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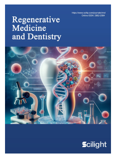

Article

Dental Brace Register for Accurate and Reproducible Bone Augmentation Evaluation in Dental Implantology

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Abstract: Accurate evaluation of bone augmentation is essential for surgical planning in dental implantology, and it is also crucial for validating the efficiency of bone augmentation approaches. However, the prevailing evaluation methods are complicated, time-consuming, operator-dependent, and hardly reproducible, undermining their feasibility and reliability in clinic. In response to these limitations, a registration apparatus composed of a transparent orthodontic retainer and radiographic markers was developed, enabling image superimposition before and after bone augmentation. A mandibular specimen underwent cone beam computed tomography (CBCT) scans at baseline, three, and six months, with and without the apparatus. Image registrations were independently performed by two examiners using the registration apparatus and two alternative methods. Root mean square (RMS) deviations were calculated to quantify registration accuracy. Statistical analyses were conducted using ANOVA and paired *t*-tests. Significant differences in RMS deviations were observed between the registration methods (p = 0.002), and using the registration apparatus achieved the lowest RMS deviation (0.055 ± 0.030 mm) and consistency at different timepoints (p = 0.856) and examiners (p = 0.441). This registration apparatus demonstrated high accuracy and reproducibility in bone augmentation evaluation, making it a potential reliable tool for quantitative evaluation of bone augmentation in dental implantology.

Keywords: bone augmentation evaluation; accuracy and reproducibility; three-dimensional image registration; dental implantology

1. Introduction

Due to the profound long-term success rate and patient comfort, dental implants are increasingly used for edentulism repair [1]. The achieved long-term success critically depends on the adequate residual alveolar bone surrounds the inserted implants. However, following tooth extraction, progressive alveolar bone resorption often leads to insufficient bone volume, requiring bone augmentation procedures for successful implant placement [2–

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5]. Especially in the esthetic zone, accurate three-dimensional (3D) position of the implant is a key prerequisite for optimal long-term functional and esthetic outcome [6].

Accurate evaluation of augmented bone is vital for subsequently placing implants in ideal 3D positions. Conventional methods for evaluating bone augmentation, such as periodontal probing, calipers, and two-dimensional (2D) radiographs, suffer from limited accuracy and reproducibility [7–9]. To overcome these issues, 3D digital assessments based on cone-beam computed tomography (CBCT) data have gained prominence given their ability to visualize volumetric changes of bone. However, the accuracy of CBCT-based measurements is strongly inflected by the accurate image registration after pre/post-operational CBCT scans.

Image registration refers to the spatial alignment of images of the same object acquired at different times, with different modalities, or by various devices [10]. For dental image registration, internal and external strategies are widely used. Intraoral registration is typically dependent on characteristic points on the dentition or mucosal surface in order to achieve image overlay through intraoral scanning or the utilization of customized dental trays. The system offers high precision but is significantly affected by scanning range limitations and soft tissue changes [11]. Extraoral registration employs craniofacial bony structures or external markers (e.g., metal pins, zirconia beads) for registration, rendering it suitable for extensive reconstruction and long-term follow-up [12]. Compared to intraoral registration, the external registration usually offers higher precision as teeth are commonly employed as external reference markers due to their anatomical stability [13]. In some specific circumstances, for instance when orthodontic brackets or metallic prostheses produce metal artifacts or imaging noise on CBCT, tooth-based external registration points may no longer provide accurate alignment. Nonetheless, non-invasive external markers often fail to achieve sufficient fixation and stability in edentulous cases, thereby compromising registration accuracy [14]. Instead, invasive markers, such as mini-screws, can address this issue, while it may cause discomfort [15–17]. Apart from these markers perse, various factors, such as operator variability, marker placement error, and image noise, can further reduce registration accuracy [18,19].

To address these limitations, a transparent orthodontic retainer registration device embedded with radiopaque zirconia beads were developed. This device combines these beads and the personalized anatomical structure of teeth, improving precision image registration that can be used for bone augmentation evaluation. The present study aims to validate the accuracy, reproducibility of this new method. To our best knowledge, this personalized dental template for precise 3D image registration is first documented.

