Received: 8 December 2021 | Revised: 13 June 2022 | Accepted: 22 June 2022

DOI: 10.1111/clr.13983

ORIGINAL ARTICLE

CLINICAL ORAL IMPLANTS RESEARCH WILEY

Impact of radiographic field-of-view volume on alignment accuracy during virtual implant planning: A noninterventional retrospective pilot study

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Abstract

Objective: To evaluate the impact of reducing the radiographic field of view (FOV) on the trueness and precision of the alignment between cone beam computed tomography (CBCT) and intraoral scanning data for implant planning.

Materials and Methods: Fifteen participants presenting with one of three clinical scenarios: single tooth loss (ST, $n = 5$), multiple missing teeth (MT, $n = 5$) and presence of radiographic artifacts (AR, $n = 5$) were included. CBCT volumes covering the full arch (FA) were reduced to the quadrant (Q) or the adjacent tooth/teeth (A). Two operators, an expert (exp) in virtual implant planning and an inexperienced clinician, performed multiple superimpositions, with FA-exp serving as a reference. The deviations were calculated at the implant apex and shoulder levels. Thereafter, linear mixed models were adapted to investigate the influence of FOV on discrepancies.

Results: Evaluation of trueness compared to FA-exp resulted in the largest mean (AR-A: 0.10 ± 0.33 mm) and single maximum discrepancy (AR-Q: 1.44 mm) in the presence of artifacts. Furthermore, for the ST group, the largest mean error (-0.06 ± 0.2 mm, shoulder) was calculated with the FA-FOV, while for MT, with the intermediate volume (-0.07 ± 0.24 mm, Q). In terms of precision, the mean SD intervals were ≤0.25 mm (A-exp). Precision was influenced by FOV volume (FA < Q < A) but not by operator expertise.

Conclusions: For single posterior missing teeth, an extended FOV does not improve registration accuracy. However, in the presence of artifacts or multiple missing posterior teeth, caution is recommended when reducing FOV.

KEYWORDS
ALADA, ALARA, CBCT, FOV, guided implantology, virtual planning

1 | INTRODUCTION

Prosthetically driven virtual implant planning and guided surgery result in more successful rehabilitations and less complications (Canullo et al., 2016; Schneider et al., 2019; Tattan et al., 2020). Digital reconstruction of the intraoral tissues and ideal digital planning of the implant position necessitates three-dimensional (3D) radiographic images, usually acquired via cone beam computed tomography (CBCT). These tomographic images are exported in DICOM format (Digital Imaging and Communications in Medicine) (Jacobs & Quirynen, 2014) and are superimposed with optically acquired surface datasets (Kernen et al., 2016). The latter ones are obtained with intraoral scanners or by stone cast digitization in the dental laboratory and are usually exported as Standard Tessellation Language (STL) data (Emara et al., 2020; Papaspyridakos et al., 2016).

CBCT is an imaging technology used to visualize bone morphology, as well as soft tissue structures and hollow spaces in the bone, for example, the course of the inferior alveolar nerve canal, and should be limited to the region of interest (ROI) to minimize the size of ionizing irradiation in the head and neck region (Pauwels, 2015). The exposure parameters and size of the field of view (FOV) are related to the absorbed radiation dose and should be carefully selected (da Silva Moura et al., 2019; Harris et al., 2012; McGuigan et al., 2018). In the guidelines for implant imaging proposed by the European Association for Osseointegration (EAO) (Harris et al., 2012), the use of techniques requiring less exposure to radiation for patients was stated as an obligatory development to be addressed in future research. Almost a decade after, specific recommendations for low-dose imaging protocols associated with virtual implant planning are still missing (Yeung et al., 2019). Regardless of the clinical situation, the selected FOV acquired for implant planning with subsequent guided surgery is routinely overextended and includes several anatomical structures located outside the ROI. This appears in contrast to the ALARA (as low as reasonably achievable)/ALADA (as low as diagnostically acceptable) principles (White et al., 2014), and their requirement for careful use of ionizing radiation (Bornstein et al., 2014).

