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SYSTEMATIC REVIEW

Intraoral scan bodies in implant dentistry: A systematic review

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ABSTRACT

Statement of problem. Intraoral scan body (ISB) design is highly variable and its role in the digital workflow and accuracy of digital scans is not well understood.

Purpose. The purpose of this systematic review was to determine the relevant reports pertaining to ISBs with regard to design and accuracy and to describe their evolution and role in the digital dentistry workflow. Special attention was placed on their key features in relation to intraoral scanning technology and the digitization process.

Materials and methods. A MEDLINE/PubMed search was performed to identify relevant reports pertaining to ISB usage in dentistry. This search included but was not limited to scan body features and design, scan body accuracy, and scan body techniques and the role of ISBs in computer-aided design and computer-aided manufacturing (CAD-CAM) processes. Commercially available scan bodies were examined, and a patient situation was shown highlighting the use of ISBs in the digital workflow.

Results. Deficiencies in the reports were found regarding various scan body topics, including ISB features/design, accuracy, and the role of ISBs in CAD-CAM processes.

Conclusions. ISBs are complex implant-positioning-transfer devices that play an essential role in the digital workflow and fabrication of accurately fitting implant-supported restorations. With scanner technology rapidly evolving and becoming more widespread, future studies are needed and should be directed toward all parts of the digital workflow when using ISBs. By understanding the basic components of ISBs and how they relate to digital scanning and CAD-CAM technology, more emphasis may be placed on their importance and usage in the digital workflow to ensure accurate transfer of implant position to the virtual and analog definitive cast. Efforts should be made by clinicians to identify an optimal ISB design in relation to the specific intraoral scanning technology being used. (J Prosthet Dent 2018;120:343-52)

Digital dental technology has evolved rapidly since the introduction of the computer-aided design and computer-aided manufacturing (CAD-CAM) process in the 1980s.[1] By definition, CAD-CAM consists of 3 elements: computer-aided data acquisition, data processing and design, and CAM.[2] By 2003, it became possible to use these 3 elements to scan and produce a 3-dimensional (3D) digital image which could be used to fabricate single-tooth restorations.[3] It was not long before computer-aided data acquisition was applied to other aspects in dentistry, including orthodontics, prosthodontics, and implant dentistry, through the use of digital scanning systems.

Dental impressions are a crucial step in implant dentistry.[4] Inaccurate transfer of the implant position can lead to an ill-fitting prosthesis, which may ultimately result in both biological and mechanical complications.[5] With the advent of CAD-CAM technology, it is now possible to use a digital workflow when fabricating implant-supported restorations,[6] which can be either direct or indirect in nature.[7,8] The indirect workflow involves making a conventional implant impression which is then digitized in the laboratory by using an optical benchtop scanner and laboratory scan bodies (ISBs). The direct workflow, however, includes the use of ISBs and an intraoral scanning device to generate a digital scan directly from the patient's mouth. Once captured accurately, a digital implant analog can then be placed in a digital model with specific implant/ISB libraries, and dentistry-specific CAD software is used in fabricating the restoration. Digital implant impressions offer advantages over conventional impressions including reduced risks of distortion during the laboratory phases; improved patient comfort and acceptance; and improved efficiency.[6] Although digital implant impressions have been well studied,[9-13] little has been reported about the

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Clinical Implications

Because scientific information regarding intraoral scan bodies and their variations and accuracy of the scans using intraoral scan bodies is scarce, clinicians should carefully study digital intraoral scanning of implants and the workflow when intraoral scanning of implants is planned to be performed.

ISBs themselves. The purpose of this review was to describe the evolution of ISBs, identify key ISB features in relation to intraoral scanning technology, and discuss their role in the digital workflow in implant dentistry.

In 1994, a technique was first described to measure the 3D position of a dental implant by using photogrammetry.[14] The authors concluded that this technique showed a level of precision similar to that of conventional methods and was a valid option for recording implant positions intraorally, which has subsequently been confirmed.[15,16] In 2004, the first digitally scannable implant components were introduced by using an innovative coded healing abutment (The Bellatek Encode; Biomet 3i), which provided 3D information on the implant location in relation to the adjacent teeth, opposing dentition, and surrounding soft tissues (Fig. 1).[17] However, studies of the accuracy of the impressions made with this ISB compared with that of conventional impression techniques have been controversial.[18-21]

In 2008, the possibility of using other 3D image acquisition technologies was proposed as an alternative to conventional impression-making procedures.[22] The first scannable impression copings were released shortly afterward and were termed scan bodies by the Straumann Group. Initially, these scan bodies were commercially available only for a single-implant system and required a specific scanner and scanning technology (Itero, parallel confocal microscopy). As scanner technology has improved and gained popularity, however, so has the design and usage of scan bodies. Today, almost all major implant manufacturers offer scannable impression copings, as do numerous dental laboratories and dental implant accessary companies. Commercial ISB design is highly variable with regard to material, shape, size, surface, connection, reusability, software/scanner compatibility, and cost (Fig. 2).[1,23]

Although highly variable in size and shape, an ISB generally consists of 3 distinct components: the upper portion, called the scan region; the middle portion, known as the body; and the most apical portion, known as the base (Fig. 3). ISBs are smaller than laboratory scan bodies due to space constraints inside the oral cavity and must be hand tightened into the implant. The scan

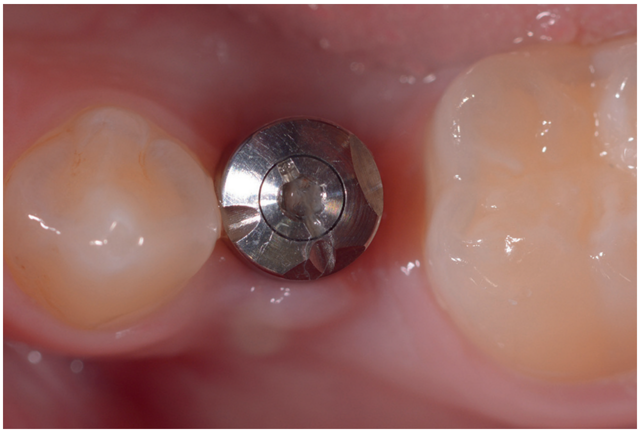

Figure 1. First scannable implant component (Encode Abutment, Biomet 3i) contained 3D information about implant position coded on its surface.

region is the main component used to digitally register the orientation and angulation of an implant.[24] A flat side is usually incorporated to create an asymmetrical shape which helps to index the ISB and improve the surface recognition performed by the CAD software (www.intralock.com).

