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Characteristics of intraoral scan bodies and their influence on impression accuracy: A systematic review

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Table of Contents

B. Special Part

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- Ευχαριστίες

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A. General Part

Chapter 1: Introduction

Implant-supported prostheses are well established as a reliable treatment plan for the rehabilitation of partial or complete edentulism (Frisch E et al. 2020). They present high survival and success rates and are also encountered with increased patient satisfaction, being a viable and reliable option for functional and esthetic rehabilitation. Oral-health-related quality of life seems to be improved when choosing implant restorations and that justifies why they are proposed even more frequently in everyday clinical practice. (Canallatos JE et al. 2020).

Prerequisite for the success of this treatment is the accuracy of the dental impression (Ortorp A et al. 2012). This is defined as a negative imprint of an oral structure leading to the positive replica of the desired structure, as a record or for the manufacturing of dental restoration (The Glossary of Prosthodontic Terms, 9th edition, 2017). Any distortion in the transfer of the implant position will result in a compromised fit of the restoration (Zarb GA et al. 1990).

Passivity of an implant-supported prosthesis is of utmost importance for its long-term success (Kurtulmus-Yilmaz S et al. 2014). Teeth are surrounded by periodontal fibers and present a buccolingual micromovement of approximately 56-108 μm and micro-intrusion of about 28μm. However, when it comes to osseointegrated dental implants, there is an important difference, since there is absence of the periodontic ligament and therefore, they demonstrate a minimum micromovement of only 10μm, meaning that any distortions in impression accuracy would lead to their direct transfer to the surrounding bone. This would inevitably mean non-passive fit, and thus mechanical strain leading to further mechanical and biologic complications (Mizumoto RM et al. 2020).

Mechanical complications mentioned in the literature include loosening or fracture of the prosthetic screw, changes in occlusal contacts, overloading and even implant fracture.

Biologic complexities may refer to plaque accumulation due to the gap between the implant and the restoration, inflammation, peri-implant mucositis and in more advanced situations, peri-implantitis or even loss of osseointegration (Kurtulmus-Yilmaz S et al. 2014).

Although it is clear that passivity is the main goal, it is not yet scientifically clear the limit up to which absence of it would be bearable and clinically accepted (Papaspyridakos P. 2015), nonetheless it is important to minimize the discrepancy of fit (Sahin S et al. 2001).

Chapter 2. Conventional implant impression

2.1. Factors that influence impression accuracy

The impression process is based on the manufacturing of a high-accuracy definitive cast which transfers exactly the intraoral three-dimensional position of the implant (Kim JH et al. 2015). The accuracy of the definitive cast is of paramount significance and is influenced by:

- The impression method used
- The implant inclination
- The impression material chosen
- The length of the impression copings
- The depth of the implant position
- The dimensional stability and properties of the gypsum used to fabricate the final cast
- The die system used (Kim JH et al. 2015).

The accuracy of the definitive cast is of utmost importance for the sequencing implant-supported restoration. Four kinds of possible implant component displacements may take place during the pouring of the definitive cast (Fernandez MA et al. 2013).

The first is the displacement of each impression coping on the mating surface of each implant withing the range of the machining tolerance (Fernandez MA et al. 2013). Machining tolerance is defined in literature as "the difference in rest position between the components when these components are held in place by their respective fastening screws" (Ma T et al. 1997). For instance, the machining tolerance between Branemark standard abutment parts are between 22 and 100 μm (Fernandez MA et al. 2013).

The second type is the displacement of each transfer coping as a result of the impression technique (Fernandez MA et al. 2013). Various studies have been conducted about the assessment of possible distortion (Daoudi MF et al. 2003, Rashidan N et al. 2012, Ebadian B et al. 2015). Among the methods used are microscopes and strain gauges.

The third factor is the type of impression material selected (Fernandez MA et al. 2013). There are numerous publications evaluating the dimensional accuracy of materials used in impression procedures (Tjan AH et al. 1986, Dounis GS et al. 1991, Liou AD et al. 1993). The material, among other properties discussed in next chapter, should be adequately rigid to prevent any rotation of the components during the analog connection onto the coping or the impression transfer and the cast fabrication (Wee AG et al. 1998, Anusavice KJ et al. 2003).

Last but not least, the fourth factor is the possible displacement of each abutment replica in the final cast due to the dimensional distortion of the dental stone (Fernandez MA et al. 2013). Type IV dental stone presents a linear setting expansion of o,10% at most, which means that there is risk for displacement of the impression coping or implant analog during the expansion of dental stone (Anusavice KJ et al. 2003).

2.2. Implant impression copings

Impression of osseointegrated dental implants is traditionally based on the use of impression or transfer copings, which are then linked to the implant body and with the appropriate impression trays and elastomeric materials serve to represent the intaoral situation (Chee W et al. 2006).

Impression copings are necessary parts used for implant impressions and present a variety in their characteristics, depending on the implant system and on the selected technique. In some implant systems, the implant copings used may be the same for both techniques, differing only on the length of the screw used. They are connected directly in implant level or upon the abutment, if they have already been placed clinically (Τσιγάρου Σ. 2017).

Concerning the materials used, they are usually made out of metal alloys and fixed by screw. Alternatively, they are fabricated out of polymer materials and are then fixed by sctrew or snapped in the implant. Fernandez et al. studied the comparison between plastic and metal impression transfer copings for two implant systems (Nobel Biocare™ and Straumann SynOcta) in an in vitro study. They found out that plastic presented significantly larger average gaps than metal for Straumann, but for Nobel they were not significantly different.

After the impression procedure, implant analogs are connected onto the impression copings, which represent and transfer the implant position from the clinical environment to the final cast. The implant analogs consist of two parts: the upper represents the platform and part of the implant thread and the lower part is placed and stabilized into the final cast (Καββαδία Β. 2013).

The geometry and dimensions of the impression copings may influence the impression accuracy and this factor can be more significant even than the impression technique (Rashidan N et al. 2012). The researchers concluded that the impression copings with the less retentive geometry (square) were related with less impression distortions, independently of the impression technique used.

Different techniques have been proposed for the enhancement of the retention of the impression coping. Transfer copings used for the closed tray technique that come in two parts were found to achieve better impression accuracy, eliminating distortions during their repositioning after the procedure (Στέφος Σ. 2014). Other techniques mentioned in literature include lengthening of the transfer coping, sandblasting of its surface or appliance of a bonding agent (Παλάντζα Ε. 2020).

2.3. Implant impression techniques

Implant impression techniques can be classified as either direct (pick-up) or indirect (transfer).

Direct methods are sometimes referred to as open tray impression techniques, since the tray used has an open window so that the unscrewing of the impression copings can be feasible (Lee SJ et al. 2011).

Indirect impression is also mentioned as closed tray technique. The copings are connected to the implants and after the setting time of the material, the impression is removed, while the impression copings remain on the implant fixtures (Ismail IA et al. 2020). The process following that includes repositioning of the copings in the impression material.

In both techniques, the copings are then connected to the implant analogs and the definitive cast is poured.

Although there is much scientific interest and many researches have been conducted for implant impression accuracy, materials and systems, yet no consistent results have been demonstrated (Lee H et al. 2008). Nevertheless, although the impression technique seems not to influence the accuracy, the design of the impression coping was found to be significant. Rashidan N et al. proved in their study that copings with less retentive design like a square leaded to less impression distortions.

Comparison of the two techniques is multivariable. For the closed tray method, the advantages include its simplicity and ease for the clinician, fastness and comfort, as it is similar to impression for teeth. In addition, it can be easily implemented in either anterior or posterior regions and makes it possible to take an impression simultaneously for teeth and implants (Τσιγάρου Σ. 2017). Another benefit is that no custom tray is necessary and sometimes not even modifications are needed. However, the transfer coping involves the risk of errors during the repositioning of the copings into the impression material (Ismail IA et al. 2020). Another disadvantage concerns the difficulty encountered in cases where the implants present very different inclinations or if they are in proximity. The design of the impression coping is also important, since it may influence the impression accuracy (Τσιγάρου Σ. 2017).

Concerning the open tray technique, it was proven to be optimal in cases of full-arch prostheses, but for partially edentulous patients there are seemingly no statistically significant differences (Papaspyridakos P et al. 2014). In open tray technique, no re-placing of the coping is necessary, so possible distortions can be avoided. It was also observed that less strains are accumulated in the impression material especially during the removal out of the oral cavity (Τσιγάρου Σ. 2017). Another important aspect is that it is a convenient method to take an impression even in cases of very proximal or divergently placed implants.

There is increased scientific interest as for the splinting or not of the impression copings. This is met in cases of open tray impressions and is indicated mainly when there is significant diversion between the implants or they have been placed too close, so it would be difficult for the material to penetrate in between them (Tsagkalidis G et al. 2015). The results in the literature are encouraging towards splinting, especially when it comes to full-arch cases, but also for partial edentulism, producing more accurate casts. The only disadvantages have to do with the additional time and material needed and that is therefore perhaps more demanding for the patient as well (Papaspyridakos P et al. 2014).

2.4. Splinting of impression copings in open tray technique

An alternative to the open tray technique is the method of open tray with splinting of the impression copings. The purpose of this technique is to enhance the impression accuracy.

Different materials have been proposed for the splinting, among which acrylic resin, dual-cured composite resin, polyvinylsiloxane used for registration bite and polyether. The most frequently used is acrylic resin, either as a single material or supported by dental floss, a metallic bur, orthodontic wire or any other supportive material (Tsagkalidis G et al 2015).

The clinician should always take into consideration, however, the polymerization shrinkage of the acrylic resin so that maximum impression accuracy can be achieved. This phenomenon is observed especially during the first 17 minutes when approximately 80% of this volumetric change takes place and reaches about 7,9% 24 hours after (Mojon P et al. 1990). Therefore, it is essential to limit as possible the effects of polymerization shrinkage on impression procedures. It is suggested that after the initial 17 minutes the mass of acrylic resin used to splint the copings should be cut in certain positions and then re-connected with a new small mass of the same material (Cabral LM et al. 2007).