2. Materials and Methods

2.1. Materials

A cadaveric adult mandibular specimen with a complete posterior dentition was prepared by replacing missing teeth using resin material (3M ESPE Protemp™ 4; 3M) to maintain dentition integrity and stability. A custom registration apparatus was fabricated from thermoplastic material and embedded with 11 zirconium beads (1.0 mm diameter).

CBCT scans were acquired using standardized protocols at baseline (with and without the registration device), three, and six-month follow-ups (registration apparatus only). The CBCT images were converted to the STL (Standard Tessellation Language) format using Mimics software. Two independent examiners performed manual image registrations using three methods: this reported registration device, anatomical dental landmarks, and arbitrary points.

2.1.1. Preparation of the Dental Template for Registration

An impression of the mandibular dentition was obtained using alginate (ALG Jeltrate; Dentsply Sirona, Charlotte, NC, USA), and a medical-grade plaster (Tropicalcin; Zhermack) to create a plaster model. A 1 mm thick transparent thermoplastic sheet (Thermoforming Blank DV D42451; Drufosof) was then adapted to the plaster model to fabricate the corresponding transparent registration apparatus.

Eleven semicircular grooves (1 mm diameter) were created and evenly distributed at different heights, following previously described methods on the buccal and lingual surfaces of each register [20,21]. Zirconia beads (1.0 mm diameter; ISO 9001 certified; density ≥6.0 g/cm^3; Xiong Sheng, China) were positioned at the center of each groove and fixed using a transparent cyanoacrylate-based adhesive (502 adhesive; HG/T2492-2007 standard; Aibida, China). The adhesive exhibits low radiopacity, minimizing interference with CBCT imaging and ensuring clear visualization of the zirconia markers. A minimal amount of adhesive was applied to avoid imaging artifacts. The fit of each registration template on the mandibular dentition was evaluated to ensure secure and stable seating (Figure 1).

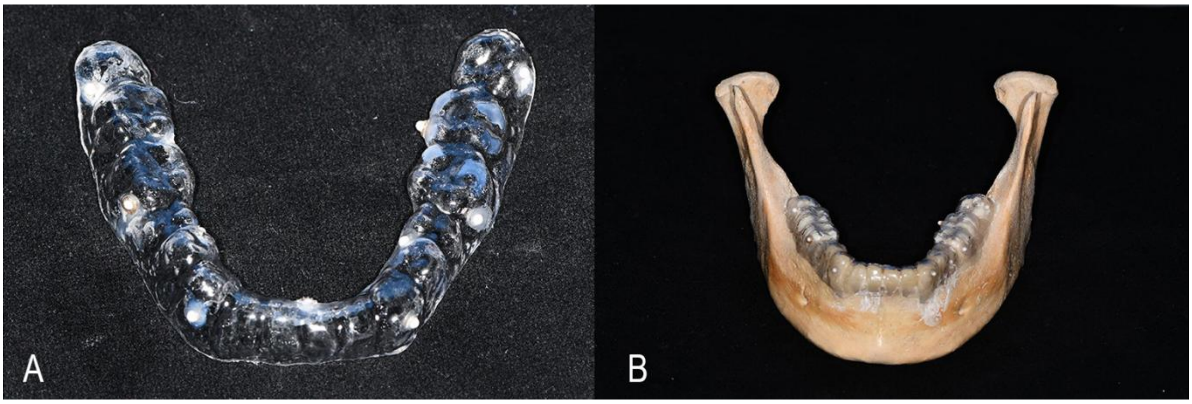

Figure 1. (**A**) The novel dental template register with zirconia beads. (**B**) The mandibular specimen with the dental template register positioned on the dentition.

2.1.2. Acquisition, Reconstruction, and Registration of 3D Models

The occlusal plane of the mandible was aligned parallel to the CT table using commercially available tape. Mandibular specimens were scanned with and without the registration apparatus using a high-resolution CBCT system (Planmeca ProMax; Planmeca Oy) under standardized conditions. Axial multi-slice images (four slices) were acquired at a table speed of 3.75 mm per rotation (9.0 s per rotation) with 96 kV and 7.1 mA (LightSpeed Qx/I CT [A6.1]; General Electric Healthcare, Milwaukee, WI, USA). Two baseline datasets were obtained: (A) mandible with the apparatus and (B) mandible without the apparatus. Scans of the mandible with the apparatus were repeated at three (C) and six months (D) to assess potential deformation over time. The specimen was stored under controlled conditions to prevent changes. All datasets were saved in DICOM format.