Implant planning software are used to overlay intraoral scan data as STL files with CBCT data in a process called registration (Flügge et al., 2017). The latter ones, in the form of DICOM files, are converted into a 3D image visually comparable to the created STL file using volume rendering technique (VRT) based on grayscale thresholds. In addition, multiplanar image reformation (MPR) is used to match the boundaries of the STL file to the cross-sectional data from CBCT. The registration process can be automatic, based on best-fit algorithms, and/or requires initial manual selection of the corresponding areas/points, usually teeth or other hard tissue reference markers (Kernen et al., 2020). Finally, manual fine-tuning might be required for an ideal matching. While the ideal implant position is determined according to both CBCT and intraoral scanning data, the surgical guide design is solely based on the latter. Therefore, accurate matching is mandatory to avoid implant misplacement (Tahmaseb et al., 2018). Consequently, software-based inaccuracies resulting from a compromised matching process might subsequently result in hardware-based inaccuracies, for example, due to the manufacturing process of the surgical guide or the implant installation procedure, thereby affecting the outcome (Chen et al., 2020; Raico Gallardo et al., 2017; Zhou et al., 2018).

The importance of reducing FOV volume for virtual implant planning was addressed in a recent conference paper (Singh & Hamilton, 2021). To the best of the authors' knowledge, no previous study has evaluated whether the accuracy of the registration process is affected by FOV extension. A reduction in the FOV could potentially lead to decreased patient irradiation; therefore, an assessment of accuracy in case of different FOV extensions in diverse clinical scenarios is needed.

In this investigation, three different FOV volumes were extracted from 15 clinical CBCT datasets representing three different clinical scenarios and used for superimposition with the intraoral surface data of the selected patients. One partial volume was limited to the quadrant (Q), whereas the other was further reduced to the adjacent (A) tooth/teeth next to the implant site. This study aimed to investigate the effect of three FOV volumes for alignment on the accuracy of the planned implants.

The null hypothesis of the study assumed no difference in terms of matching trueness and precision as a function of the FOV volume or the clinical scenario.

2 | MATERIALS AND METHODS

2.1 | Study design

This investigation was designed as a noninterventional retrospective pilot study and was conducted in accordance with the Declaration of Helsinki. Approval to conduct the study was obtained from the Ethics Committee of the Medical Center, University of Freiburg, Germany (investigation number: 20/1205; ethics committee vote: November 24, 2020). Both the EQUATOR guidelines (http://www.equator-network.org) and Strobe-statement 2020 for observational studies (http://www.strobe-statement.org) were adhered to in the study. All participants signed an informed consent form and approved the use of their clinical data.

The eligibility criteria included patients with a single missing tooth (ST) or multiple adjacent missing teeth (MT) in the posterior region. In addition, participants presenting with sources of radiographic metal strip artifacts (AR) originating from implants and/or full-coverage restorations located in the proximity of the implant site were included as the third group.

2.2 | Data collection

Three-dimensional radiographic and surface datasets of 15 patients used for implant planning at the Department of Oral and Maxillofacial Surgery, University of Freiburg, Germany, between

2019 and 2020 were retrospectively collected. Intraoral digitization was performed by one experienced operator (F.K.) using a scanning device (TRIOS 3, 3Shape), whereas CBCT scans were performed by medical technicians using one device (Morita Accuimoto 170, J. Morita GmbH) with the following settings: FOV: 170 mm × 50 mm (diameter × height), circulation time: 14.5 s, tube voltage: 120 kV, and current intensity: 32 mA. The FOV volume for each patient scan included the entire jaw as the standard procedure. Thereafter, the original DICOM dataset was exported directly from the imaging software (i-Dixel, J. Morita GmbH), integrated within the CBCT device, into the beta version (99.00.9) of an implant planning system (Version 2.17.1 SMOP, Swissmeda AG), and merged with the STL file of the corresponding intraoral scan. A single 4.1 mm × 10 mm bone-level implant (Straumann® Bone Level [BL], Straumann AG) was virtually positioned in the edentulous area of each included clinical case and subsequently used as a landmark for the measurement of discrepancies (Figure 1).

2.3 | Radiographic subsample volumes and registration process

To generate volumes with a reduced FOV, an additional "cropping function" of the planning software (Swissmeda AG) was developed. For this purpose, a portion of the alveolar ridge of the original radiographic dataset was selected and all voxels along this segment were used to define the partial volume. For each clinical case, two reduced volumes from the original FA were created: One was limited to the quadrant (Q), and one was reduced to the tooth/teeth (A) adjacent to the planned implant site. All FOV extensions were exported with the same coordinates to allow for further comparison.

Each FOV volume (FA, Q, A) of the 15 clinical cases was uploaded as a separate file and merged with the STL data incorporating the implant 10 times by an inexperienced operator who had received basic training in dataset alignment and had no expertise before this investigation (C.B.) (Figure 2). An experienced user (J.B.), a long-time professional in the field of virtual implant planning and dataset superimposition, performed 10 alignments for every FOV partial volume of two randomly selected cases each of the ST, MT, and AR. In addition, one-time matching was conducted by J.B. for each FOV size in all remaining cases (n = 9). Overall, the accepted reference for trueness was the combination expert-FA of each included clinical case.