The advantages of this technique include the rigidity of the impression copings during the impression removal out of the oral cavity. It also enhances the rigidity during the connection of the laboratory implant analogs (Παλάντζα Ε. 2020).

Nonetheless, there are certain limitations, too. It is an extra clinical step which requires additional time and this means more time during which the patient remains with open mouth (Μπίκος Π και συν. 2013). This could mean less comfort for them, especially in cases with orofacial pain.

A clinical indication for splinting the open tray impression copings is the increased implant inclination or their proximity. In this case, if the copings remained stud, there would probably be no space for the impression material to be placed between them (Καββαδία Β. 2013).

The literature supports that splinting of the implant transfer copings can enhance impression accuracy. Papaspyridakos et al. in their systematic review demonstrated that this technique leads to higher impression accuracy, both for completely and partially edentulous patients (Papaspyridakos P et al. 2014). As for patients with complete edentulism in any jaw, it was mentioned that the majority of in vitro and all of the clinical studies that were included, supported that splinting leads to superior impression results (15 studies were in favor of splinting, only rejected the necessity of the technique and 9 studies showed no difference).

2.5. Impression trays

As far as the impression tray is concerned, the main materials used are:

- metallic or polymer, when they are stock trays or

- light-cured or chemically cured, when a custom tray is chosen.

Custom trays are proven to be superior than the stock ones and they seem to produce significantly more accurate impressions (Burns J et al. 2003). Due to their custom fabrication, they exhibit the optimal fit and rigidity and therefore better ease in the process for the clinician. For the optimal retention of the impression material on the stock tray, it is advisable that an appropriate bonding agent is applied, so that a higher material bond strength can be achieved (Payne JA et al. 1992, Cho GC et al. 1995).

2.6. Level of implant impression

For implant impressions, it is also useful to divide the techniques into implant-level and abutment-level technique.

For these procedures transmucosal abutments are used. They are fixed and not removed.

For the implant-level method, the impression coping is connected onto the implant and after pouring of the definitive cast it is easy to know the precise inclination, the platform and the connection geometry, along with the accurate location in relation to the adjacent sites.

In the cases where the abutment-level impression is selected, the abutment has already been chosen. The concept behind this clinical decision is the so-called "one abutment, one time" concept which is proven to limit the bone resorption around the crucial area in the implant neck (Degidi M et al. 2011). In this way, the definitive cast depicts the three-dimensional position of the abutment, without any further details about the implant.

The factors that are usually considered for the abutment selection are the implant depth and the thickness of the soft tissues. These are even more important for cases where tilted abutments are needed (Παλάντζα Ε. 2020).

The comparison between these two techniques shows that the implant-level impression may induce more inaccuracy risks, for instance in cases of deeply placed implants. It has additionally been proved that splinting of impression copings is of utmost importance when it comes to implant-level impression taking, however it presents no significant difference on abutment-level (Papaspyridakos P. 2015).

Chapter 3. Materials for Conventional Impression

3.1. Properties of impression materials for implants

Materials used for implant impressions need to fulfill some prerequisites, so that impression accuracy can be achieved. An ideal impression material has not yet been established.

Clinically, it is important to produce a dimensionally accurate final cast. According to American Dental Association specification #19, elastomeric impression materials should reproduce detail of 25μm or less (Tjan AH et al. 1991). The different viscosities are very significant and influence the accuracy in detail reproduction (Hamalian TA et al. 2011).

Optimal mechanical properties are also desired concerning yield strength and optimal Young's modulus in order to achieve sufficient elastic recovery upon removal from the mouth (Craig RG et al. Elsevier, 2001). There is no ideal impression material with 100% elastic recovery, so it is essential to take into consideration that the material should be at least three or four times thicker than the largest undercut, for undercuts are responsible for material distortion (Donovan TE et al. 2004). For this reason, it is suggested that undercuts should be eliminated before impression taking. Among the materials usually used, polyvinylsiloxane showed the best results in elastic behavior, with approximately elastic recovery high over 99%, while polyethers and polysulfides showed lower percentages (Hamalian TA et al. 2011).

Another important factor is the dimensional stability of the material to maintain the accuracy over time which is a time-dependent procedure. This is the reason why the impression materials should ideally have as low polymerization shrinkage as possible (Donovan TE et al. 2004). Polyvinylsiloxane comes up with the best results, as it can be poured even after 1 week after the impression taking (Craig RG et al. Elsevier, 2001), (Shen C, Saunders, 2003). Similar but lower percentages are also shown for polyethers (Hamalian TA et al. 2011). However, condensation silicones and polysulfides are more time-dependent and need to be poured in less than half an hour after removing them extraorally (Hamalian TA et al. 2011).

Therefore, the latter two materials are not indicated for implant impressions.

The impression materials, additionally, need to be flexible enough to be removed from any existing undercuts. Polyethers are known to be the most rigid impression material, while alginate is the one considered the most flexible (Hamalian TA et al. 2011). According to Craig, viscosity is of utmost importance so that gypsum casts are manufactured with minimal bubbles and distortions and maximum accuracy (Craig RG. 2001).

Hydrophilicity is a property related with their ability to flow better in moisture areas like the intraoral conditions, showing high precision and a lower risk of bubbles (Hamalian TA et al. 2011). Also, it should be appropriate fort accurate manufacturing of multiple casts.

Another factor to be taken into consideration are the rheological properties of the selected material, which is the wettability or flowability. They should be able to flow even into small regions and capture any fine detail (Donovan TE et al. 2004). Reasonable financial costs should definitely be considered and biocompatibility remains a prerequisite for any dental material (Hamalian TA et al. 2011).

Impression materials selected for implant-supported restorations are mainly polyether materials and polyvinylsiloxanes. The main reason is their superior mechanical properties in comparison to other commonly used impression materials, among which are condensation silicones, polysulfides, reversible hydrocolloid, irreversible hydrocolloid (alginate) and impression stone (Kurtulmus-Yilmaz S et al. 2014).

3.2. Polyether as an impression material

Polyethers are commonly used impression materials since the 1960s. They are presented as a base and activator paste of the same viscosity. In contrast to the silicone impression materials, polyethers are available in two viscosities (Lepe X et al. 2002) and are consequently an example of a monophase impression material, that is the same viscosity material is syringed intraorally as is loaded onto the impression tray. It is therefore a monophase material that should always be used in a single-stage technique (Ritter AV et al. 2000).

The base paste of a polyether contains inert fillers and polyether polymer chains which include a terminal amine group. These polymer chains are cross-linked by an aromatic sulphonate ester in the activator paste, which is also enhanced with inert filler particles.

There are no by-products to this setting reaction and, as such, the material presents high dimensional stability. Nonetheless, since the materials will take up water, the set impression should be stored dry.

Polyethers which are included in tubes for manual blending on a pad are generally considered messy and difficult to mix. For this reason they are preferably mixed in special devices with mechanical mix, such as the Pentamix Automatic Mixing Unit (3M-ESPE).

Polyether impressions should be cast within a few days as prolonged storage leads to deterioration of the material.

They have good elastic properties and are particularly suited for implant prosthodontics. They are moderately hydrophilic and do not encounter problems when taking impressions in the presence of some moisture like saliva or blood. Their low wetting angle enables them to easier capture a full-arch impression than additive silicones (Craig RG et al. 2001), (Hamalian TA et al. 2011).

One of their main advantages is their excellent reproducing ability, their ability to manufacture multiple casts and their dimensional stability over time (Hamalian TA et al. 2011). It is possible to manufacture multiple stone casts from the same impression and it remains dimensionally stable even after 8 days (Παλάντζα Ε. 2020). The working and setting times are considered good and it is influenced neither by probable contamination nor by latex gloves like PVS.

However, in comparison to additive silicones, they are more rigid and exhibit high elastic modulus, therefore, it is more difficult to remove the impression from undercuts (Giordano R, 2000). Additionally, it is not suggested in cases with large undercuts and in any clinical case the removal out of the oral cavity would be difficult or risky. Its high cost and the fact that dentists are not equally familiar with its use make its selection less frequent in comparison to addition silicones (Anusavice KJ et al. 2012, Rubel BS. 2007).

3.3. Polyvinylsiloxane as an impression material

Polyvinylsiloxane impression materials or addition-type silicones (type A), often called PVS, include amorphous polymer chains of oxygen atoms and silicone which are at random coiled and due to the lack of crystallinity, they tend to be flexible rather than brittle.

They are in fact a modification of the original condensation silicones. Both materials are structured upon the polydimethylsiloxane polymer, but the difference in their terminal groups is responsible for their different curing reactions (Van Noort R et al. 1994). Their elastic properties are attributed to cross linking and addition of long chains. These oligomers are double-bond-functional silicones after polymerization by free radicals from chloroplatinic acid.

The base material contains a polymethyl hydrogen siloxane co-polymer. This is a moderately low molecular mass polymer that includes silane terminal groups (Van Noort R et al. 1994), (Craig RG et al. 1990). The accelerator contains the vinyl-terminated polydimethyl siloxane. This is a moderately low molecular mass polymer as well but has vinyl terminal groups. The accelerator material also contains chloroplatinic acid in the role of a homogeneous metal complex catalyst (Surapaneni H et al. 2013) The mixture is also enhanced with silica, since this is the only thing with the right degree of hydrophilicity to be mixed into the material.

Polyvinylsiloxanes as dental impression materials, were formulated with different loading combination of six types of fillers, including nano-sized fumed silica. The fillers were mixed with three types of silicone polymers together with cross-linker and inhibitor in base paste and with plasticizer and platinum catalyst in catalyst paste. By replacing parts of crystalline quartz with other fillers, the setting time became much shorter (Surapaneni H et al. 2013). The combination with fumed silica resulted in increased viscosity, tensile strength and maximum% strain.

Colouring agents are often added to the base and the catalyst material to distinguish them and to aid evaluation of the mixing visually.

