



Accuracy Assessment of Intraoral Scanners for Complete-Arch Implant Impressions: A Standardized Bench Protocol

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Abstract

Intraoral scanners are widely used to record the positions of dental implants, yet their accuracy over a complete edentulous arch remains contested. Published bench studies reach different conclusions about the same devices, and much of the disagreement can be traced to method: how the reference model was built and measured, how scans were aligned to the reference, which quantity was reported, and whether trueness and precision were kept apart. This article proposes a standardized bench protocol intended to make such studies comparable. It defines the terms according to the international standards on measurement accuracy, specifies a reference model with scan bodies and a reference measurement of stated uncertainty, fixes the environmental and operator conditions, prescribes a repetition scheme, and sets out an analysis based on scan body positions instead of global surface fitting. Linear, angular and three-dimensional deviations between implants are the primary outputs, with trueness and precision reported separately. A reporting checklist accompanies the procedure. The protocol is a proposal derived from the standards and the existing literature. It has not been applied to any scanner here, and no performance figures are offered. The article also states what a bench protocol cannot show about behaviour in the mouth.

Keywords: *Intraoral scanner, Digital implant impression, Trueness, Precision, Complete-arch, Scan body*

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1. Introduction

A fixed prosthesis supported by several implants is rigid, and the implants beneath it have none of the physiological mobility of teeth. Errors in the recorded implant positions are therefore transferred to the framework as misfit. How much misfit is tolerable has never been defined with confidence, and the aim in practice is to keep it as small as the method allows (Sahin and Cehreli, 2001). The conventional method, a splinted open-tray impression poured in stone, has known sources of error but a long record of use.

Intraoral scanners record implant positions optically by capturing scan bodies attached to the implants (van der Meer et al., 2012). For single implants and short spans their accuracy is generally accepted. For

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the complete edentulous arch the picture is mixed. An early clinical pilot study concluded that the scanner tested was not accurate enough for multiple implants in the edentulous mandible (Andriessen et al., 2014), while later laboratory comparisons found digital impressions comparable to conventional ones under their test conditions (Papaspolidakos et al., 2016). A systematic review of impression techniques for implant prostheses noted that heterogeneity of methods prevented firm conclusions for complete-arch cases (Flügge et al., 2018).

This article proposes a standardized bench protocol for assessing complete-arch implant scans. Its purpose is to make results from different laboratories comparable. The protocol has not been applied here, and no scanner is evaluated.

2. Background

Two matters need to be settled before a protocol can be written: what is meant by accuracy, and why existing studies disagree.

2.1. Terms and standards

ISO 5725-1 defines accuracy as the combination of trueness and precision. Trueness is the closeness of agreement between the average of a large series of results and an accepted reference value. Precision is the closeness of agreement between independent results obtained under stipulated conditions (ISO, 1994). A scanner can be precise and untrue, returning the same wrong arch width every time, and the two properties have different clinical meanings. ISO 12836 sets test methods for laboratory digitizing devices (ISO, 2015), and ISO 20896-1 extends accuracy testing to intraoral devices (ISO, 2019). Neither standard is written for implant scan bodies on an edentulous arch, which is the gap this protocol addresses.

2.2. Why published results differ

Figure 1 groups the sources of deviation in a bench study under four headings. Device factors are the object of study. The other three are conditions that must be controlled or reported, and each has been shown to matter.

