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BASIC RESEARCH:

Titanium Scanbody Repeated Use for Complete-Arch Implant Impression: An *In Vitro* Accuracy Analysis

Uso repetido del cuerpo de escaneo de titanio para la impresión de implantes de arcada completa: análisis de precisión *in vitro*

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ABSTRACT: The aim of the study was to assess the effect of titanium scanbody (Ti ISB) repeated use on the accuracy of complete-arch implant impression *in vitro*. A mandibular resin model with four conical connection implant analogues was digitized using an extraoral scanner to achieve a reference file. Thirty-eight test files were obtained with an intraoral scanner (IOS) and superimposed to the reference file. Screw-retained sand-blasted Ti ISB were screwed and unscrewed between each test scan. Implant positions (n=152) were analyzed through linear (ΔX, ΔY and ΔZ- axis) and angular deviations (ΔANGLE). Three-dimensional (3D) deviation was calculated as Euclidean distance (ΔEUC) from the linear deviations. Effect of implant position was also calculated. A significative reduction of ΔEUC over time (p=0.001, b=-0.00099) was noticed, with position 4.5 as the least accurate with a significant difference compared to 3.2. Considering ΔANGLE a significant reduction was noticed over time (p=0.041, b=-0.0031), with position 4.5 as the least accurate with a significant difference compared to 3.2 and 4.2. Conclusions: Ti ISBs repeated use didn't show a significant negative effect on complete-arch IOS implant impression accuracy both in terms of angular and 3D deviation. Implant position showed a significant effect on accuracy with posterior tilted identified as most critical positions.

PALABRAS CLAVE: Scanbody; Repeated use; Wear; Complete-arch; Accuracy; Intraoral scanner.

RESUMEN: El objetivo del estudio fue evaluar el efecto del uso repetido de los scanbody de titanio (Ti ISB) sobre la precisión de la impresión de implantes de arco completo *in vitro*. Se digitalizó un modelo mandibular de resina con cuatro análogos de implantes de conexión cónica mediante un escáner extraoral para obtener un archivo de referencia. Se obtuvieron treinta y ocho archivos de prueba con un escáner intraoral (IOS) y se superpusieron al archivo de referencia. Los Ti ISB atornillados, retenidos por tornillo y arenados, fueron atornillados y desatornillados entre cada escaneo de prueba. Las posiciones de los implantes (n=152) se analizaron mediante desviaciones lineales (ΔX, ΔY y ΔZ) y angulares (ΔANGLE). La desviación tridimensional (3D) se calculó como la distancia euclidiana (ΔEUC) a partir de las desviaciones lineales. También se evaluó el efecto de la posición del implante. Se observó una reducción significativa de ΔEUC a lo largo del tiempo (p=0.001, b=-0.00099), siendo la posición 4.5 la menos precisa, con una diferencia significativa en comparación con la posición 3.2. En cuanto a ΔANGLE, se registró igualmente una reducción significativa a lo largo del tiempo (p=0.041, b=-0.0031), siendo la posición 4.5 la menos precisa, con diferencias significativas frente a las posiciones 3.2 y 4.2. El uso repetido de los Ti ISB no mostró un efecto negativo significativo en la precisión de la impresión de implantes de arco completo mediante IOS, tanto en términos de desviación angular como tridimensional. La posición del implante mostró un efecto significativo en la precisión, siendo los implantes posteriores inclinados los que presentaron peor desempeño.

PALABRAS CLAVE: Cuerpo de escaneado; Uso repetido; Desgaste; Arcada completa; Precisión; Escáner intraoral.

INTRODUCTION

Implant impression accuracy is a fundamental step to deliver a well-fitting prosthesis (1,2). The achievement of a passive fit is beneficial in terms of implant-prosthetic rehabilitation prognosis, reducing the occurrence of biological and mechanical complications (3). In fact, in a condition of passive fit, the prosthetic system and surrounding tissues are not subjected to static loads (4,5).

Intraoral scanning (IOS) is now considered a valid alternative to conventional impression in recording implant coordinates and surrounding gingival anatomy, with great benefit in terms of patient compliance (6-8).

IOS accuracy is recognized as a reliable technology for single implant-supported crowns and short-span fixed dental prostheses (FDPs) (9).

However, the use of IOS to rehabilitate long-span and complete-arch implant-supported FDPs is still considered controversial. This is mainly due to the lack of stable anatomical reference point, that could negatively influence the stitching and so limit the practicality and compromise the overall impression accuracy (10,11).