The scan region may contain 1 or multiple scan areas, which may improve the accuracy of the digital scan.[24] This portion is usually made of the same material as the body but usually has a different shape. The body extends from the scan region to the base and is made of a variety of materials including polyetheretherketone (PEEK), titanium alloy, aluminum alloy, and various resins. The machinability of these materials and the manufacturing tolerances may be an important consideration in the accuracy of scan bodies. The base is responsible for creating the mating surface between implant and ISB and may or may not be the same material as the body. A deeply tapered connection or mismatch in materials between the base and the implant may influence displacement of the ISB when tightened into place. Wear of this component through repeated use and sterilization may also cause changes in positioning over time, which is problematic as the overall fit of any ISB is a decisive factor for a high-precision transfer of the implant position and inclination.[25]

Currently, ISBs require the use of an intraoral scanner (IOS) to collect raw data in the form of point clouds, which represent the 3D coordinates in the x, y, and z planes of the digitized surface.[26] The intraoral digital scan and digitization of an ISB for a missing maxillary right first premolar is demonstrated in Figure 4, and the steps involved in the workflow for the same patient situation are displayed in Figures 5 to 11.

There are 2 main categories of scanners, contact and noncontact. Most scanners used in dentistry are noncontact type, and use a variety of methods to capture

Manufacturer	Dentsply	DESS	Core-3D	Elos	NT-Trading	Medentika	Biohorizons	Zimmer
Implant System	Most major	Most major	Most major	Most major	Most major	Most major	Biohorizons	Zimmer
Scanner	All	All	All	All	All	All	Trios	All
CAD software	Proprietary	All major	All major	All major	All major	All major	3shape	3shape (Proprietary)
Body Material	PEEK	PEEK	PEEK	PEEK	PEEK	Ti	PEEK	PEEK
Mating Surface	Metal	PEEK	PEEK	Ti	Metal	Ti	PEEK	PEEK
Shape/Geometry	Flat cylinder with ball top	Cylinder with triangular region	Tapered flat cylinder	Cylinder with angled flat surface	Rectangular	Flat cylinder	Cone	Flat cylinder
Recommended Torque	Hand tighten	Hand tighten	Hand tighten	5 Ncm max	10 Ncm max	Hand tighten	Hand tighten	Hand tighten
Reusable	Yes, unlimited	Single use	10x for FPDs 20x single units	100x (max 2 years)	Single use	Yes, unlimited	Single use	Single use

Figure 2. Commercially available ISBs. ISB design highly variable with regard to software/scanner compatibility, material, shape, size, mating surface, reusability, and consumer cost. ISB, intraoral scan body. MSRP, manufacturer's suggested retail price. PEEK, polyetheretherketone.

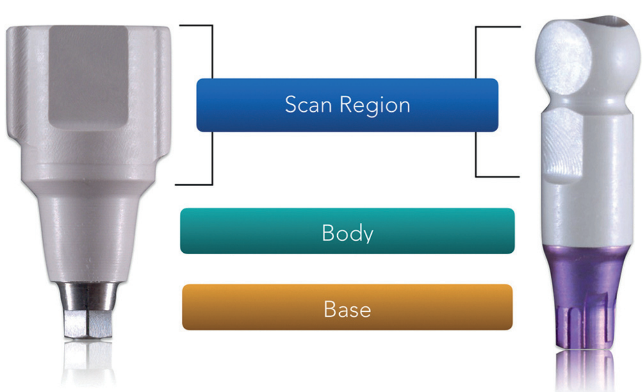

Figure 3. ISB has three components (dash) scan region, body, and base. ISB, intraoral scan body.

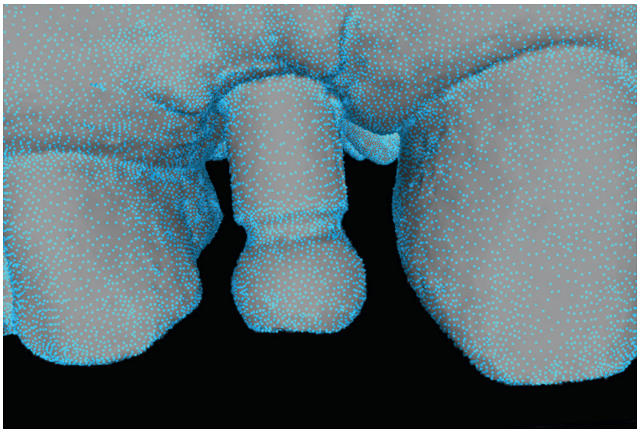

Figure 4. Intraoral scanner used to capture series of data points referred to as point cloud.

raw data including confocal microscopy, triangulation, interferometry, wavefront sampling, structured light, laser, and video.[27] The variability in scanner accuracy due to differences in technologies has been documented.[28-32] Regardless of the specific technology used, IOS can capture only part of an object at a time. Therefore, the acquired point cloud data sets must first be registered to a global coordinate system dictated by the scanner position, so they can be stitched together further downstream in the image reconstruction steps.[33] Generally, the more point cloud density generated during scanning, the more accurate the virtual surface reconstruction.[34] The opposite is true as well, in that, missing data points in a point cloud will cause problems when the surface is recreated, both of which could lead to inaccuracies when attempting to register and align the ISB surface with the implant library.