2.4 | Calculation of discrepancies

After matching, all surface scans were exported as STL files from the implant planning system and imported into a three-dimensional inspection software (Geomagic Control X, 3D Systems), maintaining the same coordinates (Figure 3). A best-fit algorithm was used to align the imported datasets using several reference points located on the outer part of the STL files, such as teeth and mucosa. The submerged implants included in the STL files were initially not visible from the

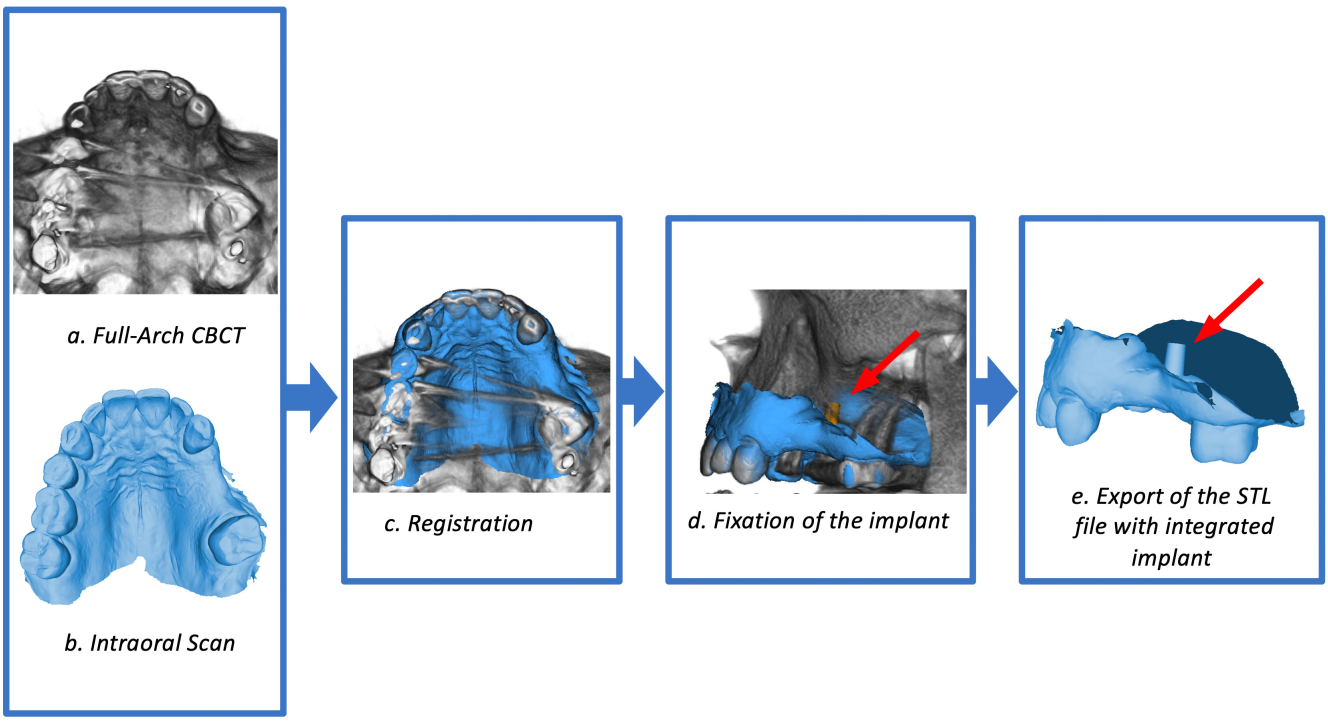

FIGURE 1 Creation of an STL file with integrated landmark in form of a 4.1 × 10 mm oral implant for each case. A CBCT scan (DICOM) covering the full arch (a) and the corresponding intraoral scan (STL) (b) were matched (c) using an implant planning software. An implant was positioned (d) and served, subsequently, as reference for the measurement of discrepancies. Finally, the STL file with integrated implant was exported (e) and used as reference for all further registration processes with different FOV volumes.