DICOM datasets (A, B, C, and D) were converted to STL format and imported into Mimics 2.1.0 (Materialise NV, 2018). 3D models were generated using threshold segmentation, with the same threshold applied to all datasets to ensure consistent, high-quality images (Figure 2). The STL models were subsequently imported into Geomagic Control X (version 2020; 3D Systems, Rock Hill, SC, USA) for further processing.

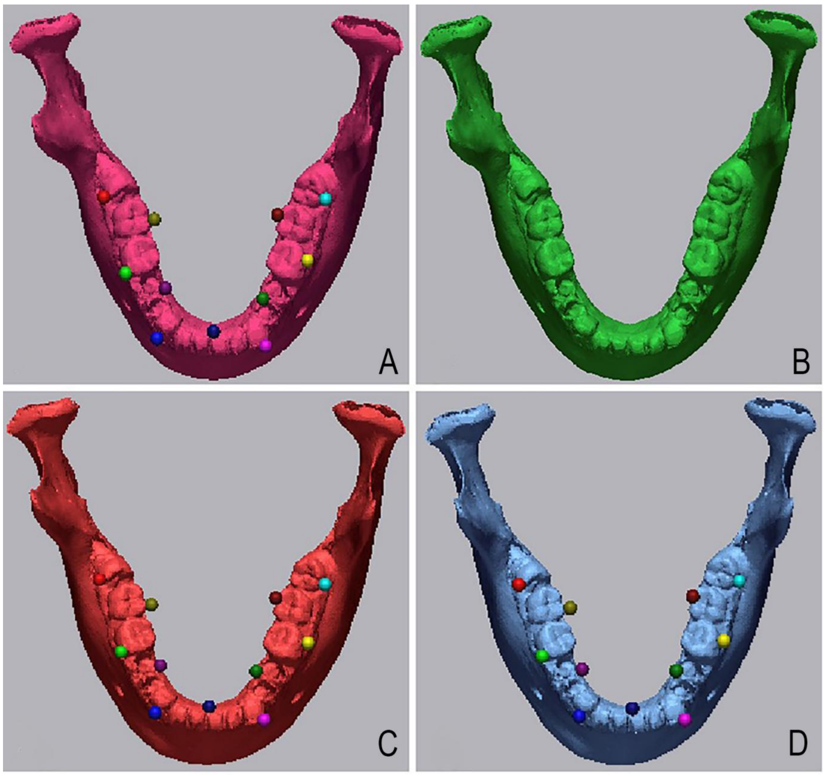

Figure 2. (**A**) Phase I: Three-dimensional model of the mandibular specimen with the REGISTER. (**B**) Phase I Three-dimensional model of the mandibular specimen without the REGISTER. (**C**) Three-dimensional model of the mandibular specimen with the REGISTER after 3 months. (**D**) Three-dimensional model of the mandibular specimen with the REGISTER after 6 months.

2.1.3. Evaluation of the Accuracy of the Dental Template Register

A clinician with one year of experience (Examiner 1) performed manual registration of the two-part 3D models (A-A) using this developed registration template (Method 1, Time 0) (Figure 3). Each registration was repeated five times to assess the accuracy of the registration appliance. The two-part 3D models without the apparatus(B-B) were registered using two alternative methods: Method 2, based on 11 anatomical landmarks of the tooth cusps, and Method 3, using 11 self-selected arbitrary points (Figure 3). Each of these registrations was also repeated five times. Examiner 2, a second clinician with one year of experience conducted the evaluation using the same abovementioned protocol.