While the overall quality of the digitized data depends primarily on the measuring system used, another important factor that can affect point cloud density is the characteristics of the surface to be scanned.[35] The quality of a digitized surface reconstruction and any subsequent

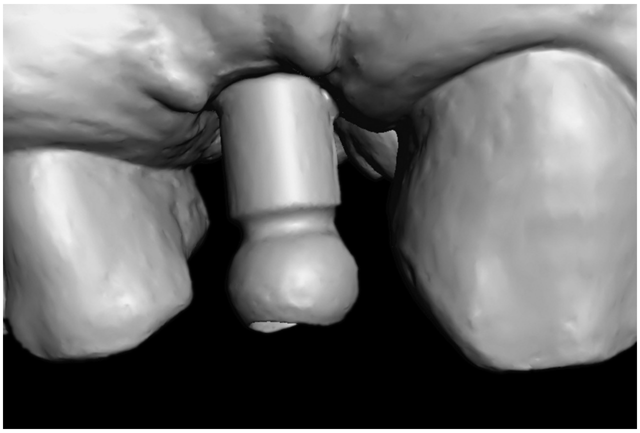

Figure 5. Point clouds processed to reconstruct surface virtually. Newer systems able to incorporate color information into reconstruction.

Figure 6. Virtual surface actually reconstructed from series of flat polygons or triangles, referred to as mesh.

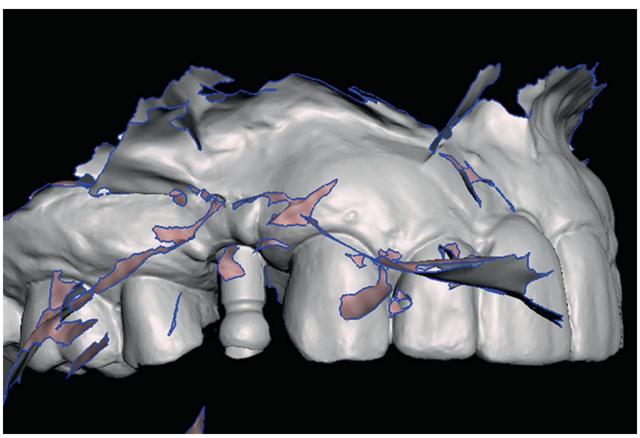

Figure 7. Reconstructed mesh not defect free and must be cleaned up by using post-processing algorithms.

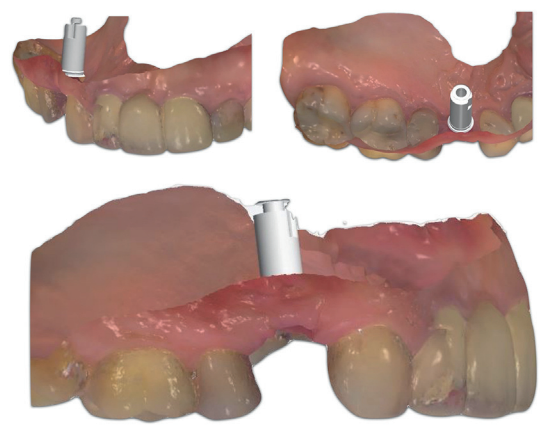

Figure 8. Once surface reconstructed, it can be matched with correct implant analog using CAD software. CAD, computer-aided design.

measurements are generally accepted to be shape-dependent, whereas the type of material affects the number of points acquired.[36-38] The overall shape, known as the primary structure, is easier to digitize than the finer details seen on secondary and tertiary structures.[39,40] Dull, smooth, and opaque surfaces are easier to scan than shiny, rough, or translucent ones, which can be especially challenging in the mouth, where saliva tends to create reflective surfaces and the hard and soft tissues have a variety of textures.[41-43] Studies have indicated that deep, undercut, steep, sharp, angled, or crowded surfaces are also more difficult to scan, leading to less accurate point clouds.[44-48] Thus, it may be necessary and advantageous to create scan bodies with specific characteristics for intraoral situations. A narrow ISB, for example, may be more effective in situations with limited interproximal space. Likewise, a shorter ISB may be easier to capture in patients with complete edentulism. The interplay between scanner technology and ISB design must also be considered when attempting to generate a point cloud. Scanning technologies are proprietary and vary among manufacturers, therefore, certain scanning systems may be better suited and more accurate when paired with a specific ISB feature or design. To date, studies evaluating this concept are lacking.

Once a dataset has been acquired and arranged in a common coordinate system, image reconstruction can begin through reverse engineering processes.[33] Surface reconstruction is the process of using the point clouds from the surface of an object and recovering the original surface from which those points came.[49] This is done by using highly specific software algorithms which are responsible for stitching together, filtering, and converting the various point clouds into a single virtual image, an engineering process referred to as the 3D model acquisition pipeline.[50,51] There are 2 fundamental streams of processing within this pipeline, 1 for geometry (termed *range images*) and 1 for the fine scale surface appearance properties (*intensity images*). As part of the intensity images, newer scanners are also able to

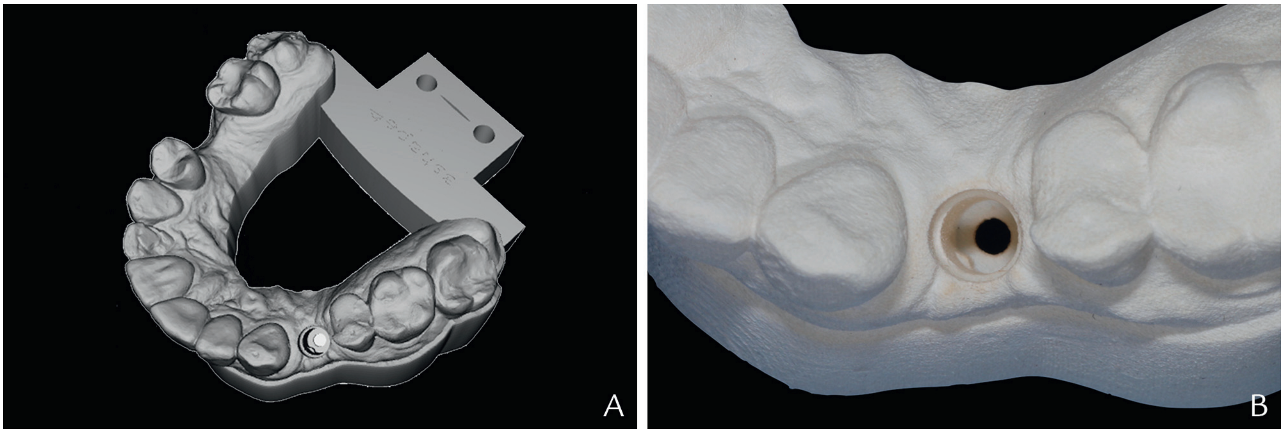

Figure 9. A, STL file used to print or mill cast with space for implant analog to be positioned manually. B, Enlarged view of milled cast with indexing groove to replicate proper timing of implant. STL, standard tessellation language.