Other modifications include addition of intrinsic surfactants in an attempt to negate the hydrophobicity of these materials (Panicchuttra R et al. 1991). Compositions are proprietary. Nevertheless, they are often supplied in two equal-size tubes, usually in cartridges for use in an automix dispenser gun. The base-to-catalyst ratio is 1:1. Newer PVS have been manufactured to be more hydrophilic. Shelf life is usually about 2 years but is reduced by warm conditions (Surapaneni H et al. 2013).

They produce no byproducts during their polymerization, in contrast to condensation silicones which produce hydrogen, and as a result this leads to their dimensional stability.

Due to their low polymerization shrinkage (only 0,05%), polyvinylsiloxanes are characterized by high impression accuracy and excellent detail impression.

They also present good tear strength, good working and setting times, excellent wettability and an option for automixed system. Other advantages include minimal distortion on removal, dimensionally stable even after 1 week. They are a biocompatible material and indeed non-allergic, as there are no reports of patient sensitivity to the addition silicones.

The main disadvantages have to do with the material cost, its possible contamination and polymerization inability due to powder or latex as well as its hydrophobic properties (Surapaneni H et al. 2013).

3.4. Other implant impression materials

The problems encountered due to the hydrophobic nature of polyvinysiloxanes would lead to the production of new PVS with better wettability. They are considered more "hydrophilic".

New PVS have also been produced especially for implant impression cases. These materials are more rigid and can even be scanned directly by laboratory scanners. Full-arch edentulous jaws with two or more implants are an indication where they could be selected (Παλάντζα Ε. 2020).

Further advances in dental materials have led to the production of “less” rigid polyether. This is suggested as a solution to the difficulties encountered during the impression removal. These products have also shown high surface detail and is faster in time demands.

In recent years, hybrid impression materials have been developed as well. The purpose of this combination is to blend desirable propertis both from PVS and from polyethers. These innovative materials are nominated as Vinylpolyethersilicone (VPES). They present high dimensional stability and hydrophilic properties.

However, these results need to be interpreted with caution due to the limited data available in scientific literature about their long-term results (Kurtulmus-Yilmaz S et al. 2014).

Chapter 4. Digital Impressions

4.1 History of Digital Impressions

Elastomer materials are still considered the gold standard in Prosthodontics. However, it was in 2007 when for the first time a digital impression was attempted and since then digital dentistry has long evolved and changed fundamentally the workflow between the clinician and the laboratory.

CAD/CAM (Computer Aided Design/Computer Assisted Manufacturing) had been used since 1960s in the manufacture of airplanes and automobiles. The First application of CAD/CAM in dentistry was by Dr. Francois Duret in 1970s in his thesis “Optical Impression”.

In 1984, Duret invented and patented a CAD/CAM device and illustrated the crown fabrication in 4 hours. At the same time, Dr. Mormann and Dr. Brandestini originated, the first profit oriented digital impression system the CEREC1, in 1985 (Priyanka G et al. 2020). CEREC 1 combined a 3-dimensional (3D) digital scanner with a milling unit to create dental restorations from commercially available blocks of dental ceramics in a single appointment. The goal for CEREC 1 was the fabrication of ceramic inlays and onlays. Dr. Mormann also licensed today Sirona Systems. Cerec 2, cerec 3, cerec 3D were introduced in 1994, 2000 and 2003 (Priyanka G et al. 2020).

4.2. Intraoral Scanning technologies

An intraoral scanner (IOS) is composed of an intraoral camera that is handheld, a computer and the corresponding software. Their aim is to record three-dimensional geometry of an object with precision and trueness.

An STL (Standard Tessellation Language) type of file is the most frequently produced digital data form from IOS and it is indeed an extensively used digital format. Other formats include PLY files, Polygon File Format, regardless of imaging technology used by IOS (Priyanka G et al. 2020).

After identification of POI (point of interest) software assembles individual images or videos recorded by the camera under a light projection (Richert R et al. 2017).

In 3d reconstruction field there are two main fields of techniques: active and passive.

Active techniques involve Triangulation, which is a procedure that uses red, white or blue light for real texture and color of tissues. After that follows the reconstruction by projecting the light from the camera onto an object. Intraoral tissues are illuminated only by ambient light and reliant to a certain level of the texture of the object in passive technique (Mangano F et al. 2017).

Another technique is Laser Confocal microscopy Scanning. It is a microscopic technique for scanning 3-dimensional objects by fluorescent microscopy. It was in 1957 when Marvin Minsky introduced the basic principle in confocal scanning (Richert R et al. 2017).

Optic triangulation is also another method used. It measures the object to the distance without touching them in microns to millimeters (Taneva E et al. 2015).

Last but not least, optical coherence tomography uses light instead of sound, and it is similar to ultrasound imaging while Active Wavefront Sampling (AWS): is a surface imaging technique, which uses only a single camera and optical path (Taneva E et al. 2015).

Various Commercially available Scanning systems are commercially available nowadays, among which these are most usually met in research studies:

1. iTero (Cadent Inc-Carstadt, NJ)
2. TRIOS (3Shape A/S - Copenhagen, Denmark)
3. CEREC (Sirona Dental System GmbH-Bensheim, Germany)
4. Primescan (Sirona Dental System GmbH-Bensheim, Germany)
5. Lava Chairside Oral Scanner - C.O.S. (3M Espe- St.Paul, MN)

6. Carestream CS (Carestream Health – Rochester, NY, USA)

4.3. Digital impressions and Accuracy

The accuracy of digital implant impressions has long been well established and evidence-based (Christensen GJ. 2009, Rudolph H et al. 2016).

The parameters that may influence digital implant impression accuracy are:

- the inclination of the implant placement (Gimenez-Gonzalez B et al. 2017)

- the distance between adjacent implants (Tan J et al. 2019)

- the design characteristics of the scan bodies (Stimmelmayr M et al. 2012, Mizumoto RM et al. 2018)

- the scanning protocol (Muller P et al. 2016, Anh JW et al. 2016)

- the recent alibration of the intraoral scanner (Richert R et al. 2017)

- the experience and familiarization of the operator (Kim J et al., 2016, Lim JH et al. 2018)

- the lighting conditions of the scanning environment (Arakida T et al. 2018, Revilla-León M et al. 2019)

- the precision and trueness of the respective intraoral scanner (Patzelt SB et al. 2013, Joda T et al. 2017, Renne W et al. 2017, Medina-Sotomayor P et al. 2018, Kong L et al. 2022)

4.4. Advantages of Digital Impressions

Many advantages have been reported in the scientific literature concerning this field.

There is, first and foremost, the ease of recording digitally the clinical situation simultaneously for implants, teeth and oral mucosa, without the need of trays or materials. This is even more significant in cases where modifications are needed, because in conventional impression techniques this would mean extra material, thus extra costs, time and probably discomfort for the patient (Lo Russo L et al. 2019).

Any possible distortions due to material properties can be avoided, such as gaps, strains and insufficient polymerization. It is also very helpful for the clinician since the learning curve is easily feasible even for inexperienced dentists (Lee SJ et al. 2013) and the intraoral scanning can reduce operation time as well (Ahlholm P et al. 2018).

It gives the opportunity to have visual control of the impression because it can be observed either as the negative imprint or as its positive representation which can be either the clinical three-dimensional situation or a virtual cast, which is not possible in conventional techniques before pouring the final cast.

Intraoral scanner software provide the clinician with additional benefits. These include virtual tools that can detect undercuts, areas of possible errors or inadequate prosthetic space. This can be applied in implant cases as well, when the virtual implant libraries can help with the appropriate selection of implant parts offering direct view of the available solutions. In this way, the clinician can control completely the clinical steps and the data that are promoted to the dental laboratory and in this way cases that need revision of the impression procedures can be eliminated (Παλάντζα Ε. 2020).

Patient comfort is an additional benefit and the limitation of gag reflex risks which offers better ease during clinical time (Amin S et al. 2016).

Another advantage concerns the non-contaminating nature of digital data. In cases of conventional impressions, this would mean they should be decontaminated before being sent to the dental laboratory and especially as soon as possible. However, an optical impression can be sent anytime to the lab which can be located even in another town or country. This offers the benefit of eliminating time and storage space needed. It is very important that the data can be recalled at any time and remain to the patient’s personal archives available.

There are many advantages for the laboratory part of course. The workflow can become faster and therefore this enhances productivity. In any stage of the procedure, the lab and the clinician can easily communicate and have in picture any possible disagreement which eliminates the number of clinical sessions and the overall time needed for the patient.

4.5. Disadvantages of Digital Impressions

There are some limitations that definitely need to be considered.

Some digital softwares remain “closed” which means that it is not possible to send the data to any dental lab unless they use compatible systems.

Concerning the intraoral scanning devices, some of them have voluminous tips so that their intraoral manipulations can be difficult or uncomfortable for the patient. Many manufacturers try to reduce their size, however, it was observed that systems with very small tip, although help with the clinical procedures and the patient comfort, scan fewer digital data and they found it harder to stitch the pictures in neighbouring areas of the impression, especially when it comes to edentulous regions (Kim KR et al. 2019).

After the impression of the desired arch, then comes the impression of the opposite arch and the bite registration. Bite registration in a digital environment is easy in clinical cases that are to be rehabilitated in maximal intercuspation, but in more complex cases they are more demanding in recording the intermaxillary relation.

In addition, another area of scepticism, at least for now, are more extensive cases where a facebow is considered necessary (Amin S et al. 2016), although in some digital environments this is possible with special devices and digital facebows.

Last but not least, increased costs for the purchase of the digital equipment and in some systems for the subscription to the digital systems need to be taken into account, as well as the learning curve and time needed to become familiar with new technologies.

4.6. Intraoral Implant Scan Bodies

In the implant digital workflow, scan bodies are connected to implants or laboratory replicas and are captured by an intraoral scanner (IOS) or a dental laboratory scanner (DLS).

The scanner design software program matches the geometric features of the scan body to a library (Ireland AJ et al. 2008), and by surface matching, positions the digital scan body and in this way the digital implant 3-dimensionally (3D) in the virtual dental arch (Mizumoto RM et al. 2018).