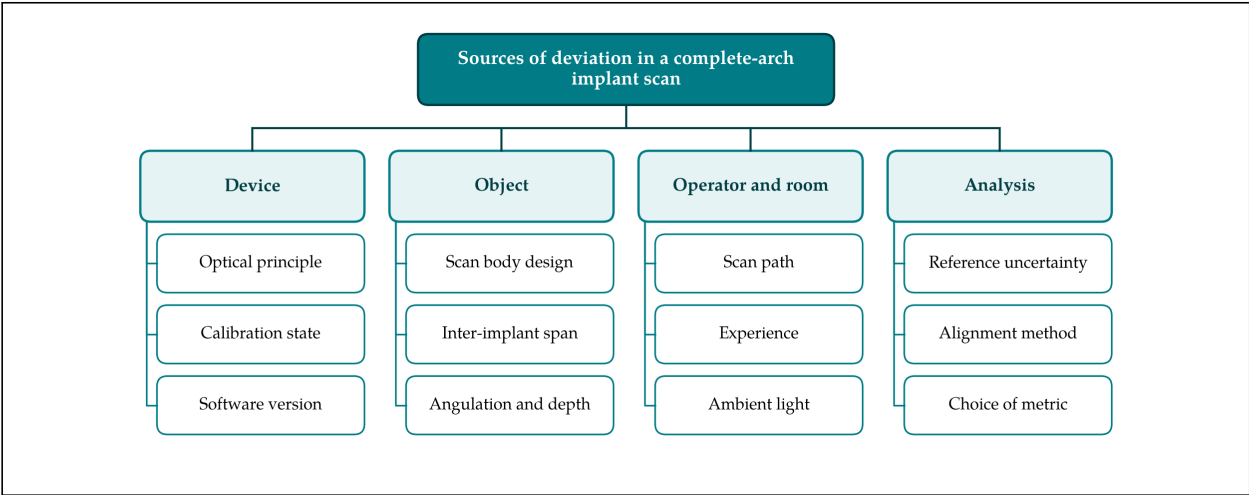


Figure 1: Sources of deviation in a bench assessment of complete-arch implant scans, grouped under four headings

Object factors include the distance between implants, their angulation and depth, and the geometry and material of the scan bodies (Giménez et al., 2014). Precision falls as the distance between scan bodies increases, because errors accumulate as successive images are stitched across featureless tissue (Flügge et al., 2016). Operator and room factors include the scan path (Müller et al., 2016), experience, and ambient lighting, which altered the accuracy of several scanners in a controlled comparison (Revilla-León et al., 2020).

Analysis factors are the least visible and may be the most influential. Many studies superimpose the test scan on the reference by a global best-fit algorithm of the iterative closest point type (Besl and McKay, 1992) and report the mean surface distance. Best-fit alignment distributes error across the arch and can understate a systematic distortion at its ends, a problem analysed for sequential dental scans by O'Toole *et al.* (2019). Surface distance is also a poor proxy for what the prosthesis experiences, which is the relative position and axis of each implant. Comparative studies that report inter-implant distances and angles are easier to interpret (Vandeweghe *et al.*, 2017).

3. The Proposed Protocol

The protocol consists of six stages. Table 1 lists what each stage specifies and what must be reported. The stages are described below in the order in which they are carried out.

Table 1: Stages of the proposed bench protocol, the specification at each stage and the items to be reported		
Stage	Specification	Items to report
1. Reference model	Rigid edentulous arch with four to six implant analogues and scan bodies	Material, implant layout, scan body make and batch
2. Reference measurement	Coordinate measuring machine or industrial scanner with traceable calibration	Instrument, stated uncertainty, date
3. Test conditions	Fixed temperature, lighting, calibration and software	Room conditions, versions, calibration record
4. Scanning	Predefined path, trained operators, fixed number of repeats	Path, operators, repeats, discarded scans
5. Registration	Scan body positions extracted by library fitting; alignment on one implant	Software, fitting residuals, alignment rule
6. Metrics and statistics	Linear, angular and three-dimensional deviations; trueness and precision separate	Full distributions, analysis plan

3.1. Stage 1: Reference model

The model represents an edentulous arch of realistic form with implant analogues placed in a distribution typical of a fixed complete-arch prosthesis, including at least one tilted posterior implant. It is made from a dimensionally stable material, and the analogues are fixed so that they cannot move between sessions. The surface between implants should offer as little texture as an edentulous ridge does, since a richly textured model flatters the stitching algorithm. Scan bodies of a single make and batch are tightened to the manufacturer's torque and left in place for the whole study, because reseating introduces its own error.

3.2. Stage 2: Reference measurement

The reference positions are measured with an instrument at least several times more accurate than the devices under test, such as a tactile coordinate measuring machine or an industrial optical scanner with traceable calibration. The uncertainty of the reference is stated in accordance with the Guide to the Expression of Uncertainty in Measurement (JCGM, 2008). A trueness result smaller than the reference uncertainty has no meaning, and this simple point is often overlooked. The reference measurement is repeated at the end of the study to confirm that the model has not changed.