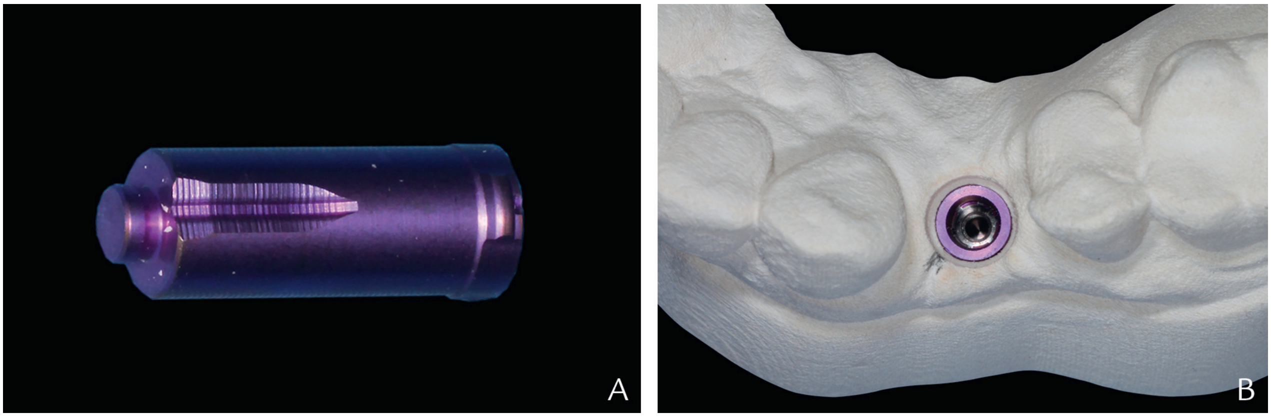

Figure 10. A, Indexed implant analog. B, Analog placed into cast by using special guide grooves, vertical stops, or other keyways, and luted into place. Definitive cast now ready for various steps of workflow.

generate and store data for the object's color. Information is exchanged between the 2 processing streams to improve the quality and efficiency of the processing, and in the end, a single, compact numerical description of the object is created which is then used to reconstruct the surface virtually (Fig. 5).[50]

Although the algorithms used by intraoral scanning device companies are proprietary, the algorithm most commonly used is some form of the *iterative closest point* algorithm, which finds correspondences by computing the distances between common points on 2 separate point clouds and computes an aligning transformation that minimizes the least mean square error for the 2 point sets.[26,52] The point cloud is then used to generate a digital image, which is often referred to as a *polygon mesh*, because the scanned surface is represented by a series of flat polygons (Fig. 6). Generation of the polygonal surface is often simplified to triangles to speed up the visualization of reconstructed model and reduce the complexity of the processing algorithms.[33] However, the reconstructed image shown on the IOS monitor is not necessarily an exact representation of the acquired data points, nor is the data set defect free. Most polygon meshes contain erroneous areas such as isolated or dangling elements, singular edges or vertices, holes, gaps

Figure 11. Intraoral view of definitive restoration fabricated from digital scan using ISB. ISB, intraoral scan body.

or overlaps, intersections, degeneracies, noise, aliasing, topological noise, or inconsistent orientation (Fig. 7).[53] Thus, the postprocessing phase is a critical step in improving the surface matching and alignment with the digital implant library downstream.

Although current intraoral scanners are capable of producing large amounts of raw, dense, point cloud data, one of the biggest challenges is limiting the noise and outliers that result from the inherent problems associated with scanning the oral cavity, including movement of the patient, poor visibility and lighting, high reflectance, and limited depth of field and focal distances. The software algorithms, therefore, must be able to not only stitch the point clouds together accurately but also filter out the noise in either the reconstruction or postprocessing step. When the original scanned surface contains sharp features, such as those seen on certain scan bodies, the necessity of being robust to noise is especially challenging, because noise and sharp features can be ambiguous to the eyes of the scanning software. This makes sharp, distinguishing features prone to blur and noise, ambiguous samples subject to overamplification.[49]

One way to limit the amount of noise when scanning is to use preset parameters that allow the scanner to search for specific shapes.[54] This may not be possible with teeth due the morphological variability among individuals; however, it may be beneficial when scanning ISBs because it is possible to input ISB dimensions and unique features ahead of time into the software. Another way to improve the image reconstruction process is by increasing the scanning resolution.[55] Lower resolutions have been shown to increase global errors, especially in regions with high surface detail or increased curvatures.[55] Scanning at high resolution, however, does have its disadvantages and may not be practical in clinical dentistry, as it can increase scanner costs, slow the scanning process, and use considerably more memory.

The biggest challenge during the reconstruction phase occurs with an edentulous patient when the scanned surface does not have enough unique data points or is lacking quality reference points between point clouds.[10] In this situation, the images may not be stitched together properly, resulting in an inaccurate and noisy mesh with compounding error as the images are stitched together; or the postprocessing algorithm may cut out key parts of the scan, which it can mistakenly identify as redundant points.[56] A straightforward and more practical technique to improve scan accuracy in this situation may be to increase the number of reference data points between the scan bodies prior to scanning by splinting them together or by modifying the surfaces that are to be scanned.[57,58]

Once the ISB surface has been recreated digitally, it must be exported as a usable file usually in the form of a standard tessellation language (STL) file. IOS systems are available in closed, semiclosed, and open architectures, which refers to the degree of freedom in exporting and importing usable digital files. An open or semiclosed system may be preferred in this step as it offers the clinician and partnering laboratory more flexibility. In this step, the exported file is imported into a dental CAD software program with specific features used to recognize and match the ISB surface and position the implant analog in the digital model. For a surface-matching algorithm to perform accurately and efficiently, an appropriate representation scheme for the surface is needed, which is provided by the ISB manufacturer in the form of an implant library.[59] Using this information, the CAD program can then align the file by using a surface-matching algorithm, which automatically positions the digital implant analog in the proper 3D position (Fig. 8). Although many companies make their implant libraries freely available, some manufacturers require this and other downstream steps to be done with an associated dental laboratory.