In addition, the IOS workflow could be influenced by several factors related to the patient (anatomical features, inter-implant distance, and implant number and position) and to the operator (IOS technology, wand size, calibration protocol, ambient light, temperature and humidity, operator experience, scanning strategy, implant scanbody (ISB) shape, material and repeated use) (12-14).

ISB structure could be divided in a scan region and a base. The scan region is the portion to be scanned by the clinician and then recognized by the dental technician with the ISB computer aided design (CAD) library. The base is the portion to be coupled with the implant connection.

The ISB material configuration could be monolithic, like polyetheretherketone (PEEK), aluminum, titanium (Ti) and various resins or a combination of different materials and was found to influence the overall impression accuracy. (4,6,15,16) The material of the ISB base could play a role also in the repeated use of the component, as the attrition created during the screwing and unscrewing procedure could produce a deformation of the base with a consequent unproper fit with the implant connection (17).

Furthermore, the sterilization process could also be responsible of some type of deformation of both the base and the scan region invalidating the implant position recording (18).

The monolithic PEEK ISB configuration was found to be subjected to lose accuracy after repeated use after 30 cycles of screwing and unscrewing, without including the sterilization in the study protocol (17). The explanation of that accuracy drop after repeated use could be related to the physical properties of the material, that as a plastic polymer could be susceptible to deformation under mechanical strains (17).

Another *in vitro* study evaluated, with 3D digital image correlation (DIC) technique, linear displacements of a total of 10 PEEK and 10 Ti SBs when applying different screw tightening (10 and 15 Ncm), and after 25 sterilization cycles. PEEK ISBs were more susceptible to loss of accuracy especially under 15 Ncm torque and after sterilization (19). However, there is a lack of data on possible displacement of Ti ISBs repeated use after high number of screwing and unscrewing cycles and how it can affect the accuracy of IOS.

The primary aim of the present study was to evaluate the accuracy performance of Ti ISBs repeated use on the accuracy of complete-arch implant impression *in vitro*. The secondary aim was to assess the effect of implant position on the accuracy.

MATERIALS AND METHODS

MASTER MODEL

A custom edentulous mandibular model was fabricated from polymethylmethacrylate (PMMA) using a milling technique, featuring a removable soft tissue frame. Four implant analogs (In-Kone, Tekka, GlobalD) were placed at the following anatomical positions: right second bicuspid (30° distal angulation, 2.5 mm depth), right lateral incisor (0° angulation, 1 mm depth), left lateral incisor (0° angulation, 2.5 mm depth), and left second bicuspid (17° distal angulation, 1 mm depth) (Figure 1). These positions were sequentially labeled from 1 to 4. The implants used have an 8° steep conical connection with a hexagonal interlocking design (Figure 2).

Figure 1. Resin model without removable soft tissue frame.

Figure 2. Implant steep conical connection.

REFERENCE SCAN

A desk scanner equipped with a 2.5-megapixel camera (Optor Performance, Opentech3d) was employed to acquire a Standard Tessellation Language (STL) file enclosing the digital positions of the four implants, used as a reference for accuracy measurements. The scanner is certified with a trueness of 4 μm and precision of 2 μm (ISO 12836). Prior to scanning, an automated calibration protocol was executed to ensure optimal performance.

INTRAORAL SCANNER, SCANBODY, AND TEST SCAN PROCEDURE

A powder-free, pen-grip confocal microscopy IOS (TRIOS4, 3Shape A/S), with software version 1.4.7.5, was used to capture 38 STL files containing the digital positions of the four implants. These files were subsequently compared to the reference scan for superimposition. Prior to each scan session, color and three-dimensional (3D) calibration of the system was completed. All test scans were conducted by a single, experienced operator who was blinded to the study's objectives. Scanbodies, made from anodized titanium (Tekka, GlobalD), were equipped with a hole structure for securing the fixation screw (Figure 3). Prior each scan, a second operator ensured proper seating of the ISB by applying a torque of 10 N/cm and verifying alignment with magnifying loupes (Eyezooma 5X, Orascoptic). The scanbodies were removed and reattached between each of the thirty-eight test scans. A dedicated extractor was used to disengage the ISB-dental implant connection after the removal of the fixing screw (Figure 4). A consistent scanning protocol was followed for all sessions, beginning with the right second bicuspid implant and proceeding to the left distal implant, with a rest period of 5 minutes between scans. All the scans were performed in the same room in the same environmental conditions.

Figure 3. Implant scan body.

Figure 4. Extractor.