The majority would state that scan bodies are manufactured to high precision and fit onto implants or laboratory replicas absolutely. Nonetheless, original or third-party scan bodies can differ in geometry, shape, and size, as well as machining tolerance. As a consequence, different resultant fit of mating components or surfaces to implants or laboratory replicas may occur (Ma T et al. 1997).

The impact of these parameters on dimensional distortion after an increased torque application, repeated usage, or disinfection procedures is also undefined (Tan JZH et al. 2020).

The majority of scan body systems are manufactured out of metal, polymers, or a combination of materials (Tan JZH et al. 2020).

Polyetheretherketone (PEEK) is a semicrystalline structure with properties that vary depending on the manufacturing temperature.

Thermal processing or annealing of the polymer affects the crystallinity of the structure and thus this has direct influence on the mechanical properties of the material (Jaekel DJ et al. 2011). The yield strength of PEEK increases with increasing crystallinity.

Some PEEK materials are reinforced industrially with hydroxyapatite or carbon fibers. The fiber content and orientation are known to affect the elastic modulus (Schwitalla AD et al. 2016). However, information on the specific PEEK variant used in the fabrication of the different scan body systems is generally unavailable.

Concerning the horizontal machining tolerance fit to implants for polymeric it was significantly larger compared with metal parts

(Braian M et al. 2014). Other researchers have observed a reduction in height with increased torque applied on a scan body system made entirely of PEEK (Tan et al. 2020).

There are various types of intraoral scan bodies and they come in different shapes, sizes, surfaces, and connections over the years (Yilmaz B et al. 2021). However, the geometry of a conventional scan body (SB) or a coded healing abutment (HA) generally does not always concur with the anatomical shape of a natural tooth (Mizumoto RM et al. 2018).

It can also be hard to accurately position a SB on an apically placed implant, especially if there is surrounding thick mucosa. Repeated removal and placement of an HA in these situations may jeopardize the integrity of the peri-implant soft tissues (Mizumoto RM et al. 2018).

Recently introduced combined HA-scan body (CHA-SB) system can encounter these problems because it consists of an HA that contours the peri-implant soft tissue and a SB that is fitted into the screw access hole of the HA.

This assembly enables the acquisition of the implant position and the surrounding soft-tissues simultaneously (Yilmaz B et al. 2021, Yilmaz B et al. 2020).

Coded (HAs) could help digital impressions by eliminating the number of appointments needed in order to deliver definitive restorations. In addition to that, they could minimize the trauma to soft tissues caused by the removal of the HA (Yilmaz B et al. 2020).

As a consequence, potential soft-tissue collapse, which could occur during the removal of a custom HA or interim prosthesis that was used to anatomically shape the peri-implant soft tissues, is minimized HA (Yilmaz B et al. 2020).

IOSs depend on different data acquisition mechanisms. The most common among them are confocal microscopy, optical triangulation, interferometry, active wave front sampling, stereophotogrammetry structured light, laser, and video (Mizumoto RM et al. 2018, Cakmak G et al. 2020).

Other recent studies that also exist on this research field demonstrated that a wide range of factors (Yilmaz B, Rizzo Marques, et al, 2021, Revilla-Leon M et al. 2020) including IOSs, affect the accuracy of a scan (Mizumoto RM et al. 2018, Cakmak G et al. 2020, Mangano FG et al. 2020, Revell G et al. 2022).

However, an accurate scan is only the initial stage of the digital workflow of an implant-supported restoration.

After the scan, the SB mesh is replaced with the corresponding CAD file in the library. It is advised to design the definitive restoration using the CAD library file. The reason is that it is geometrically optimal, whereas the mesh is an approximation of the scanned data to the actual geometry of the object (Donmez MB et al. 2022).

A definitive restoration designed by using the library file would lead to improved marginal adaptation (Mangano F et al. 2020). Therefore, dimensional congruence between the library file and the mesh is essential for an optimal restoration (Schmidt A et al. 2019, Motel C et al. 2020).

This has been searched only once when different IOSs were used (Mangano F et al. 2020). The SBs that were then evaluated did not include an HA.

A recent study has investigated the accuracy of scans of the new CHA-SB system when 4 different IOSs were used (Cakmak G et al. 2021). Another research group compared the accuracy of CHA-SB scans with a regular scan body (Yilmaz B et al. 2021). However, those studies did not focus on the dimensional congruence of this.

A recent literature review on IOS accuracy and practicality showed the longer the scan range, the larger the error with a trueness below 50 μm and between 50 and 250 μm for partial and complete arch digital impression respectively (Kihara H et al. 2020, Mangano F et al. 2017).

Accuracy is composed by trueness and precision (ISO5725–1); trueness defines the conformity of measurements to the actual values, and precision defines the conformity of multiple repeated measurements (Flügge T et al. 2018).

The IOS devices record consecutive single images, which are then aligned and assembled on time by the elaborating software through a best-fit alignment algorithm. Such digital image processing known as "stitching", is enhanced by detailed and stable anatomic reference points, if such exist.

The length and shape of edentulous ridge anatomy, quantity of keratinized fixed mucosa and distance between implant scanbodies (ISBs) can negatively affect stitching performance, lowering IOS accuracy and thus limiting its clinical applicability (Andriessen FS et al. 2014, Rutkunas V et al. 2017, Vandeweghe S et al. 2017, Iturrate M et al. 2019).

The application of a pressure-indicating paste or artificial landmarks on the edentulous area, the positioning of an auxiliary geometry part reproducing dental anatomy in between the ISBs, the use of ISBs with a lateral flag and the splinting of ISBs with dental floss were advocated as possible clinical solutions to provide an easy stickable scanning route for the IOS devices and were tested in vitro (Iturrate M et al. 2019, Kim JE et al. 2017, Huang R et al. 2020, Mizumoto RM et al. 2020).

Recently, a scanbody splinting technique by means of thermoplastic resin was also proposed and tested in vivo (Imburgia M et al. 2020).

In addition to that, Complete-arch implant digital impression with scanbody splinting showed an important improvement of the overall accuracy. This was more clear particularly in reducing linear and angular deviations at the most critical posterior implant positions (Pozzi A et al. 2022).

This means in a more clinical interpretation that intraoral scanner accuracy for implant complete-arch digital impression could be improved by splinting, which is a low cost, easy to assemble method. The use of a splinting 3D printed modular chain would be helpful (Pozzi A et al. 2022).

The geometry of scan bodies varies from a spherical design to a cylindrical design with diverse intermediate forms. The dimension relates to the respective system and to the implant diameter. The height of commercially available scan bodies ranges from 3 to 17 mm (Flügge T et al. 2018).

The requirements of the surface geometry and dimension of the implant scan body for an accurate transfer of the implant position to the virtual model have not been analyzed (Ender A et al. 2013). The literature does not provide information on the precision of capturing the dimensions of the scan bodies in regard to different surface geometries and dimensions, various designs of the implant/abutment interface, and on deviations caused by repositioning of scan bodies in the implant or implant analog (Flügge T et al. 2018, Mizumoto RM et al. 2020).

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REVIEW ARTICLE

WILEY

Characteristics of intraoral scan bodies and their influence on impression accuracy: A systematic review

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Abstract

Objective: The aim of this systematic review was to evaluate the influence of the characteristics of intraoral scan bodies (ISBs) on the accuracy of intraoral scanning.

Materials and Methods: An electronic search was conducted through PubMed (MEDLINE), Scopus and Cochrane Library, up to March 2023. The literature search intended to retrieve all relevant clinical and in vitro studies about the effect that the various properties of ISBs may have on the accuracy (trueness and precision) of intraoral scanning. Only publications in English language were selected with animal studies, case reports, case series, technique presentation articles and expert opinions being excluded.

Results: A total of 28 studies met the inclusion criteria and were included in this systematic review. They were published between 2019 and 2023 and were all in vitro studies. Among the parameters described, the scan body material, position, geometry, height, diameter, and fixation torque were evaluated. The most common materials used for ISBs were polyetheretherketone (PEEK) and titanium alloys. The diameter and position of ISBs seemed to affect the trueness of implant impressions. Subgingival implant position and decreased ISB height affected negatively the trueness of scanning. Geometrical characteristics of ISBs also affect the implant impression accuracy, especially the bevel location and the types of designing modifications.

Conclusions: The characteristics of the currently used ISBs vary widely and the available scientific evidence is not yet conclusive about the optimal design of ISB. The implant impression accuracy achieved by any of the studied parameters is encouraging. Clinical studies are however necessary for more concrete conclusions.

Clinical Significance: ISBs play a vital role in the digital workflow and influence significantly the accuracy and fit of implant restorations. More clinical trials are needed in order to conclude to the optimal characteristics of ISBs which would further enhance the success of the restorations.

KEYWORDS
dental implants, implant impression, impression accuracy, intraoral scanning, scan abutment, scan body

1 | INTRODUCTION

Digital dental technology has rapid evolution in the recent years and its application is expanding in Prosthodontics and Restorative Dentistry, ranging from single implant crowns to long-span and even full-arch implant-supported rehabilitations.[1] Intraoral scanning facilitates the clinical and laboratory procedures and is widely used nowadays.[2]

An accurate impression is the first important step for the fabrication of an implant-supported prosthesis and the most significant parameter for the success of the restoration.[3] Any distortion of the implant impression results in inaccurate transfer of the implant position and consequently to compromised, nonpassive fit of the restoration, which may lead to further prosthetic and biologic complications, such as screw loosening, fractures, peri-implant lesions, or plaque accumulation.[3,4] Passive fit of an implant restoration is a prerequisite for long-term survival and is directly dependent on impression accuracy.[5]

In scientific literature, many advantages have been reported about intraoral scanning. The most important is the ease of recording digitally the clinical situation simultaneously for implants, teeth, and oral mucosa, without the need for trays or other impression materials. This is even more significant in cases when the repeat of the impression might be necessary because in conventional impression techniques this would mean extra material, thus extra costs, time, and probably patient discomfort.[6] Any possible distortions due to material properties can be avoided, such as gaps, strains or incomplete polymerization.[7] The learning curve is easily feasible—even for inexperienced dentists[8]—while the intraoral scanning requires reduced clinical time.[9] Patient comfort is an additional benefit as the gag reflex is minimized.[10]

In the intraoral scanning, scanbodies are attached to the implants, while in the indirect scanning that is performed in the laboratory, where the scan bodies are fixed to implant analogues on a working cast fabricated from a conventional impression.[5] In the indirect technique, scan bodies are fixed on the implant analogues of the working cast and a standard triangulation language (STL) file is obtained by the laboratory scanner. The data captured from scanning allow the transfer of the implant location, depth, and angulation to the design software.[11] The majority of scan bodies are fabricated of metal alloys or polymer materials, like PEEK, or a combination of these two (hybrid ISBs).[5] Other variables that often differ among the various types of ISBs are geometrical characteristics, design, size, and surface characteristics.[5] In general, an ISB consists of three regions: the most apical area which is called the base; the middle region, referred as the body and finally the upper part, which is characterized as the scan region.[11] Compared to laboratory scanbodies, ISBs for intraoral use are smaller in size to fit in the oral cavity and are torqued by hand in the implant. In other types of scanbodies a retaining screw or a press-fit fixation has been introduced.