The algorithm most commonly used to align the CAD geometry with the acquired surface geometry is a best-fit algorithm, which minimizes the global distances between the acquired ISB point cloud and its corresponding reference ISB stored in the implant library. This algorithm offers advantages, as it inherently attempts to minimize the root-mean-square error, which is used to identify the precision of the surface alignment. Root-mean-square errors below 0.010 mm are rated as excellent, whereas values above 0.050 mm indicate poor correspondence.[60] In addition, most dentistry-specific CAD software programs have a surface alignment mapping feature that visually depicts the surfaces that are matched best, and those areas can be specifically selected to improve the accuracy of the alignment. Some programs will also use a 3-point or manual shape-matching algorithm in efforts to minimize the point sampling area, which can speed up the recognition process.[61]

Once the implant file has been properly aligned, the ISB data sets can be removed by using a Boolean subtraction algorithm.[62] With this step, specific polygons are cut out of the mesh, which leaves the digital implant analog properly positioned and merged with the original imported file. Although the proprietary algorithms attempt to accommodate for outliers and other noisy data, it is imperative that the acquired data sets are as accurate as possible when surface matching. Even small errors in the upstream processes will accumulate throughout the digital workflow and lead to a digital misrepresentation of the true implant position.[63]

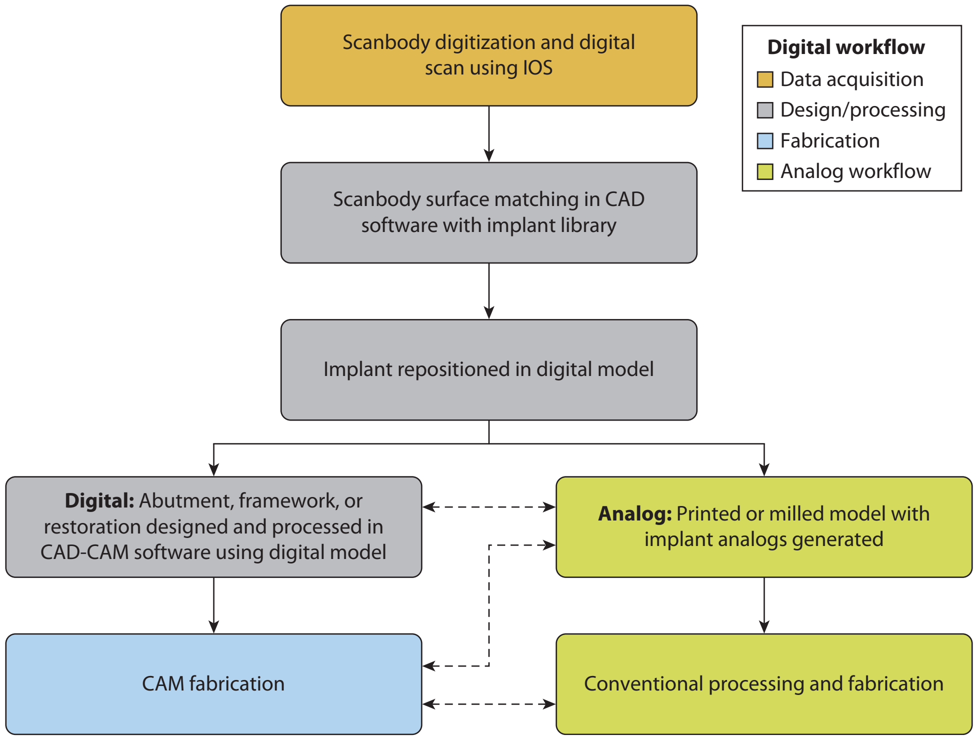

Figure 12. Workflow with ISBs can be either completely or partially digital depending on situation. CAD-CAM, computer-aided design and computer-aided manufacturing. ISBs, intraoral scan bodies.

Once data have been acquired, the file is now ready to be used in the processing and fabrication steps in the digital workflow.[64] If an analog cast is necessary, for example, when the application of layering porcelain is required, an STL model (Fig. 9A) can be printed or milled with space for the implant analogs to be manually positioned in the proper 3D orientation (Fig. 9B). The implant analog (Fig. 10A) is then luted into the model by using special guide grooves, vertical stops, or other keyways (Fig. 10B). It is even possible to generate a definitive cast with a printed implant interface/connection, although the authors are unaware of studies that have validated this, or any other implant repositioning technique. Nevertheless, once a physical cast has been generated, a conventional workflow can be resumed, and the definitive restoration can be fabricated (Fig. 11). Thus, the workflow may be completely or partially digital when using ISBs (Fig. 12).

MATERIAL AND METHODS

A MEDLINE/PubMed search was performed to identify relevant reports pertaining to ISB features and accuracy. The keywords included but not limited to scan body features/design, scan body accuracy, scan body techniques, role of ISBs in CAD-CAM processes, and digital implant impressions. Only 2 papers were identified that evaluated ISB features in relation to impression accuracy; therefore, the search was broadened to include any articles with information about intraoral digital scans using ISBs. Fifteen articles were selected for further review. Statistical analysis was not performed because of the variability in the reporting of the studies and the limited number of identified studies.