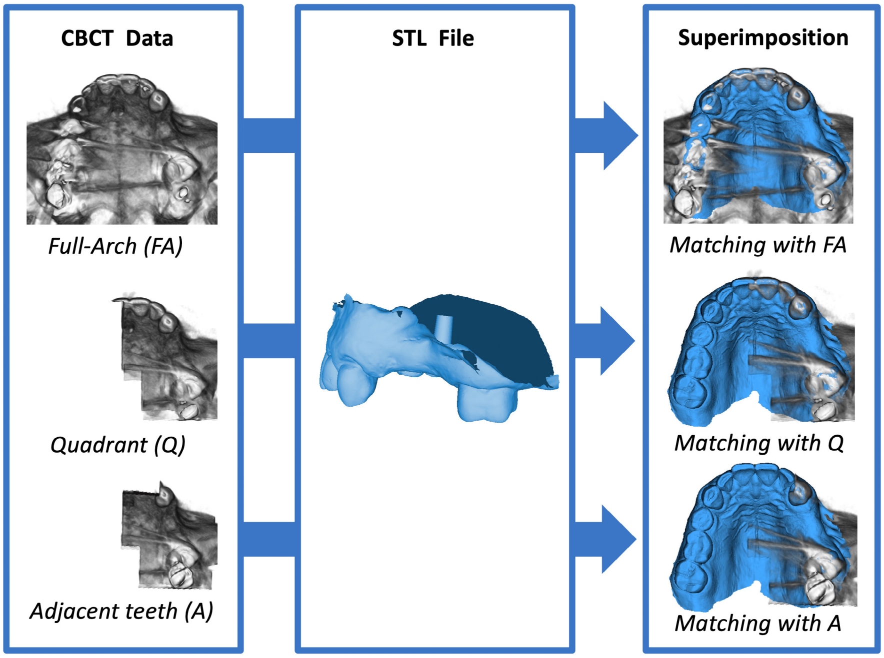

FIGURE 2 All radiographic original and reduced volumes were matched with the same intraoral scan of each clinical case, incorporating an implant, using the implant planning software. After superimposition with the different FOV volumes, the STL file with the new coordinates from the registration was exported and imported in a measuring software for the calculation of discrepancies. Exemplary presentation of a clinical case with artifacts.

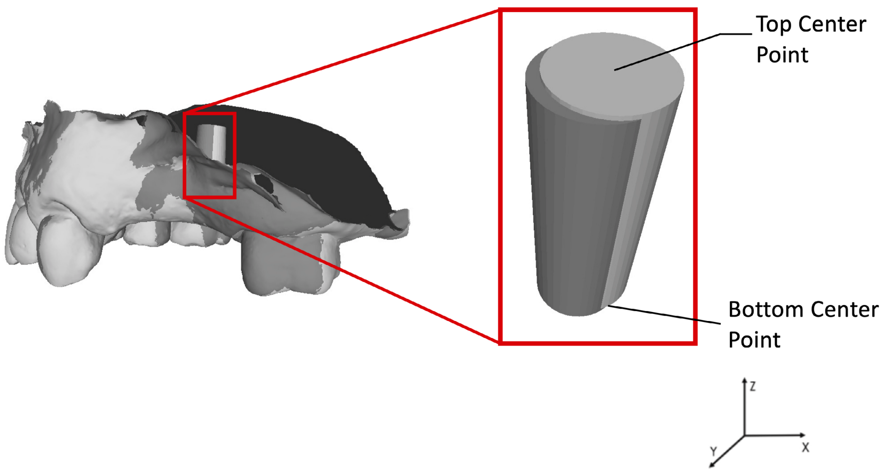

FIGURE 3 After matching with the planning software, each aligned STL file was imported in a measurement software and superimposed with the reference (FA-exp) to assess trueness. For the evaluation of precision, standard deviations were calculated for each coordinate of all situations (ST, MT, AR) and FOVs (FA, Q, A) for both expert and nonexpert. Discrepancies were measured at implant shoulder (top center point) and apex (bottom center point). Exemplary presentation of trueness evaluation.

outside and were therefore not used as a reference for alignment. They later measured the discrepancies between test and reference implants after increasing the translucency of the STL files. One point, positioned at the top center of the implant, was considered the reference for the shoulder, while the other point, located at the bottom center, represented the apex. Both were used as landmarks to measure discrepancies at the horizontal and vertical levels between the aligned datasets (x: sagittal (mesiodistal), y: transverse (buccolingual–palatal), z: vertical (coronoapical)). To assess trueness, exported scan data were aligned 10 times for each FOV size (FA, Q, A) with the corresponding reference (exp-FA), resulting in a total of 450 alignments. To calculate precision, the standard deviation interval for each coordinate (x, y, z) of the superimposed datasets was analyzed for both expert and inexperienced clinicians. For better comprehension, after pooling the clinical situations (ST, MT, AR), the average standard deviation of each FOV volume (FA, Q, A) was calculated for each operator.