Accuracy is described as a combination of two factors: precision and trueness.[12] The term "precision" is used to describe the closeness of repetitive measurements, whereas "trueness" demonstrates the closeness of the measured data compared to the actual value.[13] Concerning the accuracy of digital implant impressions, it is generally considered as acceptable for clinical use and comparable to conventional techniques.[13–16] However, there is still controversy about the accuracy of full-arch digital implant impressions which is still considered inadequate or at least highly challenging for clinical use.[17]

The need to understand and further investigate the influence of the various characteristics of intraoral scan bodies on implant impression accuracy was the causal factor behind this systematic review. Therefore, the aim of this systematic review was to investigate a possible correlation between the characteristics of intraoral scan bodies and their effect on implant impression accuracy.

2 | MATERIALS AND METHODS

A systematic approach was prepared according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement.[18] The focused question of the search was in a PIO (population, intervention, outcome) format as follows: "What is the influence of the different characteristics of intraoral scanbodies on impression accuracy?"

2.1 | Information sources and search strategy

A search strategy was developed following a PIO framework including an electronic search in the following databases: PubMed, Scopus, and Cochrane Library. In addition, the contents pages of the following journals were hand searched to identify potentially pertinent articles: *Journal of Esthetic and Restorative Dentistry*, *The Journal of Prosthetic Dentistry*, *International Journal of Prosthodontics*, *Journal of Prosthodontics*, *Quintessence International*, *Journal of Oral Rehabilitation*, *Journal of Dental Research*, *Journal of Prosthodontic Research*, *Clinical Oral Implants Research*, *Journal of Oral Implantology*, *The International Journal of Oral & Maxillofacial Implants*, *Journal of Implant Dentistry*, *International Journal of Implant Dentistry*, and *Clinical Implant Dentistry and Related Research*.

The results were also enhanced with a hand search and the references of all the full-text articles that were selected after title and abstract selection were manually searched. The search was conducted until March 2023 and included articles without any time limit. The search terms were (Intraoral scan OR intraoral scanner OR IOS) AND (Scan body OR scan bodies OR scan post* OR scan flag* OR post flag* OR implant scan body OR implant scan bodies OR digital scan body

OR scanbody OR digital impression post*) AND (impression accuracy OR accuracy OR effect OR influence OR scan accuracy OR trueness OR precision) NOT (Pet scan), combining free text words in single or multiple conjunctions.

2.2 | Eligibility criteria

Regarding the inclusion criteria, clinical studies (randomized clinical trials, prospective, and retrospective studies) and in vitro studies focused on the influence of different characteristics of intraoral scan bodies on the implant impression accuracy were to be included. In addition, only studies using intraoral and not laboratory scanners were selected.

Exclusion criteria were: case report/series, animal studies, literature reviews, expert opinions, studies with insufficient information regarding the characteristics studied, studies based on surveys or chart reviews only, studies not allowing extraction of the required data, no author response in case of inquiry, and finally studies not in English language.

2.3 | Selection of studies

The search process was completed in three stages. During the first stage, two investigators (Aspasia Pachiou and Evangelia Zervou) independently conducted a title screening. In situations where disagreement was not resolved, an additional review author (Panagiotis Tsirogiannis) was consulted. During the second stage, the investigators independently screened and analyzed the abstracts. For any abstracts or titles that were not mutually excluded, a third independent investigator (Panagiotis Tsirogiannis) screened those studies and a majority decision was reached to resolve the disagreement. During the third stage, the full-text articles were assessed for eligibility, and after the exclusion criteria were applied, the remaining articles were included in the definitive list for the qualitative synthesis. The final selected studies were screened by all three reviewers (Aspasia Pachiou, Evangelia Zervou, and Panagiotis Tsirogiannis) and double-checked.

2.4 | Data extraction and method of analysis

The two reviewers (Aspasia Pachiou and Evangelia Zervou) independently extracted the data of the final included studies. The extracted data was double-checked and any arising questions during screening were discussed until an agreement was reached. The following information was extracted from the selected articles: authors' name, study design, year of publication, study design, sample, ISB manufacturer, ISB material, ISB type, ISB shape, type of scanner, scanner manufacturer, partial or full-arch edentulism, jaw (maxilla/mandible), implant manufacturer, implant connection, outcome criteria, and main conclusions.

2.5 | Risk of bias (quality assessment)

The methodological quality of the included articles was assessed using a modified Joanna Briggs Institute (JBI) critical appraisal checklist for

TABLE 1 Modified Joanna Briggs Institute (JBI) critical appraisal checklist for quasi-experimental studies (nonrandomized experimental).

	Yes	No	Unclear	Not applicable
1. Is it clear in the study what is the "cause" and what is the "effect" (i.e., there is no confusion about which variable comes first)?	☐	☐	☐	☐
2. Were the participants included in any comparisons similar?	☐	☐	☐	☐
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	☐	☐	☐	☐
4. Was there a control group?	☐	☐	☐	☐
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?	☐	☐	☐	☐
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	☐	☐	☐	☐
7. Were the outcomes of participants included in any comparisons measured in the same way?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Note: Question 6 concerning the possible "follow up" between the groups in the JBI checklist for quasi-experimental studies was not pertinent to in-vitro studies and was, therefore, eliminated.

quasi-experimental studies (nonrandomized experimental).[19] This consists of nine clearly defined questions. Question 6 concerning the possible "follow up" between the groups in the JBI checklist for quasi-experimental studies was not pertinent to in vitro studies and was, therefore, eliminated (Table 1). Thus, the quality assessment tool was modified, with a total of eight questions to be assessed and scored. Two independent reviewers (Aspasia Pachiou and Evangelia Zervou) assessed the risk of bias and if a disagreement would present, a third reviewer (Panagiotis Tsirogiannis) was consulted. The final score of each article was calculated based on the percentage of positive answers ("yes") and was classified as having a "high" risk of bias [score ≤ 49%], "moderate" risk of bias [score ranging from 50%–69%] and "low" risk of bias [score > 70%].[20]

3 | RESULTS

3.1 | Search and selection

A total of 384 studies were identified in the initial survey in PubMed, Scopus, and Cochrane Library. Following the PRISMA statement, all abstracts were analyzed.[18,21] After excluding duplicates, and applying the inclusion criteria, 33 papers were selected for full-text evaluation with five of them being excluded. The main reason for exclusion was use of a laboratory scanner for the accuracy measurements. The selection process is depicted as a flow chart in Figure 1.

3.2 | Risk of bias

The results of the quality critical appraisal of the included studies are summarized in Tables 2 and 3. Out of the 28 studies included in this systematic review, all of them presented an overall low risk of bias. The only one of the criteria assessed that was not fulfilled in many of the included studies was Question 4 about the existence of a control group or not. This result can be explained because the included studies were in vitro studies.

3.3 | Study characteristics

Table 2 provides information of the studies included. They were all published from 2019 to 2023 and were all in vitro studies.

From the included articles, five[7,16,23,30,34] referred to parameters concerning the material of the ISB. The material is considered a crucial influencing factor of the impression accuracy and the most frequently mentioned in the included studies are polymer, metal alloys or a combination of them.

Seven[7,29–31,35,42,43] studies presented details about the effect of implant location on scanning accuracy. Three studies[28,32,39] focused on the height of ISB.

The geometric characteristics of the ISB and their variances are parameters that attract scientific attention. Nine studies[22,25,26,32,33,35,40,44,45] referred to factors about the

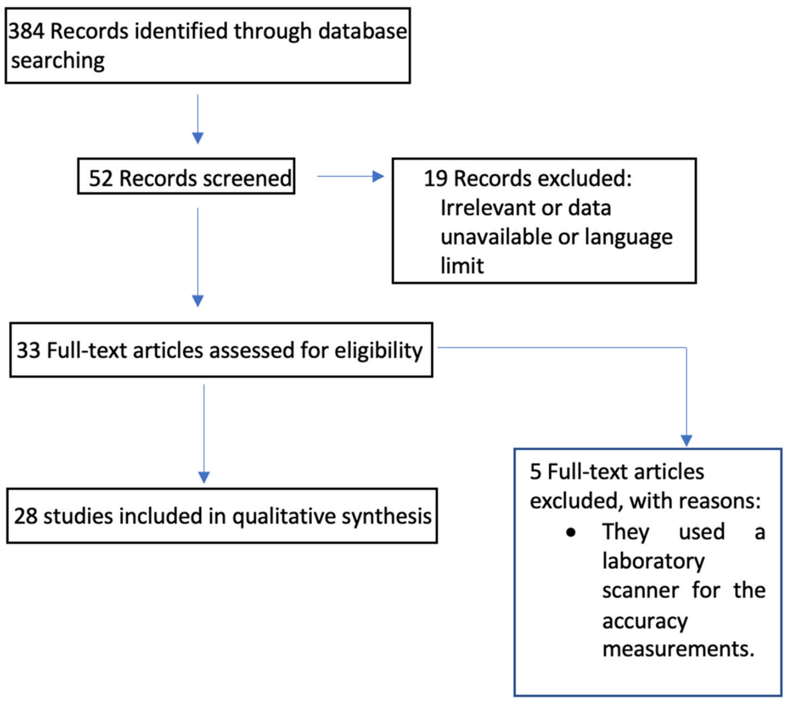

FIGURE 1 Flow chart of included studies.