RESULTS

The total number of articles selected for this review was 15. Twelve articles considered the accuracy of digital scans using ISBs, 3 focused on the accuracy of specific features of ISBs, and 2 compared the accuracy of different IOS devices with specific ISBs. Early studies reported the accuracy of scanning the 3D position of osseointegrated implants by using ISBs to be between 14 and 21 μm.[22] More recent studies reported that the accuracy between digital scans using ISBs and conventional impressions was similar.[44,65-68] For multiple units, the mean distance error and angular deviation has been reported to be as low as 12.7 μm and 0.2 degrees.[32] Studies show, however, that the distance between the ISBs, the depth of the implant, and the location within the scan can affect the accuracy of digital scans with multiple ISBs.[47,69] Angled implants do not seem to have a negative effect on the accuracy of digital impressions using ISBs.[44,47,65,70,71]

In fact, 1 study showed that divergent implants actually improved the accuracy of the resulting digital scan.[48] According to a recent systematic review, the most accurate techniques for implant impressions are splinted transfers with polyether impression material and digital scans with ISBs.[25]

Regarding the specific features of ISBs in relation to their accuracy, even less information is available. Increased torque has been shown to cause positional discrepancies of certain ISBs; however, repeated detachment and repositioning does not have any negative influence on their accuracy.[72,73] Although detachment may not have any effect, 1 study reported a significant difference in the positioning of an ISB on the original implant fixtures as opposed to the laboratory analogs, suggesting discrepancies in the machining tolerances of the various components.[23] Only 1 study evaluated the influence of scan body geometry and shape on the accuracy and found significant differences in the 3D positioning and angular deviation between 2 commercially available ISBs.[72] Results from this study[73] should be interpreted with caution, however, as the scans were performed by using a laboratory scanner. Two studies compared the accuracy of various IOS devices when using ISBs and found significant differences among the systems; however, those studies used only 1 type of scan body.[73,74]

DISCUSSION

This systematic review attempted to focus on the relationship between certain scan body features and the accuracy of the resulting digital scans. The number of published studies was limited because of the relatively short time that ISBs have been used in implant dentistry. Although the data are limited in relation to specific scan body features, digital scans with ISBs appear to be similar in accuracy to their conventional implant impression counterparts. Although similar in accuracy, digital implant impressions using ISBs offer other advantages, such as an improvement in patient-centered outcomes and reduced procedure time.[46,75,76]

Digital scans using ISBs are not problem free, however, and limitations do exist in relation to both the placement and scanning of an ISB. In implant dentistry, mismatches in the mating surfaces of abutments and certain implant internal connection designs have been shown to affect the amount of abutment displacement under varying degrees of torque.[77-79] Additional studies are necessary to investigate this finding as it applies to ISBs. Even after an ISB has been positioned properly within the fixture, other factors may influence the ability to scan and accurately digitize its surfaces. These factors may be related to the positioning within the arch and neighboring structures as well as the scanning technology and physical features of the ISB being used. Currently, there is limited information available for these topics, and more studies are necessary to investigate the relationship between ISB features and digital scanning accuracy.

CONCLUSIONS

Based on the findings of this review, the following conclusions were drawn:

1. ISBs are complex implant position transfer devices with considerable variability with regard to features and design.
2. The digitization process of an ISB involves data acquisition, virtual surface reconstruction, and ISB surface matching.
3. The interaction between scanner technology and ISB design is an important consideration that is not well understood.
4. The workflows and processes using ISBs can be completely or partially digital.
5. Data available to guide the clinician when choosing an ISB for various clinical situations are limited.
6. The use of ISBs appears promising, although more studies are needed to investigate the accuracy of digital intraoral implant impressions.

REFERENCES

1. Ramsey C, Ritter R. Utilization of digital technologies for fabrication of definitive implant-supported restorations. J Esthet Restor Dent 2012;24:299-308.
2. Davidowitz G. The use of CAD CAM in dentistry. Dent Clin North Am 2011;55:559-70.
3. Mörmann WH. The evolution of the CEREC system. J Am Dent Assoc 2006;137(suppl):7s-13s.
4. Örtorp A, Torsten J. CNC-milled titanium frameworks supported by implants in the edentulous jaw: a 10-year comparative clinical study. Clin Implant Dent Related Res 2012;14:88-99.
5. Papaspyridakos P, Chen CJ, Chuang SK, Weber HP, Gallucci GO. A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. Int J Oral Maxillofac Implants 2012;27:102-10.
6. Brandt J, Lauer H, Thorsten P, Brandt S. Digital process for an implant-supported fixed dental prosthesis: a clinical report. J Prosthet Dent 2015;114:469-73.
7. Christensen GJ. Impressions are changing: deciding on conventional, digital or digital plus in-office milling. J Am Dent Assoc 2009;40:1301-4.
8. Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci 2016;24:85-94.
9. Seelbach P, Brueckel C, Wöstmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig 2013:1759-64.
10. Rhee YK, Huh YH, Cho LR, Park CJ. Comparison of intraoral scanning and conventional impression techniques using 3-dimensional superimposition. J Adv Prosthodont 2015;7:460-7.
11. Cho SH, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent 2015;113:310-5.
12. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int 2015;46:9-17.
13. Goracci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. Eur J Orthod 2016;38:422-8.
14. Lie A, Jemt T. Photogrammetric measurements of implant positions. Description of a technique to determine the fit between implants and superstructures. Clin Oral Implants Res 1994;5:30-6.
15. Jemt T, Lie A. Accuracy of implant-supported prostheses in the edentulous jaw: analysis of precision of fit between cast gold-alloy frameworks and