2.5 | Statistical methods

With 10 alignments per case, a difference of 1 mm in one of the coordinates (x, y, z) could be detected with a power of 90%, assuming a standard deviation of 0.5. Linear mixed models with random intercepts were fitted for each implant position and coordinate to evaluate the differences between FOV sizes. Scheffé's method was applied to correct for multiple testing, and the probability level for statistical significance was set at $p = .05$. To analyze the precision for each clinical situation (ST, MT, A), 10 repetitions were performed by both expert and nonexpert for two of the five cases of each category (ST, MT, A). Linear mixed models with independent residuals and restricted maximum likelihood techniques were used to compute standard deviations for expert and nonexpert in a pooled setting for all situations. The calculations were performed using the statistical software STATA 17.0 (StataCorp).

3 | RESULTS

3.1 | Outcome data

Fifteen participants (six female and nine male, mean age: 56.8 years) were included, representing three different clinical scenarios (ST, MT, AR; $n = 5$ cases each; ST: 3 maxillae and 2 mandibles, MT: 2 maxillae, and 3 mandibles and AR: 4 maxillae and 1 mandible). The smallest FOV volume, A, resulted in a diameter of 45–60 mm and a height of 35 mm. For trueness assessment, five cases per clinical scenario with $n = 10$ alignments, each by nonexpert and expert, were considered. To evaluate precision, two cases per indication were selected, each examined 10 times by both operators.

3.2 | Trueness assessment

In the ST group, the mean outcomes were significantly affected by the FOV volume (Figure 4). When comparing FA with Q at the implant apex or FA with A at both implant apex and shoulder, significant transverse deviations were found ($p = .02$). No further significance could be calculated (Table 1).

In the MT group, the highest mean deviation compared to the reference was measured at the implant apex in the transverse direction using the FOV volume Q (−0.07 ± 0.24 mm). No significant differences were observed when comparing the three FOV extensions.

When analyzing the mean results of the inexperienced operator within the AR group, significant vertical differences were assessed at the implant shoulder level in favor of the largest (FA) compared to the smallest (A) FOV volume ($p = .02$).

The highest differences compared with the reference measurements were calculated at the implant apex level (Table 2). For the ST group, the highest discrepancy was calculated for the FA-FOV (0.58 mm, transverse). In the MT group, the maximum deviation was measured with the smallest FOV (A: 0.90 mm, sagittal). Scenarios with radiologic artifacts (AR) showed highest discrepancy compared to the reference when using the FOV volume Q (Q: 1.44 mm, vertical).

3.3 | Precision assessment

To obtain an overview of the precision of the different FOV volumes, the individual scenarios were pooled and descriptive statistics were generated.

For all scenarios, the mean SD was ≤0.25 mm (A-exp) (Table 3). When considering single coordinates, SD intervals appeared in most cases depending on the FOV volume: FA < Q < A. Mean standard deviation intervals did not depend on the operator's expertise (expert vs. inexperienced clinician).

4 | DISCUSSION

The objective of this investigation was to evaluate whether reducing the radiographic FOV influences the accuracy of the registration process with the intraoral surface dataset when virtually planning the implant. To the best of our knowledge, the authors of the present study could not identify any comparable studies in the literature, except for a recent conference paper by Singh and Hamilton (2021). This demonstrates both the lack of data on the topic and the current efforts of other research groups to find viable solutions. The importance of this investigation lies in the fact that it explores a novel method to improve the workflow of virtual implant planning. Reducing the FOV means less irradiation for the patient but also a smaller diagnostic field for the radiologist/clinician and potentially lower costs of the CBCT scans, depending on the clinical case.

The null hypothesis, which presumed no differences at the implant level in terms of accuracy regardless of the FOV extension and clinical situation, had to be partially rejected. According to the ISO standard 5725, accuracy is defined as the combination of both trueness and precision of a system (Boulanger et al., 2012). While trueness relates to the closest representation of the arithmetic mean of multiple measurements to a "true or accepted reference value," precision refers to the consistency and repeatability between the test results and is calculated considering the standard deviation interval.