DATA PROCESSING AND ACCURACY ASSESSMENT

The 38 test STL files were aligned to the reference scan using best-fit alignment with a tolerance of 0.01 mm by means of a dedicated software (MeshMixer, Autodesk). The geometries of the digital analogs in both test and reference scans were visualized as cylinders. The aligned files were imported into a metrology software (Hyper Cad S, Cam HyperMill, Open Mind Technologies) to calculate linear deviations (ΔX, ΔY, ΔZ) and angular deviations (ΔANGLE) for each implant position (n=152). The X, Y, and Z coordinates defined lateral, longitudinal, and vertical axes, with negative values representing deviations towards the left, backward, and upward, respectively. Linear discrepancies were combined into a single three-dimensional discrepancy value, referred to as the Euclidean distance (ΔEUC).

STATISTICAL ANALYSIS

A multiple linear regression analysis was performed to explore the relationship between the Euclidean distance (ΔEUC) and two independent variables: implant position and scansion. Multicollinearity among the predictors was initially assessed using the Variance Inflation Factor (VIF). The dataset included 152 observations, and the final regression model was assessed based on coefficients, standard errors, and significance levels, with a threshold of $p < 0.05$ for statistical significance. The goodness-of-fit of the model was evaluated using the coefficient of determination (R^2). Statistical analyses were conducted using STATA 16.0, and a post-hoc power analysis was performed in G*Power to determine the statistical power of the model. Using the ΔEUC model, with 152 observations, two predictors, and a significance level of 0.05, the statistical power was calculated to exceed 0.99.

RESULTS

Deviations between the reference scan and the 38 test scans were calculated for each implant on the Y, X, Z axes and for angulation (n=152). The alignment of each test scan relative to the reference scan was assessed based on both negative and positive deviation values. Negative deviations on the X, Y, and Z axes indicated a ISB positioned towards the front, left, and downward, respectively, while positive values indicated deviations in the opposite direction. The univariate analysis revealed the following results: ΔY mean 19.81 μm (SD 50.79) ranging from –129.2 to 164.5 μm; ΔX average 19.15 μm (SD 19.23) ranging from -154.9 to 285.6 μm; ΔZ mean 23.27 μm (SD 75.14) ranging from -141.1, 170.0 μm. When the linear discrepancy was considered a tridimensional one, ΔEUC reported these results: mean 107.65 μm (SD 40.79) ranging from 14.84 to 308.0 μm. Lastly, the ΔANGLE error mean was 0.41°(SD 0.23), ranging from 0.04 to 0.99° (Table 1).

For the multivariate analysis, ΔEUC was considered as the dependent variable (Table 2), the model indicated a significant reduction of ΔEUC over time ($p = 0.001$), with each additional scan contributing a decrease of 0.00099 in ΔEUC. Among implant positions, only position 3.2 showed a significant difference, with ΔEUC values approximately 0.022 lower than those for position 4.5.

When ΔANGLE was analysed as the dependent variable (Table 3), time progression was associated with a significant decrease ($p = 0.041$, $b = -0.0031$). Specifically, each additional scan resulted in a decrease of approximately 0.0031 in ΔANGLE. Position 4.2 exhibited lower ΔANGLE values compared to position 4.5 ($p < 0.001$), while position 3.2 also showed significantly lower ΔANGLE values than position 4.5 ($p = 0.017$).

Table 1. Descriptive analysis for considered variables.

	Number of observations	Mean	SD	Range
ΔY (μm)	152	19.81	50.79	(-129.2, 164.5)
ΔX (μm)	152	19.15	19.23	(-154.9, 285,6)
ΔZ (μm)	152	23.27	75.14	(-141.1, 170.0)
ΔEUC (μm)	152	107.65	40.79	(14.84, 308.0)
ΔANGLE (°)	152	0.41	0.23	(0.04, 0.99)

Table 2. Analysis of covariance. Dependent variable Euclidean distance.

ΔEUC	Coef.	Std. Err.	t	P>ItI	[95% Conf. Interval]		R^2
Implant							0.1330
4.2	-.0101307	.0088311	-1.15	0.253	-.027583	.0073216	
3.2	-.0221855	.0088311	-2.51	0.013	-.0396378	-.0047332	
3.5	.0040167	.0088311	0.45	0.650	-.0134356	.021469	
Scan	-.0009874	.0002847	-3.47	0.001	-.0015501	-.0004247	
cons	.1339802	.0083559	16.03	0.000	.1174671	.1504934	

Table 3. Analysis of covariance. Dependent variable Angle.