master casts by means of a three dimensional photogrammetric technique. Clin Oral Implants Res 1995;6:172-80.
16. Bergin JM, Rubenstein JE, Mancl L, Brudvik JS, Raigrodski AJ. An in vitro comparison of photogrammetric and conventional complete-arch implant impression techniques. J Prosthet Dent 2013;110:243-51.
17. Wilk BL. Intraoral digital impressioning for dental implant restorations versus traditional implant impression techniques. Compend Contin Educ Dent 2015;36:529-30, 532-3.
18. Howell KJ, McGlumphy EA, Drago C, Knapik G. Comparison of the accuracy of Biomet 3i Encode Robocast Technology and conventional implant impression techniques. Int J Oral Maxillofac Implants 2013;28: 228-40.
19. Eliasson A, Ortorp A. The accuracy of an implant impression technique using digitally coded healing abutments. Clin Implant Dent Relat Res 2012;14 Suppl 1:e30-8.
20. Al-Abdullah K, Zandparsa R, Finkelman M, Hirayama H. An in vitro comparison of the accuracy of implant impressions with coded healing abutments and different implant angulations. J Prosthet Dent 2013;110:90-100.
21. Ng SD, Tan KB, Teoh KH, Cheng AC, Nicholls JI. Three-dimensional accuracy of a digitally coded healing abutment implant impression system. Int J Oral Maxillofac Implants 2014;29:927-36.
22. Del Corso M, Abà G, Vazquez L, Dargaud J, Dohan Ehrenfest DM. Optical three-dimensional scanning acquisition of the position of osseointegrated implants: an in vitro study to determine method accuracy and operational feasibility. Clin Implant Dent Relat Res 2009;11:214-21.
23. Stimmelmayr M, Güth JF, Erdelt K, Edelhoff D, Beuer F. Digital evaluation of the reproducibility of implant scanbody fit—an in vitro study. Clin Oral Investig 2012;16:851-6.
24. Jahn D, inventor. NT-Trading GmbH, assignee. Scan body for determination of positioning and orientation of a dental implant. US patent 14 011 936. December 25, 2014.
25. Moreira AH, Rodrigues NF, Pinho AC, Fonseca JC, Vilaça JL. Accuracy comparison of implant impression techniques: a systematic review. Clin Implant Dent Relat Res 2015;17(suppl 2):e751-64.
26. Ireland AJ, McNamara C, Clover MJ, House K, Wenger N, Barbour ME, et al. 3D surface imaging in dentistry - what we are looking at. Br Dent J 2008;205: 387-92.
27. Logozzo S, Zanetti EM, Franceschini G, Kilpelä A, Mäkynen A. Recent advances in dental pptics - Part I: 3D intraoral scanners for restorative dentistry. Opt Lasers Eng 2014;54:203-21.
28. Hack GD, Patzelt SB. Evaluation of the accuracy of six intraoral scanning devices: an in-vitro investigation. ADA Prof Prod Rev 2015;10:1-5.
29. Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig 2014;18:1687-94.
30. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. J Prosthodont 2015;24:313-21.
31. Su TS, Sun J. Comparison of repeatability between intraoral digital scanner and extraoral digital scanner: an in-vitro study. J Prosthodont Res 2015;59: 236-42.
32. Vandeweghe S, Vervack V, Dierens M, De Bruyn H. Accuracy of digital impressions of multiple dental implants: an in vitro study. Clin Oral Implants Res 2017;28:648-53.
33. Campbell RJ, Flynn PJ. A survey of free-form object representation and recognition techniques. Comput Vis Image Und 2001;81:166-210.
34. Persson AS, Odén A, Andersson M, Sandborgh-Englund G. Digitization of simulated clinical dental impressions: virtual three-dimensional analysis of exactness. Dent Mater 2009;25:929-36.
35. Rudolph H, Quaas S, Luthardt RG. Matching point clouds: limits and possibilities. Int J Comput Dent 2002;5:155-64.
36. Holst S, Persson A, Wichmann M, Karl M. Digitizing implant position locators on master casts: comparison of a noncontact scanner and a contact-probe scanner. Int J Oral Maxillofac Implants 2012;27:29-35.
37. Persson AS, Andersson M, Odén A, Sandborgh-Englund G. Computer aided analysis of digitized dental stone replicas by dental CAD/CAM technology. Dent Mater 2008;24:1123-30.
38. Zhu L, Barhak J, Srivatsan V, Katz R. Efficient registration for precision inspection of free-form surfaces. Int J Adv Manuf Tech 2007;32:505-15.
39. Barbero BR, Ureta ES. Comparative study of different digitization techniques and their accuracy. Comput Aided Des 2011;43:188-206.
40. Várady, Tamás, Ralph R. Martin, and Jordan Cox. Reverse engineering of geometric models—an Introduction. Comput Aided Des 1997;29:255-68.
41. Li H, Lyu P, Wang Y, Sun Y. Influence of object translucency on the scanning accuracy of a powder-free intraoral scanner: a laboratory study. J Prosthet Dent 2017;117:93-101.
42. González de Villaumbrosia P, Martínez-Rus F, García-Orejas A, Salido MP, Pradíes G. In vitro comparison of the accuracy (trueness and precision) of six extraoral dental scanners with different scanning technologies. J Prosthet Dent 2016;116:543-50.
43. Kurz M, Attin T, Mehl A. Influence of material surface on the scanning error of a powder-free 3D measuring system. Clin Oral Investig 2015;19: 2035-43.
44. Gimenez-Gonzalez B, Hassan B, Özcan M, Pradíes G. An in vitro study of factors influencing the performance of digital intraoral impressions operating on active wavefront sampling technology with multiple implants in the edentulous maxilla. J Prosthodont 2017;26:650-5.
45. Chan DC, Chung AK, Haines J, Yau EH, Kuo CC. The accuracy of optical scanning: influence of convergence and die preparation. Oper Dent 2011;36: 486-91.
46. Wismeijer D, Mans R, van Genuchten M, Reijers HA. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (intraoral scan) of dental implants. Clin Oral Implants Res 2014;25:1113-8.
47. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. Int J Oral Maxillofac Implants 2014;29:853-62.
48. Lin WS, Harris BT, Elathamna EN, Abdel-Azim T, Morton D. Effect of implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: an in vitro comparative study. Int J Oral Maxillofac Implants 2015;30:102-9.
49. Wang J, Z Yu, W Zhu, J Cao. Feature-preserving surface reconstruction from unoriented, noisy point data. Comput Graph Forum 2013;32:164-76.
50. Bernardini F, Rushmeier H. The 3D model acquisition pipeline. Comput Graph Forum 2002;21:149-72.
51. Rusinkiewicz S, O Hall-Holt, M Levoy. Real-time 3D model acquisition. ACM Trans Graph 2002;21:438-46.
52. Seung JL, Park MK, Lee KH. Full 3D surface reconstruction of partial scan data with noise and different levels of scale. J Mech Sci Technol 2014;28: 3171-80.
53. Campen M, Attene M, Kobbelt L. A practical guide to polygon mesh repairing. Eurographics Association; 2012. Available at https://diglib.eg.org/handle/10.2312/conf.EG2012.tutorials.t4. Accessed February 5, 2017.
54. Xiuzi Y, Liu H, Chen L, Chen Z, Pan X, Zhang S. Reverse innovative design—an integrated product design methodology. Comput Aided Des 2008;40:812-27.
55. Pinto JM, Arrieta C, Andia ME, Uribe S, Ramos-Grez J, Vargas A, Irarrazaval P, et al. Sensitivity analysis of geometric errors in additive manufacturing medical models. Med Eng Phys 2015;37:328-34.
56. Giménez B, Pradíes G, Martínez-Rus F, Özcan M. Accuracy of two digital implant impression systems based on confocal microscopy with variations in customized software and clinical parameters. Int J Oral Maxillofac Implants 2015;30:56-64.
57. Kim JE, Amelya A, Shin Y, Shim JS. Accuracy of intraoral digital impressions using an artificial landmark. J Prosthet Dent 2017;117:755-61.
58. Lee JH. Improved digital impressions of edentulous areas. J Prosthet Dent 2017;117:448-9.
59. Yamany SM, Farag AA. Surface signatures: an orientation independent free-form surface representation scheme for the purpose of objects registration and matching. IEEE Trans Pattern Anal Mach Intel 2002;24: 1105-20.
60. Peters MC, Delong R, Pintado MR, Pallesen U, Qvist V, Douglas WH. Comparison of two measurement techniques for clinical wear. J Dent 1999;27:479-85.
61. Rodolà E, Albarelli A, Cremers D, Torsello A. A simple and effective relevance-based point sampling for 3D shapes. Pat Recog Lett 2015;59: 41-7.
62. Gong YX, Liu Y, Wu L. Boolean operations on conic polygons. J Comput Sci Technol 2009;24:568-77.
63. Koch GK, Gallucci GO, Lee SJ. Accuracy in the digital workflow: from data acquisition to the digitally milled cast. J Prosthet Dent 2016;115: 749-54.
64. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204: 505-11.
65. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res 2016;27: 465-72.
66. Amin S, Weber HP, Finkelman M, El Rafie K, Kudara Y, Papaspyridakos P. Digital vs. conventional full-arch implant impressions: a comparative study. Clin Oral Implants Res 2017;28:1360-7.
67. Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. Clin Oral Implants Res 2015;26: 715-9.
68. Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital versus conventional impressions in fixed prosthodontics: A review. J Prosthodont 2018;27:35-41.
69. Flügge TV, Att W, Metzger MC, Nelson K. Precision of dental implant digitization using intraoral scanners. Int J Prosthodont 2016;29:277-83.
70. Chia VA, Esguerra RJ, Teoh KH, Teo JW, Wong KM, Tan KB. In vitro three-dimensional accuracy of digital implant impressions: the effect of implant angulation. Int J Oral Maxillofac Implants 2017;32:313-21.