For this study, given the impossibility of determining the ideal and most accurate superimposition (true value), an accepted reference for trueness was arbitrarily chosen. In everyday practice,

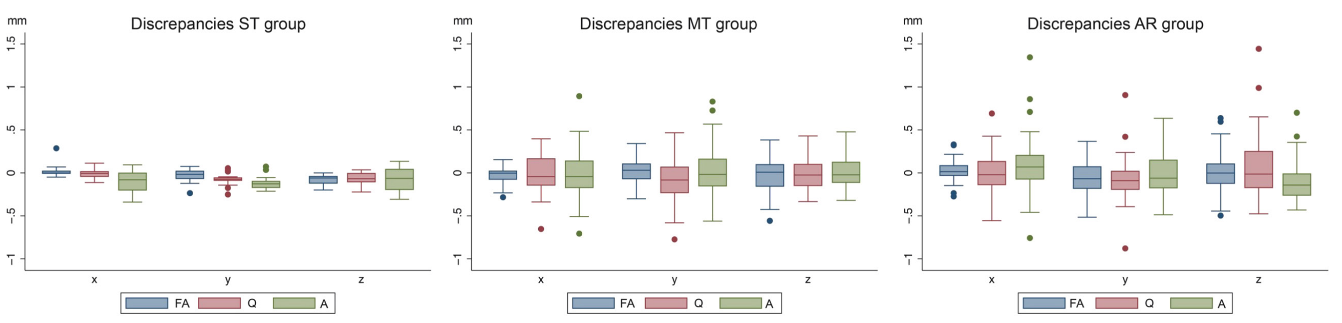

FIGURE 4 Boxplots for discrepancies of the virtual implant apical position in the ST, MT and AR groups. FOV sizes: FA (full arch), Q (quadrant), and a (adjacent). X, sagittal discrepancies; y, transversal discrepancies; z, vertical discrepancies.

TABLE 1 Trueness (mean ± SD) of implant apex/shoulder by clinical situations and FOV significances were highlighted with the same subscript letter

		Apex (mm)			Shoulder (mm)		
Clin. situation	FOV	x	y	z	X	y	z
ST	FA	−0.02 ± 0.09	$0.04 \pm 0.18_{a,b}$	−0.04 ± 0.15	0.00 ± 0.07	$0.05 \pm 0.15_{c}$	−0.06 ± 0.16
	Q	0.01 ± 0.08	$-0.03 \pm 0.13_{a}$	−0.04 ± 0.11	0.01 ± 0.07	−0.02 ± 0.11	−0.06 ± 0.12
	A	0.02 ± 0.16	$-0.04 \pm 0.12_{b}$	−0.05 ± 0.15	0.02 ± 0.12	$0.01 \pm 0.11_{c}$	−0.05 ± 0.15
MT	FA	−0.03 ± 0.09	0.02 ± 0.14	−0.02 ± 0.19	−0.04 ± 0.77	0.01 ± 0.09	−0.02 ± 0.19
	Q	−0.01 ± 0.22	−0.07 ± 0.24	−0.00 ± 0.18	−0.04 ± 0.14	−0.03 ± 0.17	−0.01 ± 0.18
	A	−0.03 ± 0.28	0.01 ± 0.28	0.02 ± 0.19	−0.07 ± 0.18	0.02 ± 0.17	0.01 ± 0.20
AR	FA	0.02 ± 0.12	−0.05 ± 0.22	0.00 ± 0.24	−0.00 ± 0.10	−0.05 ± 0.19	$0.00 \pm 0.23_{d}$
	Q	0.00 ± 0.23	−0.06 ± 0.25	0.06 ± 0.36	0.0 ± 0.17	−0.06 ± 0.16	0.05 ± 0.36
	A	0.10 ± 0.33	−0.02 ± 0.25	−0.09 ± 0.25	0.04 ± 0.25	−0.04 ± 0.18	$-0.09 \pm 0.25_{d}$

Abbreviations: ST, single tooth; MT, multiple teeth; AR, artifacts; FA, full arch; Q, quadrant; A, adjacent; x, sagittal discrepancies; y, transverse discrepancies; z, vertical discrepancies. [Correction added on 20 August 2022, after first online publication: Table 1 was updated in this current version.]

TABLE 2 Maximum discrepancy of implant apex by clinical situations and FOV

		Apex (mm)		
Clin. situation	FOV	X	y	z
ST	FA	0.29	0.58	0.30
	Q	0.20	0.53	0.21
	A	0.39	0.19	0.40
MT	FA	0.15	0.34	0.39
	Q	0.40	0.47	0.43
	A	0.90	0.84	0.48
AR	FA	0.33	0.37	0.64
	Q	0.70	0.91	1.44
	A	1.34	0.64	0.70

Abbreviations: ST, single tooth; MT, multiple teeth; AR, artifacts; FA, full arch; Q, quadrant; A, adjacent tooth/teeth; x, sagittal discrepancies; y, transverse discrepancies; z, vertical discrepancies.