TABLE 2 Study characteristics of the included studies.

Authors	Year of publication	Study design	Sample (*n*)	Scanbody manufacturer	Material	Scanbody type	Shape	Type of scanner
Alvarez et al.[22]	2022	In vitro	40	4 intraoral: ELOS, MG, Ticare MG, Talladium	PEEK on Ti-base	Direct to the implant	Cylinder with rounded and flat lateral sections	Intraoral
Arcuri et al.[23]	2022	In vitro, randomized	30	Invibio-Biomaterial solutions, Victrex	4 PEEK	Direct to the implant	Cylinder	Intraoral
Gomez-Polo et al.[24]	2022	In vitro	30	Avinent Transepithelial 4.8 scanbody; Avinent	PEEK on Ti-base	Direct to the implant	Cylindric with bevels	Intraoral
Gomez-Polo et al.[25]	2022	In vitro	15	Avinent Transepithelial 4.8 scanbody; Avinent	PEEK on Ti-base	Direct to the implant	Cylindric with bevels	1 laboratory, 1 Intraoral
Lawand et al.[26]	2022	In vitro	15	CARES Mono Scanbody for screw-retained abutments, Ø4.6 mm, PEEK/TAN; Institut Straumann AG	PEEK	Scanbody on multi-unit abutment	Cylinder with rounded and flat lateral sections	Intraoral
Çakmak et al.[27]	2021	In vitro	30	CARES RN Mono, Straumann	PEEK	Direct to the implant	Cylindric with bevels	2 intraoral, 1 industrial, 1 lab
Gomez-Polo et al.[28]	2021	In vitro	20	Elos Accurate Scan Body Brånemark system, IO6A-B; Elos Medtech	PEEK	Direct to the implant	Cylindric with bevels	Intraoral
Kim et al.[29]	2021	In vitro	100	NR	NR	NR	Cylinder	10 Intraoral scanners
Arcuri et al.[30]	2020	In vitro, randomized	18	Invibio-Biomaterial solutions, Victrex & Titan BioStar 5, Siladent, Dr.Böme & Schöps GmbH, Goslar, Germany	6 PEEK, 6 grade 5 Ti, 6 hybrid	Direct to the implant	Cylinder	Intraoral
Çakmak et al.[31]	2020	In vitro	30	CARES Mono Scanbody for screw-retained abutments; Institut Straumann AG	PEEK	Scanbody on multi-unit abutment	Cylindric with bevels	2 intraoral, 1 lab
Huang et al.[32]	2020	In vitro	20	Gialloy Ti-5; SRL Dental GmbH	Ti alloy Grade 5	ISB with and without extensional structure	Cylinder	Intraoral
Mizumoto et al.[3]	2020	In vitro	1152	AF (IO-Flo; Dentsply Sirona), NT (Nt-Trading GmbH & Co KG), DE (DESS-USA), C3D (Core3Dcentres), ZI (Zimmer Biomet Dental)	3 PEEK on Ti base, 2 PEEK	Direct to the implant	Cylinder with rounded and flat lateral sections	Intraoral
Moslemion et al.[33]	2020	In vitro	10	3 types: DESS, NT-Trading, Doowon	DESS: PEEK, NT-Trading: PEEK on Ti-base, Doowon: Ti alloy	Direct to the implant	Cylinder with rounded and flat lateral sections	Intraoral

(Continues)

TABLE 2 (Continued)

Authors	Year of publication	Study design	Sample (*n*)	Scanbody manufacturer	Material	Scanbody type	Shape	Type of scanner
Tan et al.[5]	2020	In vitro	40	4 intraoral (I): Medentika L-Series (MS), Straumann CARES Mono (SM), Core 3D (CO), Straumann RC (SS);	PEEK on Ti-base	Direct to the implant	5 Cylindric with bevels, 3 cylinder	Coordinate measuring machine
Arcuri et al.[34]	2019	In vitro	18	Invibio-Biomaterial solutions, Victrex & Titan BioStar 5, Siladent, Dr.Böme & Schöps GmbH, Goslar, Germany	6 PEEK, 6 grade 5 Ti, 6 hybrid	Direct to the implant	Cylinder	Intraoral
Mizumoto et al.[35]	2019	In vitro	56	DE (Dess-USA Dental Smart Solutions, Granite Bay, CA)	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	Intraoral
Sicilia et al.[36]	2023	In vitro	15	CARES scanbody (Straumann)	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	Intraoral
Althubaitiy et al.[37]	2022	In vitro	140	CARES scanbody (Straumann), Scanbodies REF (Medentica)	PEEK or Ti alloy	Direct to the implant	Cylinder	Intraoral
Kato et al.[38]	2022	In vitro	20	CARES scanbody (Straumann)	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	Intraoral
Sequeira et al.[39]	2022	In vitro	60	CARES scanbody (Straumann)	PEEK	Direct to the implant	Cylindric with bevels	Intraoral
Lee et al.[7]	2021	In vitro	180	Myfit, Daegu, South Korea	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	1 Desktop, 3 Intraoral
Revilla-Leon et al.[40]	2021	In vitro	30	SB-1 (Elos Accurate Nobel Biocare), SB-2 (NT Digital Implant Technology), SB-3 (Dynamic Abutment)	2 PEEK on a Ti-base/PEEK 2 pieces connected with magnet	2 direct to the implant, 1 two-piece – dynamic abutment	Cylindric with bevels	Intraoral
Shi et al.[41]	2021	In vitro	60	ScanPost S, Dentsply Sirona	Ti alloy	Direct to the implant	Cylindric with bevels	Intraoral
Thanasrisuebwong et al.[42]	2021	In vitro	45	CARES scanbody (Straumann)	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	2 Intraoral
Zhang et al.[43]	2021	In vitro	40	Scan body, Nobel Biocare	PEEK, Ti alloy	Direct to the implant	Cylindric with bevels	Intraoral
Schmidt et al.[16]	2020	In vitro	10	3D Guide, H-Series, NT Trading; cara H10/20, Kulzer; H1410, Medentika	2 PEEK on a Ti-base/1 PEEK	Direct to the implant	Cylindric with bevels	Intraoral
Park et al.[44]	2020	In vitro	49	AnyOne Scan abutment, MegaGen, Korea	PEEK	Direct to the implant	Cylinder with rounded and flat lateral sections	Intraoral
Motel et al.[45]	2019	In vitro	60	ELOS A/S, nt-trading GmbH, and TEAMZIEREIS GmbH	PEEK, Ti alloy	Direct to the implant	Cylinder with rounded and flat lateral sections	Intraoral

TABLE 2 (Continued)

Authors	Scanner manufacturer	Partial or Full-arch	Jaw	Implant manufacturer	Connection	Outcome criteria	Main conclusions
Alvarez et al.[22]	Trios, 3Shape/CEREC Omnicam	Full-arch, edentulous	Mandible	Ticare/Mozo-Grau	Internal	ISB geometry	The more pronounced the surface change is, like in sharp edges, the bigger the errors registered are
Arcuri et al.[23]	Trios 3, 3Shape	Full-arch, edentulous	Mandible	Nobel Biocare	Internal hexagon	ISB material	The ISB wear negatively influenced the accuracy of IOS. ISB base wear could be harmful for the seating of ISBs on angulated implants
Gomez-Polo et al.[24]	TRIOS3, 3Shape	Full-arch, edentulous	Maxilla	Avinent Implant System, Spain	NR	ISB position	ISB angulation and inter-implant distance affected impression accuracy. Parallel implants resulted in better accuracy
Gomez-Polo et al.[25]	7Series Desktop, DentalWings; TRIOS3, 3Shape	Full-arch, edentulous	Maxilla	Avinent Implant System, Spain	NR	ISB geometry	The scan body geometry bevel location and implant angulation and position influenced the accuracy of the IOS. The ISB geometry bevel feature is suggested to be in a lingual orientation
Lawand et al.[26]	Trios 3, 3Shape	Full-arch	Maxilla	Straumann	Internal	ISB geometry	Subtractive modification on ISBs enhanced scanning trueness. Additive modification on ISBs eliminated scanning trueness
Çakmak et al.[27]	Virtuo Vivo, Dental Wings/Trios 3, 3Shape/Cares 7 Series, Dental Wings/ATOS Core, GOM	Full-arch, edentulous	Mandible	Straumann – tissue level	Internal	ISB location	ISB location influenced only the trueness
Gomez-Polo et al.[28]	Trios 3, 3Shape	Full-arch, edentulous	Maxilla	Zimmer Biomet	Internal	ISB height	The lowest clinical ISB height tested had the lowest accuracy in both parallel and angulated implants
Kim et al.[29]	CEREC Omnicam, CEREC Primescan, CS 3600, DWIO, i500, iTero Element, PlanScan, Trios 2, Trios 3, and True Definition	Full-arch, dentate	Mandible	NR	NR	ISB position	The position of simulated cylindrical ISBs influences the magnitude and direction of deviations on trueness
Arcuri et al.[30]	Trios 3, 3Shape	Full-arch, edentulous	Maxilla	NR	Internal hexagon	ISB material, position and operator	The ISB material significantly influenced the IOS complete-arch digital impression. PEEK resulted in the best outcomes on both linear and angular measurements, followed by titanium. Implant angulation significantly influenced the linear deviations and the implant position the angular deviations
Çakmak et al.[31]	Virtuo Vivo, Dental Wings/Trios 3, 3Shape/LBS; Cares 7 SERIES	Full-arch, edentulous	Maxilla	Straumann—bone level	Internal	ISB position	Position of the ISB affected the distance deviation (trueness)
Huang et al.[32]	Trios 3, 3Shape	Full-arch, edentulous	Mandible	Straumann—bone level, RC	Internal	ISB geometry, scan body height	The design of the extensional structure on the ISB could significantly improve scanning accuracy