71. Basaki K, Alkumru H, De Souza G, Finer Y. Accuracy of digital vs conventional implant Impression approach: a three-dimensional comparative in vitro analysis. Int J Oral Maxillofac Implants 2017; 32:792-9.
72. Fluegge T, Att W, Metzger M, Nelson K. A novel method to evaluate precision of optical implant impressions with commercial scan bodies-an experimental approach. J Prosthodont 2017;26:34-41.
73. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. BMC Oral Health 2017;92:1-13.
74. Mangano FG, Veronesi G, Hauschild U, Mijiritsky E, Mangano C. Trueness and precision of four intraoral scanners in oral implantology: a comparative in vitro study. PLoS One 2016;11:1-18.
75. Joda T, Brägger U. Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. Clin Oral Implants Res 2016;27:185-9.
76. Schepke U, Meijer HJ, Kerdijk W, Cune MS. Digital versus analog complete-arch impressions for single-unit premolar implant crowns: operating time and patient preference. J Prosthet Dent 2015;114:403-6.
77. Gilbert AB, Yilmaz B, Seidt JD, McGlumphy EA, Clelland NL, Chien HH. Three-dimensional displacement of nine different abutments for an implant with an internal hexagon platform. Int J Oral Maxillofac Implants 2015;30: 781-8.
78. Semper W, Heberer S, Mehrhof J, Schink T, Nelson K. Effects of repeated manual disassembly and reassembly on the positional stability of various implant-abutment complexes: an experimental study. Int J Oral Maxillofac Implants 2010;25:86-94.
79. Yilmaz B, Seidt JD, McGlumphy EA, Clelland NL. Displacement of screw-retained single crowns into implants with conical internal connections. Int J Oral Maxillofac Implants 2013;28:803-6.

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Noteworthy Abstracts of the Current Literature

Mechanical failure of endocrowns manufactured with different ceramic materials: an in vitro biomechanical study

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Purpose. To evaluate the effect of different silica-based ceramic materials on the mechanical failure behavior of endocrowns used in the restoration of endodontically treated mandibular molar teeth.

Material and methods. Thirty-six intact mandibular molar teeth extracted because of a loss of periodontal support received root canal treatment. The teeth were prepared with a central cavity to support the endocrowns, replacing the occlusal surface with mesial-lingual-distal walls. Data acquisition of the prepared tooth surfaces was carried out digitally with a powder-free intraoral scanner. Restoration designs were completed on manufactured restorations from three silicate ceramics: alumina-silicate (control), zirconia-reinforced (Zr-R), and polymer-infiltrated (P-I). Following adhesive cementation, endocrowns were subjected to thermal aging, and then, each specimen was obliquely loaded to record the fracture strength and define the mechanical failure. For the failure definition, the fracture type characteristics were identified, and further analytic measurements were made on the fractured tooth and ceramic structure.

Results. Load-to-fracture failure did not differ significantly, and the calculated mean values were 1035.08 N, 1058.33 N, and 1025.00 N for control, Zr-R, and P-I groups, respectively; however, the stiffness of the restoration-tooth complex was significantly higher than that in both test groups. No statistically significant correlation was established in paired comparisons of the failure strength, restorative stiffness, and fractured tooth distance parameters. The failure mode for teeth restored with zirconia-reinforced glass ceramics was identified as non-restorable. The resin interface in the control and P-I groups presented similar adhesive failure behavior.

Conclusions. Mechanical failure of endocrown restorations does not significantly differ for silica-based ceramics modified either with zirconia or polymer.

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