TABLE 3 Average standard deviations (mm) calculated for expert and inexperienced operator for each coordinate and FOV volume with all clinical scenarios pooled together

	Expert			Inexperienced operator		
	FA	Q	A	FA	Q	A
X	0.14	0.20	0.25	0.07	0.13	0.24
Y	0.11	0.18	0.22	0.11	0.12	0.18
Z	0.22	0.11	0.12	0.11	0.11	0.16

Abbreviations: ST, single tooth; MT, multiple teeth; AR, artifacts; FA, full arch; Q, quadrant; A, adjacent tooth/teeth; x, sagittal discrepancies; y, transverse discrepancies; z, vertical discrepancies.

long-term professional expertise in virtual implant planning and the availability of a high-quality full-arch CBCT scan are considered ideal for dataset registration and served as the reference (FA-exp) in this study. Nevertheless, the delivery of FA-exp by a single operator may have resulted in high intra-operator bias. A sample size calculation was not possible because of the pilot design of the study; therefore, the number of five patients for each of the three clinical scenarios included was chosen arbitrarily. Power analysis was performed considering the number of alignments ($n = 10$) for each FOV volume ($n = 3$) of each clinical case ($n = 15$), based on the wish to be able to show differences in mean values of two methods of 1 mm size with 90% power. A total of 657 alignments were observed and divided into $n = 450$ by inexperienced users and $n = 207$ by experienced users. Based on the amount of data collected, interpreted, and analyzed, this investigation provides significant findings that are necessary to conduct further studies with a more detailed sample size calculation.

Clinical investigations evaluating the accuracy of guided implant procedures typically involve large FOVs (≥10 × 10 cm) (Lou et al., 2021). For this study, three FOV volumes for each of the 15 included clinical cases with single or multiple adjacent missing teeth, with and without the presence of radiographic artifacts, were repeatedly superimposed with the corresponding intraoral scans. Discrepancies were calculated at the level of a virtually positioned bone level implant. Independent of the FOV volume, the highest mean difference from the reference of ≤0.1 mm was found. This might question the clinical benefits of using large FOV volumes. Furthermore, under specific circumstances, matching accuracy was found to be significantly affected by FOV volume, for example, in the presence of radiographic artifacts.

Minor mean deviations were assessed using different FOV extensions in this study. However, it should be noted that deviations at the software level sum up with subsequent inaccuracies at the hardware level, for example, during manufacturing of the guide, insertion/fit in the mouth, or drill guidance during implant surgery (Cassetta et al., 2013). Consequently, the calculated maximum deviations may result in clinically relevant discrepancies when followed by further hardware-related inaccuracies that have not yet been specified. In this investigation, the distribution of outliers was predominantly affected by the clinical scenario (ST < MT < AR) compared with the effect of the FOV volume. Maximum deviations of up to 1.44 mm were measured using the FOV volume Q in the presence of artifacts, which confirms artifact sources as the principal cause of registration errors. For selected clinical scenarios, as for ST, a larger FOV volume did not lead to a significantly more accurate registration process, nor did it show decreased outliers.

Precision was not significantly influenced by the expertise of the operator, suggesting that high reproducibility of registration can be achieved even by non-experienced operators. Furthermore, when pooling the three clinical scenarios evaluated, SD intervals were affected by the FOV volume (FA < Q < A), but with minimal differences. This leads to the assumption that the FOV volume may have a negligible influence on the precision of the process, which is in accordance with the preliminary results presented by Singh and Hamilton (2021).

Beam hardening artifacts are the consequence of scattering radiation from high-density objects, such as fixed metal-based prosthetic restorations (Alaidrous et al., 2021) or oral implants (Sancho-Puchades et al., 2015). In their investigation, Flügge et al. (2017) assessed the negative impact of imaging artifacts on the registration accuracy between CBCT and surface scans, and encouraged research on alternative technologies that are potentially less prone to artifact impact, such as magnetic resonance imaging (Flügge et al., 2020).

In the present study, a single CBCT device and intraoral scanner (IOS) were used for all clinical cases to minimize potential confounders linked to the data acquisition process (Güth et al., 2013; Schubert et al., 2019). Other factors that may affect the accuracy of alignment are related to the type and distribution of the anatomical (Flügge et al., 2017) and fiducial (Rangel et al., 2013; Vercruyssen et al., 2014) landmarks used for registration. In this study, no fiducial markers and only anatomical landmarks, such as natural teeth, were used for registration.