ΔANGLE	Coef.	Std. Err.	t	P>ItI	[95% Conf. Interval]		R^2
Implant							0.2206
4.2	-.2038684	.0464799	-4.39	0.000	-.2957236	-.1120132	
3.2	-.1122737	.0464799	-2.42	0.017	-.2041289	-.0204185	
3.5	.0559237	.0464799	1.20	0.231	-.0359315	.1477789	
Scan	-.0030819	.0014986	-2.06	0.041	-.0060434	-.0001204	
cons	.5304049	.0439787	12.06	0.000	.4434927	.6173171	

DISCUSSION

Over the past decade, digital implant impressions acquired through IOSs have undergone significant advancements. IOSs utilize distinct imaging technologies to directly capture intraoral structures, including dentition and soft tissues, facilitating the generation of precise 3D virtual models (20). In digital implant impressions, an ISB is attached to the implant to serve as a reference for accurately determining its spatial position. The acquired virtual models are subsequently converted STL files and imported into CAD software for the fabrication of implant-supported restorations (21).

Clinical challenges make complete-arch implant scanning highly technique-sensitive, with scan accuracy significantly influenced by variations in scanner technology, software versions, scanning protocols, and operator techniques (22, 23). Additionally, factors such as increased inter-implant distances, edentulous regions lacking geometric structures, image superimposition errors, indistinct scan bodies, and the presence of mobile surrounding soft tissues further affect accuracy (24-26.

This *in vitro* study aims to evaluate the influence of Ti ISBs repeated use on the overall accuracy of complete-arch IOS implant impressions. This was carried out by evaluating the 3D (ΔEUC) and angular deviation (ΔANGLE) of each ISB compared to the reference data that were previously obtained by a reference scan obtained by a dedicated extraoral scanner with high precision. The ISBs were subject to 38 screwing and unscrewing cycles before each corresponding scan, and the deviations were assessed for each ISB for a total of 152 test data. The obtained results showed that the titanium scanbodies repeated use did not show a significant negative effect on complete-arch IOS implant impression accuracy both in terms of angular and 3D deviation after 38 scan sessions. On the other hand, ΔEUC and ΔANGLE significantly decreased over time (respectively $p = 0.001$ and $p = 0.041$), correspondingly with each successive scan leading to a reduction of 0.00099 and 0.0031 per scan.

This slight improvement observed over time could be due to the operator's increasing proficiency in performing the scans. Additionally, the absence of wear effects on these scan bodies may be attributed to the fact that the components were not subjected to any process of sterilization.

Concerning implant position, a significant effect was found both on 3D and angular deviation, with posterior implant (4.5) experiencing the higher deviations. A potential explanation could be linked to the cumulative error introduced by the "stitching" process. As the scan progresses from the first to the last implant, errors progressively accumulate, leading to deviations in the final digital model (27).

To the best of our knowledge, the influence of Ti ISB repeated use on the accuracy of IOS for the complete arch was never analyzed, hence no direct comparison reference is available in the scientific literature. However, a previous study evaluated the influence of PEEK ISB wear on the overall accuracy of digital impressions. In this study, considering ΔEUC and ΔANGLE as the response variables, a significant influence of ISB wear was identified in interaction with position 3.6 ($p < 0.0001$), whereas no significant effect of position or scans related to other positions was detected (17). That could be explained by the physical properties of the PEEK material, that as a polymer, could be worn out after repeated mechanical strains, especially at the base level. Also in this study implants with greater inclination were subjected to loss of accuracy after repeated use (17).

The limitations of this *in vitro* study include its focus on the specific IOS and ISB materials analyzed, without accounting for the potential effects of sterilization cycles on material wear. Diker et coll. measured, with 3D digital image correlation (DIC) technique, after sterilization both Ti ISBs and PEEK ISBs. Ti ISBs showed lower displacement and that may be related to susceptibility of PEEK to high temperature and pressure compared with Ti (19). Besides, repeated removal and reinsertion of scan bodies may introduce micromovements, leading to small positional shifts that accumulate over successive scans. Furthermore, the polymethyl methacrylate (PMMA) model used to support the implants may undergone slight deformations over time due to material properties and repeated handling, potentially affecting the accuracy of the impressions.

Future *in vivo* studies should be necessary to confirm the obtained results.

CONCLUSIONS

Within the limitations of this study, the repeated use of Ti ISBs did not have a significant negative impact on the accuracy of complete-arch IOS implant impressions in terms of both angular and 3D deviation. However, implant position significantly influenced accuracy, with posterior tilted implants showing lower performance.

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