Mizumoto et al.[3]	Trios, 3Shape	Full-arch, edentulous	Maxilla	Zimmer Biomet	Internal hexagon	ISB geometry	Splinting ISBs with floss led to significantly more deviation. ISBs design influences scan accuracy
Moslemion et al.[33]	Trios Cart, 3Shape	Full-arch, edentulous	Maxilla	NobelReplace, Branemark Nobel Biocare System	Internal trilobe, external hexagon	ISB geometry, ISB type	ISB geometry, implant connection and angulation could influence the accuracy of digital impressions in all-on-four restorations
Tan et al.[5]		Full-arch, edentulous	Master cast	Straumann—bone level, RC	Internal	ISB torque	ISBs significantly influence all 3D accuracy. Torque magnitude significantly affected the 3D positional accuracy of some ISBs
Arcuri et al.[34]	Trios 3, 3Shape	Full-arch, edentulous	Maxilla	NR	Internal hexagon	ISB material	The difference between polymer materials used in ISBs can be related to scanning differences.
Mizumoto et al.[35]	Trios, 3Shape	Full-arch, edentulous	Maxilla	Zimmer Biomet	Internal hexagon	ISB position	Position of the implant had a significant effect on trueness
Sicilia et al.[36]	Trios 4, 3Shape	Partially edentulous	Maxilla	Straumann	Internal	ISB height, ISB inclination	Implant inclination of 18 degrees did not significantly influence scanning accuracy, neither did supramucosal height of ISB
Althubaitiy et al.[37]	Trios 3, 3Shape	Partial	Mandible	Straumann	Internal	ISB diameter	Varying the ISB diameter affected the scanning accuracy.
Kato et al.[38]	Trios 3, 3Shape	Partial	Master cast	Straumann	Internal	ISB wear, ISB multiple use	Autoclave sterilization results in some ISB deformation Connection/disconnection itself may not affect significantly ISB deformation
Sequeira et al.[39]	CS 3600; Caresteam Dental	Partially edentulous	Maxilla	Straumann, Bone level	Internal	ISB height	The trueness and precision are highest if the implant is placed at 0 mm depth with complete visibility of the ISB and decreases in case of subgingival placement
Lee et al.[7]	Identica T500; Medit Inc/CS3600, Carestream Dental/ TRIOS3, 3shape/ Primescan, Sirona Dental Systems	Partial	Mandible	IS-III active, Neobiotech Co., Seoul, Korea	Internal	ISB material, position	The titanium ISB resulted in better trueness compared to the PEEK ISB. If the terminal implant was mesially tilted, it resulted in better trueness
Revilla-Leon et al.[40]	iTero Element	Partially edentulous	Maxilla	Nobel Biocare	Internal	ISB design	The selection of an ISB may impact the accuracy of an intraoral digital scan
Shi et al.[41]	Trios 3, 3Shape	Partially edentulous	Mandible	Straumann	Internal	ISB torque	The tightening torque of ISBs influences vertical deviations
Thanasrisuebwong et al.[42]	Trios 3, 3Shape/CEREC Omnicam, Dentsply Sirona	Partially edentulous	Maxilla	Straumann	Internal	ISB position, inter-implant distance	The deviations of trueness and precision increased along with the increasing distance between two implants
Zhang et al.[43]	Trios 3, 3Shape	Partially edentulous	Mandible	Nobel Biocare	Internal	ISB position	Angulation resulted in better accuracy of digital impressions in partially edentulous arches compared with parallel implants. Non-free-end partial edentulism showed improved accuracy
Schmidt et al.[16]	Trios 3, 3Shape	Partial	Maxilla	Zimmer Biomet	Internal hexagon	ISB material	Titanium-based ISBs did not show better results. ISBs have an influence on the transfer accuracy

Park et al.[44]	CS3600, Carestream, USA	Partial	Maxilla	MegaGen, Korea	Internal	ISB geometry	Deficiencies in the scanned images of an ISB can decrease the accuracy of the implant in case the defect is extensive
Motel et al.[45]	Trios 3, 3Shape	Partial	Master cast	NobelReplace Select, Nobelbiocare	Internal conical	ISB geometry	The quality of digital impressions is impacted by the geometry of the ISB

Abbreviations: IOS, intraoral scanner; ISB, intraoral scan bodies; NR, not referred; PEEK, polyetheretherketone.

geometry and the design of ISBs. The variances in shape and design among the different manufacturers indicates the significance for optimizing accuracy. The most common design of ISB was cylindrical with various modifications in bevels and shapes.

Other characteristics possibly affecting the scanning accuracy that were mentioned in the included studies were the diameter and the fixing torque of the ISBs.

The data acquired referred in partially edentulous areas in 12 studies, whereas in 15 the data were obtained from edentulous jaws. This indicates the more demanding clinical procedure in full-arch edentulous cases.

None of the included studies that mentioned relevant data used implants with external connection. Maxilla was more frequent (59.3%) than the mandible and Trios3 (3Shape Co.) was also the most frequently used intraoral scanner in the selected studies.

ISBs are available in two types concerning the impression level; they can be directly connected into the implant or connected on a multi-unit transmucosal abutment. The majority (85%) of the included studies used ISBs directly on implant level.

The results of the included studies were diverting both concerning the ISBs characteristics and the main outcomes.

4 | DISCUSSION

This systematic review investigated the effect of the different characteristics of ISBs on the accuracy of implant impressions. Among the parameters described were the scan body material, position, geometry, height, diameter and fixing torque.

The ISB material is a crucial factor to be taken into consideration. The type of fabrication material and its texture is known to influence the number of stitching points attained.[11] The scan region is often manufactured by the same material as the main body of the ISB but they frequently differ in their shape or texture. Different materials are used for the body of the ISB among which are polymers like polyetheretherketone (PEEK), titanium alloy, aluminum alloy, or resin materials.[11] PEEK is a material commonly used for ISB fabrication and is a high-performance thermoplastic polymer serving as an alternative to metal alloys for dental implants and prostheses.[46] It presents excellent physical and mechanical properties, biocompatibility, chemical stability and low weight.[47] It is frequently used in ISBs because it is easily scannable compared to other materials and its surface does not cause reflections which could cause difficulties in intraoral scanning.[44] However, the selection of polymer materials is recently being questioned, because they may get distorted or worn as a consequence of repeated sterilization, tightening forces or even bite forces.[48] This is the reason why PEEK ISBs are suggested to be used for single use.

Any manufacturing distortions of these materials could influence the scanning accuracy.[11] Ti-alloy components are also usually selected for the fabrication of ISB. It was shown that the ISB material significantly influences the implant impression.[7,16,30,34] However, there is inconsistency between the different studies about which is the preferable material. In a study, PEEK showed optimal results on both linear

TABLE 3 Quality assessment of the included studies according to the modified Joanna Briggs Institute (JBI) critical appraisal checklist for quasi-experimental studies (nonrandomized experimental).

	Question 1	Question 2	Question 3	Question 4	Question 5	Question 7	Question 8	Question 9	Include/exclude	Score (%)	Risk of bias
Arcuri et al.[34]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Arcuri et al.[30]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Çakmak et al.[31]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Çakmak et al.[31]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Gomez-Polo et al.[25]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Gomez-Polo et al.[25]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Gomez-Polo et al.[25]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Huang et al.[32]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Kim et al.[29]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Mizumoto et al.[3]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Mizumoto et al.[35]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Tan et al.[5]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Arcuri et al.[23]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Lawand et al.[26]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Lee et al.[7]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Motel et al.[45]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Revilla-Leon et al.[40]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Schmidt et al.[16]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Park et al.[44]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Althubaitiy et al.[37]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Sequeira et al.[39]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Moslemion et al.[33]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Alvarez et al.[22]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Kato et al.[38]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Zhang et al.[43]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include	87.50	Low
Shi et al.[41]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low
Thanasrisuebwong et al.[42]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include	100	Low

and angular measurements,[30] however this was in disagreement with another study[7] which presented better trueness of the Ti-ISB compared to PEEK ISBs. Another study[16] concluded that there is no superior material to be suggested for ISB.

An additional factor to be considered is the appropriate maintenance of the ISBs, since the wear of the material affected negatively the impression accuracy and prevents their proper fit, especially on angulated implants.[7] Wear may be caused by repeated clinical use and sterilization procedures; therefore, the manufacturers' instructions should be followed carefully.[49] Nonetheless, multiple connections of the ISBs to the implants do not have any significant influence or cause deformation.[38]

The location of the ISB is another significant parameter that is encountered in a number of relevant studies. The location of the implant and consequently of the ISB influences the scanning trueness in distance deviations.[27,31] This is in agreement with other studies[29,35] supporting these findings. Other researchers found that implant position seems to affect the angular deviations.[30] The position of the implant within the dental arch is also crucial; if the most distal implant was tilted mesially, this would result in better trueness.[7] The extension of edentulism is another important factor, since it was demonstrated that free-end partial edentulism (Kennedy I, II) results in higher deviations compared to Kennedy III, IV.[43] This is can be possibly attributed to the stitching process concept, because the inter-implant space is limited and, therefore, stitching is easier.[11,24]

The inclination of dental implants is a crucial parameter affecting implant impression accuracy both for conventional[7] and for digital techniques. For digital impression methods however, there is still controversy about the influence of implant angulation.[7] Some studies demonstrated that inclined implants resulted in superior impression accuracy,[7,43] others supported that the results were better if implants were placed parallel[24,50] and in some other experiments the results showed no difference.[14] Nonetheless, the angle deviation seems to be independent of the distance between the dental implants and their correlation does not influence impression accuracy.[42]