A novel methodology for retrospective subsample FOV creation from a single CBCT scan using a test function of a well-documented implant planning software (Kernen et al., 2020; Schneider et al., 2019) was adapted, but potential distortions of the DICOM dataset might have occurred, for example, due to voxel rounding. Generating FOV partial volumes from the raw data included in the CBCT device and not from the exported DICOM file, as was done in this investigation, would have potentially avoided alterations derived from overlapping neighboring radiological structures. However, exporting subvolumes with an identical coordinate system to the original radiographic dataset was not possible. For ethical reasons, performing CBCTs with different FOV extensions in the same patient was not considered as an option.

Protocols for virtual oral implant planning with reduced radiation dose are being investigated and involve using a different number of basic images (de Castro et al., 2021) as well as larger voxels, partial rotations and reduction in mAs (Yeung et al., 2019). This study proposed an alternative for radiation dose reduction based on the use of a smaller FOV, which was reduced to 45 × 35 mm in this study. If on the one side, reducing the FOV has proven to lead to an reduced effective radiation dose (Jadu et al., 2018), on the other side, an exact quantification of the irradiation variation depending on the FOV extension was not performed and should be further evaluated.

The limitations of the present investigation relate to the pilot design with a limited number of clinical scenarios and software operators. Therefore, their number should be increased in future studies. Clinical indications should be extended, for example, to the anterior region and to cases of partial edentulism with few remaining teeth. Additionally, numerous software operators with different expertise in virtual implant planning should be involved in assessing whether reducing the FOV size significantly compromises the alignment procedure.

Comparisons regarding the implant position (maxilla/mandible) or the time needed for registration by an experienced as well as inexperienced operator were not performed in this study and should be considered in further investigations. Furthermore, a validation process for the adapted method of FOV reduction is still required, and further studies should investigate the feasibility of reducing FOV size with alternative workflows. Future investigations should include different implant planning systems to evaluate their capability to provide accurate registration with smaller FOV volumes. For example, automatic registration can be performed using a best-fit algorithm.

In summary, in this pilot study, accurate registration of CBCT images with a reduced FOV was possible. However, caution is recommended when radiographic artifacts are present. For selected clinical scenarios, such as ST with a low expectation of artifacts, a smaller FOV is worth exploring in prospective clinical settings. The clinical advantages of FOV reduction include lower irradiation of the patient and a more time-efficient examination and diagnosis of the CBCT images by the practitioner or radiologist, as fewer structures located outside the ROI are displayed. Further studies including multiple operators are desirable to investigate the feasibility of FOV reduction in more challenging clinical scenarios to define a threshold for case-specific FOV volume selection.

5 | CONCLUSION

The following suggestions can be made based on the findings of the present study:

- According to the applied reference, the FOV volume can be reduced to adjacent teeth without affecting the registration accuracy at the implant level by more than 0.1 mm on average in the posterior region.
- Clinically relevant maximum discrepancies up to 1.34 mm were registered in the presence of radiographic artifacts and up to 0.90 mm for multiple missing teeth when reducing the FOV volume to the adjacent tooth/teeth.
- A larger FOV does not significantly improve registration accuracy in case of single missing posterior teeth.

AUTHOR CONTRIBUTIONS

Stefano Pieralli: Conceptualization (lead); data curation (lead); investigation (lead); methodology (lead); project administration (lead); software (equal); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead). **Christian Wesemann:** Conceptualization (equal); data curation (equal); investigation (equal); methodology (equal); writing – review and editing (equal). **Kirstin Vach:** Formal analysis (lead); visualization (equal); writing – review and editing (equal). **Florian Kernen:** Investigation (equal); methodology (equal); writing – review and editing (equal). **Katja Nelson:** Conceptualization (lead); writing – review and editing (equal). **Benedikt Christopher Spies:** Conceptualization (lead); data curation (equal); investigation (equal); methodology (lead); project administration (equal); supervision (lead); validation (equal); writing – review and editing (lead).

ACKNOWLEDGMENTS

The authors would like to thank Dr. Stephan Schmälzle from Swissmeda AG (Baar, Switzerland) and Mr. Jens Bingenheimer from stentists-digitale Planungsdienstleistungen (Braunschweig, Germany) for their valuable contribution to this investigation. Open Access funding enabled and organized by Projekt DEAL. Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST

The authors declare that they have 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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SUPPORTING INFORMATION

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How to cite this article: Pieralli, S., Beyer, C., Wesemann, C., Vach, K., Russe, M. F., Kernen, F., Nelson, K., & Spies, B. C. (2022). Impact of radiographic field-of-view volume on alignment accuracy during virtual implant planning: A noninterventional retrospective pilot study. *Clinical Oral Implants Research*, *33*, 1021–1029. https://doi.org/10.1111/clr.13983