3.3. Stage 3: Test conditions

Room temperature and lighting are fixed and recorded. Each scanner is calibrated according to its manufacturer's instructions before each session, and hardware and software versions are noted, since updates can change performance. The model is mounted in a phantom head or behind a mask that

restricts access to the dimensions of a mouth opening. A model scanned freely on a bench allows scanner movements that are impossible in a patient.

3.4. Stage 4: Scanning

A scan path is defined in advance for each device, following the manufacturer's recommendation where one exists, and is described in enough detail to be repeated. Operators are trained to a stated criterion before data collection. The number of repetitions per scanner and operator is fixed beforehand, and the order of devices is randomised to spread any drift in conditions. Scans that the software rejects or that the operator restarts are counted and reported, since the frequency of failed scans is itself useful information. Files are exported in an open format without smoothing or hole filling.

3.5. Stage 5: Registration

The position and axis of each scan body are obtained by fitting its library geometry to the scanned surface, and the residual of each fit is recorded. Test and reference data sets are then brought into a common coordinate system by aligning on one terminal scan body only, so that deviation accumulates visibly along the arch as it would beneath a rigid framework. Global best-fit superimposition of the whole surface may be reported as a secondary analysis for comparison with earlier work, on the method described for complete-arch scans by [Ender and Mehl \(2013\)](#). It should not be the primary one.

3.6. Stage 6: Metrics and statistics

Three quantities are computed for every implant relative to the reference implant: the deviation in inter-implant distance, the angular deviation of the implant axis, and the three-dimensional displacement of the platform centre. Trueness is the difference between the mean of repeated scans and the reference value. Precision is the dispersion of repeated scans about their own mean, reported both within and between operators. Signed deviations are retained alongside absolute values, since a consistent contraction or expansion of the arch is hidden when only magnitudes are averaged. Deviation data are often skewed, so medians and ranges are given with means, and the analysis plan is fixed before scanning begins.

4. Reporting

A protocol is useful only if studies that follow it can be recognised and checked. Reports should give every item in the right-hand column of Table 1, make the reference coordinates and, where licences permit, the scan files available, and state any departure from the procedure. General guidance on reporting laboratory studies in dentistry applies as well ([Krithikadatta et al., 2014](#)). Results should be expressed in the units of the measured quantity and accompanied by the reference uncertainty, without conversion into a single composite score. Rankings of scanners should be avoided unless differences exceed both the reference uncertainty and the between-operator variation.

5. Fitting the Protocol to a Laboratory

The most demanding requirement is the reference measurement, since few dental schools own a coordinate measuring machine. Engineering departments and commercial metrology services provide such measurements with certificates of calibration, and one well-characterised model can be shared between centres. The remaining stages need only equipment that a prosthodontic laboratory already has. Sharing a physical model, or a design file from which identical models are machined, would allow an inter-laboratory comparison of the kind ISO 5725 envisages, and that would be the most direct test of whether the protocol achieves its purpose.

6. Limitations and What Remains to Be Shown

The protocol is proposed and has not been validated. It remains to be shown that laboratories following it obtain concordant results for the same device, and that the single-implant alignment rule gives more informative results than best-fit alignment in practice as well as in principle. The choice of implant layout

is one of many possible, and conclusions will not transfer automatically to other numbers, spacings or angulations of implants.

A bench model omits most of what makes complete-arch scanning difficult in a patient: saliva, mobile mucosa, the tongue and cheeks, limited opening and movement. Bench results therefore describe the best a device can do and set an upper bound on clinical expectations. They cannot establish clinical adequacy, which depends on a tolerance for misfit that is itself undefined. Clinical studies using a verified conventional cast or a verification jig as comparator remain necessary, and the metrics proposed here could be carried over to them unchanged.

7. Conclusion

Disagreement about the accuracy of intraoral scanners for complete-arch implant impressions owes much to differences in bench method. The protocol set out here fixes the reference model and its measurement, the test conditions, the scanning procedure, the registration rule and the reported quantities, and it keeps trueness and precision apart as the standards require. Its adoption would not settle which scanner is best. It would allow that question to be asked in a form that different laboratories can answer in the same way.