The geometrical characteristics have been shown to have a significant impact on the quality of a digitized surface reconstruction.[11,33,40,45,51] The scan area of the ISBs usually consists of one or more scannable regions designed to optimize scanning.[52] In the majority of ISBs one side is flat in an asymmetrical design, easier detectable by the computer-assisted design (CAD) software.[11] Extensional structures on the ISB material have been suggested for ISBs shape, since they have the potential to increase impression accuracy by providing more reference points for the stitching procedure.[32] An interesting finding is that the scanning trueness of ISBs was improved by subtractive modifications in design, whereas it was diminished by additive alterations.[26] In addition, it was shown that sharp shapes and edgy surface moderations of the ISB may lead to impression inaccuracies.[22]

The ISB geometry bevel location also affects the scanning accuracy and the lingual placement of the bevels is proposed for optimization of the results.[25] These findings are in agreement with previous studies[53] which demonstrated that the overall design, which is called as the primary structure, is easier to digitize than the minimal features found on secondary and tertiary structures. Surfaces, which are more challenging to scan, include steep, sharp, deep, undercuts, angled or overcrowded surfaces that finally result in less precise point clouds.[54,55] When a deficiency in the scanned images of an ISB is significant, this can severely reduce the precision of implant position in the CAD software. Consequently, it is suggested to consider a less than 10% surface defect of the ISB in order to minimize registration errors when identifying the implant position.[44]

The surface characteristics of the ISB design are important, as well. This is particularly challenging in the intraoral cavity, where saliva frequently creates reflective surfaces and the different anatomical tissues have a range of textures. Surfaces that are dull, smooth, and gloomy are simpler to capture than those that are shiny, translucent or bumpy.[56,57] Recent studies, however, described that the optimal surface for an ISB is still a controversial issue and is also affected by the type of intraoral scanner as well.[48]

Another characteristic that was analyzed in the included studies was the ISB dimension. The height is an influencing factor for scanning accuracy. The optimal situation is when the implant is placed at a tissue level and, thus, the total height of the ISB is visible.[39] This means that scanning accuracy is reduced in case of subgingival implant location.[39] In addition, the reduced clinical height of the ISB affects negatively accuracy, either in parallel or angulated implants.[28] The results of another study however, are in contradiction to this statement, supporting that shorter ISBs may be easier to scan in edentulous jaws.[11] Recent studies suggested that the optimal height is dependent on the neighboring tissues, which means that shorter ISBs would be preferable in cases of adjacent teeth, but they should be taller next to edentulous regions.[48] Variances in ISB diameter may also cause alterations in scanning procedures; narrow-diameter PEEK ISBs were shown to have the most accurate results.[37] The occlusal surface is a critical parameter, since if it is diminished, this could cause difficulties in accurate matching with the software.[48]

Last but not least, the fixing torque is another aspect influencing the three-dimensional transfer of the implant position.[5] There are two main types of retention of ISBs: screw-retained or with friction fit (snap-on). It is suggested that snap-on ISBs should be avoided, if possible, since it is more difficult for the clinician to realize any possible misengagement.[48] Furthermore, the process of repeated snap-ons would result in material wear and, thus, less stability and is one the main reasons some manufacturers suggest that ISBs should be used only once.[48] Nonetheless, there is no agreement about the optimal torque magnitude among the studies. Some studies proposed a torque of no more than 10 Ncm to be the most appropriate[58] in order to avoid any displacement which might occur at higher torque values. However, other studies suggest that 30 Ncm should be the optimal but this referred to metallic ISBs.[41]

Additional clinical studies are needed for the detailed evaluation of ISBs. That is one of the main limitations of this systematic review, although results from the in-vitro studies seem promising. Another limitation is that the methods used in the included studies were varying and thus it could be only partially feasible to make comparisons between them. The heterogeneity of these methods was a further limitation and the main causal factor why a meta-analysis was not feasible.

5 | CONCLUSIONS

Within the limitations of this systematic review, it is concluded that although ISBs and their characteristics vary widely, they significantly influence implant impression accuracy. The majority of studies agree that, among the various characteristics, the material, the geometrical design, the surface and the position and inclination of the ISBs affect significantly impression accuracy. The results about the implant impression accuracy achieved are encouraging, however, clinical studies are necessary for safer conclusions, since the available scientific evidence is not yet conclusive about the optimal ISB.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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B.2. Abstract

Objective: The aim of this systematic review was to evaluate the influence of the characteristics of intraoral scan bodies (ISBs) on the accuracy of intraoral scanning.

Materials and methods: An electronic search was conducted through PubMed (MEDLINE), Scopus and Cochrane Library, up to March 2023. The literature search intended to retrieve all relevant clinical and in vitro studies about the effect that the various properties of ISBs may have on the accuracy (trueness and precision) of intraoral scanning. Only publications in English language were selected with animal studies, case reports, case series, technique presentation articles and expert opinions being excluded.

Results: A total of 28 studies met the inclusion criteria and were included in this systematic review. They were published between 2019 and 2023 and were all in vitro studies. Among the parameters described, the scan body material, position, geometry, height, diameter, and fixation torque were evaluated. The most common materials used for ISBs were polyetheretherketone (PEEK) and titanium alloys. The diameter and position of ISBs seemed to affect the trueness of implant impressions. Subgingival implant position and decreased ISB height affected negatively the trueness of scanning. Geometrical characteristics of ISBs also affect the implant impression accuracy, especially the bevel location and the types of designing modifications.

Conclusions: The characteristics of the currently used ISBs vary widely and the available scientific evidence is not yet conclusive about the optimal design of ISB. The implant impression accuracy achieved by any of the studied parameters is encouraging. Clinical studies are however necessary for more concrete conclusions.

Clinical significance: ISBs play a vital role in the digital workflow and influence significantly the accuracy and fit of implant restorations. More clinical trials are needed in order to conclude to the optimal characteristics of ISBs which would further enhance the success of the restorations.

Keywords: dental implants; implant impression; impression accuracy; intraoral scanning; scan abutment; scan body.

B.3. Abstract in Greek language – Περίληψη

Σκοπός: Σκοπός της παρούσας συστηματικής ανασκόπησης είναι να αξιολογήσει την επίδραση των διαφόρων χαρακτηριστικών των αξόνων ενδοστοματικής σάρωσης (ΑΕΣ) στην αποτυπωτική ακρίβεια της ψηφιακής ενδοστοματικής σάρωσης.

Υλικά και Μέθοδος: Πραγματοποιήθηκε ηλεκτρονική αναζήτηση στις επιστημονικές βάσεις δεδομένων PubMed (MEDLINE), Scopus και Cochrane Library, μέχρι και το Μάρτιο 2023. Η βιβλιογραφική αναζήτηση στόχευε να εντοπίσει όλες τις σχετικές κλινικές και εργαστηριακές (in vitro) μελέτες που διερευνούν τα αποτελέσματα και την επιρροή που έχουν οι διάφορες ιδιότητες των ΑΕΣ στην ακρίβεια (accuracy=trueness+precision) της ενδοστοματικής σάρωσης. Συμπεριλήφθηκαν μόνο δημοσιεύσεις στην αγγλική γλώσσα και εξαιρέθηκαν μελέτες με πειραματόζωα, κλινικές αναφορές, σειρές κλινικών περιστατικών, παρουσίαση τεχνικών και γνώμες ειδικών (expert opinions).

Αποτελέσματα: Συνολικά 28 μελέτες ικανοποιούσαν τα κριτήρια επιλεξιμότητας (inclusion criteria) και συμπεριλήφθηκαν στην παρούσα συστηματική ανασκόπηση. Όλες δημοσιεύθηκαν μεταξύ 2019 και 2023 και ήταν όλες εργαστηριακές μελέτες. Μεταξύ των παραμέτρων που μελετήθηκαν ήταν το υλικό, η θέση, η γεωμετρία, το ύψος, η διάμετρος και η ροπή τοποθέτησης των ΑΕΣ. Τα πιο συνήθη υλικά που χρησιμοποιούνται είναι η πολυαιθεραιθερκετόνη (PEEK) και τα κράματα τιτανίου. Η διάμετρος και η θέση των ΑΕΣ φαίνεται, επίσης, να επηρεάζει την πιστότητα της ενδοστοματικής σάρωσης. Η θέση του εμφυτεύματος κάτω από το επίπεδο των μαλακών ιστών και το ελαττωμένο ύψος του ΑΕΣ έχει αρνητική επιρροή στην αποτυπωτική ακρίβεια. Τα γεωμετρικά χαρακτηριστικά είναι ένας επιπλέον σημαντικός παράγοντας, ειδικά η τοποθεσία των επικλινών επιπέδων και τα είδη τροποποιήσεων του σχεδιασμού τους.

Συμπεράσματα: Τα χαρακτηριστικά των παρόντων ΑΕΣ ποικίλλουν σημαντικά και τα διαθέσιμα επιστημονικά δεδομένα δεν καταλήγουν ακόμη σε σαφή συμπεράσματα για τον ιδανικό σχεδιασμό και τις ιδιότητές τους. Η αποτυπωτική ακρίβεια των εμφυτευμάτων που επιτυγχάνεται, όμως, από οποιαδήποτε διαφορετική παράμετρο είναι ιδιαίτερα ενθαρρυντική. Ωστόσο, απαιτούνται και κλινικές μελέτες για πιο ασφαλή συμπεράσματα.

Κλινική σημασία: Οι ΑΕΣ διαδραματίζουν πολύτιμο ρόλο στην ψηφιακή ροή εργασίας και επηρεάζουν σημαντικά την ακρίβεια και εφαρμογή των επιεμφυτευματικών αποκαταστάσεων. Περισσότερες κλινικές μελέτες απαιτούνται, ώστε να υπάρξουν καταληκτικές κατευθυντήριες οδηγίες για τα ιδανικά χαρακτηριστικά των ΑΕΣ που να ευνοούν περαιτέρω την επιτυχία των αποκαταστάσεων.

Λέξεις-κλειδιά: οδοντικά εμφυτεύματα, αποτύπωση εμφυτευμάτων, ακρίβεια αποτύπωσης, ενδοστοματική σάρωση, ψηφιακή ροή εργασίας, άξονες ενδοστοματικής σάρωσης.

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