming final version

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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