Conflict of interest

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References

- Andriessen, F.S., Rijkens, D.R., van der Meer, W.J. and Wismeijer, D.W. (2014). [Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: A pilot study.](#) *Journal of Prosthetic Dentistry*, 111(3): 186-194. <https://doi.org/10.1016/j.prosdent.2013.07.010>
- Besl, P.J. and McKay, N.D. (1992). [A method for registration of 3-D shapes.](#) *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 14(2): 239-256. <https://doi.org/10.1109/34.121791>
- Ender, A. and Mehl, A. (2013). [Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision.](#) *Journal of Prosthetic Dentistry*, 109(2): 121-128. [https://doi.org/10.1016/S0022-3913\(13\)60028-1](https://doi.org/10.1016/S0022-3913(13)60028-1)
- Flügge, T., van der Meer, W.J., Gonzalez, B.G., Vach, K., Wismeijer, D. and Wang, P. (2018). [The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis.](#) *Clinical Oral Implants Research*, 29(Suppl 16): 374-392. <https://doi.org/10.1111/clr.13273>
- Flügge, T.V., Att, W., Metzger, M.C. and Nelson, K. (2016). [Precision of dental implant digitization using intraoral scanners.](#) *International Journal of Prosthodontics*, 29(3): 277-283.
- Giménez, B., Özcan, M., Martínez-Rus, F. and Pradíes, G. (2014). [Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth.](#) *International Journal of Oral & Maxillofacial Implants*, 29(4): 853-862.
- ISO (1994). [ISO 5725-1: Accuracy \(trueness and precision\) of measurement methods and results - Part 1: General principles and definitions.](#) International Organization for Standardization, Geneva.
- ISO (2015). [ISO 12836: Dentistry - Digitizing devices for CAD/CAM systems for indirect dental restorations - Test methods for assessing accuracy.](#) International Organization for Standardization, Geneva.
- ISO (2019). [ISO 20896-1: Dentistry - Digital impression devices - Part 1: Methods for assessing accuracy.](#) International Organization for Standardization, Geneva.
- JCGM (2008). [Evaluation of measurement data - Guide to the expression of uncertainty in measurement](#)

- (JCGM 100:2008). Joint Committee for Guides in Metrology, Sèvres.
- Krithikadatta, J., Gopikrishna, V. and Datta, M. (2014). [CRIS Guidelines \(Checklist for Reporting In-vitro Studies\): A concept note on the need for standardized guidelines for improving quality and transparency in reporting in-vitro studies in experimental dental research.](#) *Journal of Conservative Dentistry*, 17(4): 301-304.
- Müller, P., Ender, A., Joda, T. and Katsoulis, J. (2016). [Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner.](#) *Quintessence International*, 47(4): 343-349.
- O'Toole, S., Osnes, C., Bartlett, D. and Keeling, A. (2019). [Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment.](#) *Dental Materials*, 35(3): 495-500.
- Papaspyridakos, P., Gallucci, G.O., Chen, C.J., Hanssen, S., Naert, I. and Vandenberghe, B. (2016). [Digital versus conventional implant impressions for edentulous patients: Accuracy outcomes.](#) *Clinical Oral Implants Research*, 27(4): 465-472. <https://doi.org/10.1111/clr.12567>
- Revilla-León, M., Jiang, P., Sadeghpour, M., Piedra-Cascón, W., Zandinejad, A., Özcan, M. and Krishnamurthy, V.R. (2020). [Intraoral digital scans - Part 1: Influence of ambient scanning light conditions on the accuracy \(trueness and precision\) of different intraoral scanners.](#) *Journal of Prosthetic Dentistry*, 124(3): 372-378.
- Sahin, S. and Cehreli, M.C. (2001). [The significance of passive framework fit in implant prosthodontics: Current status.](#) *Implant Dentistry*, 10(2): 85-92.
- van der Meer, W.J., Andriessen, F.S., Wismeijer, D. and Ren, Y. (2012). [Application of intra-oral dental scanners in the digital workflow of implantology.](#) *PLoS ONE*, 7(8): e43312. <https://doi.org/10.1371/journal.pone.0043312>
- Vandeweghe, S., Vervack, V., Dierens, M. and De Bruyn, H. (2017). [Accuracy of digital impressions of multiple dental implants: An in vitro study.](#) *Clinical Oral Implants Research*, 28(6): 648-653. <https://doi.org/10.1111/clr.12853>