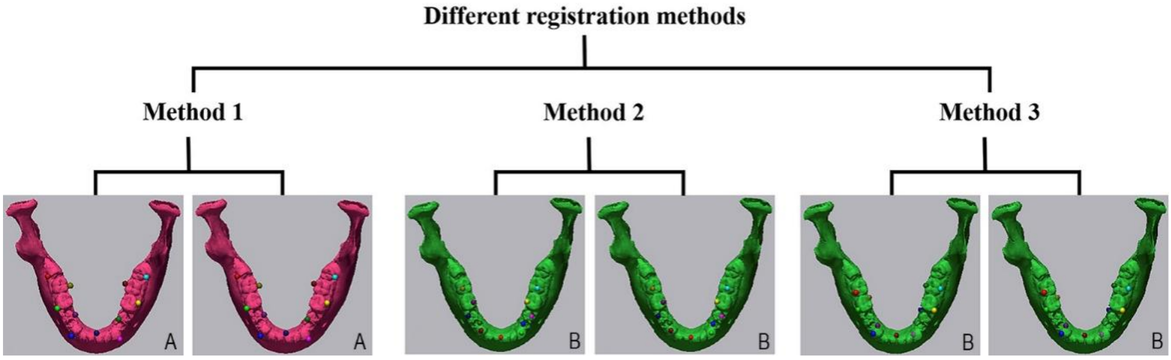

Figure 3. Method 1: Registration of the 3D models of the mandibular specimens based on the zirconium bead marking points; Method 2: Registration of the 3D models of the mandibular specimens based on 11 anatomical landmarks on tooth cusps; Method 3: Registration of the 3D models of the mandibular specimens based on 11 self-selected arbitrarily labeled points.

2.1.4. Assessment of Registration Reproducibility across Time Points

To evaluate the temporal stability of the registration device, 3D models obtained at baseline (A), 3 months (C), and 6 months (D) were registered using zirconia bead-based alignment (Figure 3). The mandibular specimen remained unchanged throughout the study period. This design was used to control biological variables, such that any deviations observed across time points would primarily reflect changes in the positioning stability and reproducibility of the registration device rather than anatomical changes. Each registration was repeated five times. A second examiner independently performed the same procedures to assess inter-examiner consistency.

2.1.5. Analysis of Inter-Examiner Consistency of the Register

The consistency of the register between examiners was evaluated by having a second clinical resident (Examiner 2, one year of experience) independently perform manual pairwise registration of the 3D models using the same procedures as Methods 1–3 (Figure 3). Each registration was repeated five times for each method to assess inter-examiner reliability.

2.1.6. Statistical Analysis

Statistical analyses were performed using SPSS software (version 23, IBM SPSS Statistics; IBM Corp). RMS deviations of registered 3D models were first compared across groups using analysis of variance (ANOVA). Paired t-tests were then conducted with Method 1 at Time 0 as the reference. A p-value < 0.05 was considered statistically significant.

Inter-examiner registration results were assessed for normality using the Shapiro–Wilk test, followed by paired t-tests. Descriptive statistics for each group, including mean, standard deviation, 95% confidence interval, and minimum and maximum values, were calculated.

3. Results

3.1. Accuracy of the Register

The novel registration appliance demonstrated significantly higher accuracy (RMS = 0.055 ± 0.030 mm) than the anatomical landmark (RMS = 0.171 ± 0.063 mm) and arbitrary point methods (RMS = 0.491 ± 0.255 mm, p = 0.002). RMS deviations after 3D model registration differed significantly among the three methods (p = 0.002). Pairwise comparisons revealed no significant difference between Method 1 and Method 2 (p = 0.409), whereas

Method 1 and Method 3 differed significantly ($p = 0.001$). Method 1 achieved the smallest RMS deviation (0.055 ± 0.030 mm), while Method 3, using 11 self-selected arbitrary points, had the largest deviation (0.491 ± 0.255 mm) (Table 1).

Table 1. RMS deviation after registration using different methods.

Method	Max	Min	Mean (±SD)	*p*-Value	95% Confidence Interval		F	*p*-Value
					Lower Bound	Upper Bound		
1	0.089	0.022	0.055 ± 0.030	/	/	/		
2	0.239	0.074	0.171 ± 0.063	0.409 #	−0.126	0.357	10.921	0.002
3	0.857	0.255	0.491 ± 0.255	0.001 #	0.194	0.678		

RMS, root mean square; #: comparison with Method 1.

The highest overall model overlap was observed in Method 1, with complete alignment of occlusal surfaces and dentition (Figure 4).

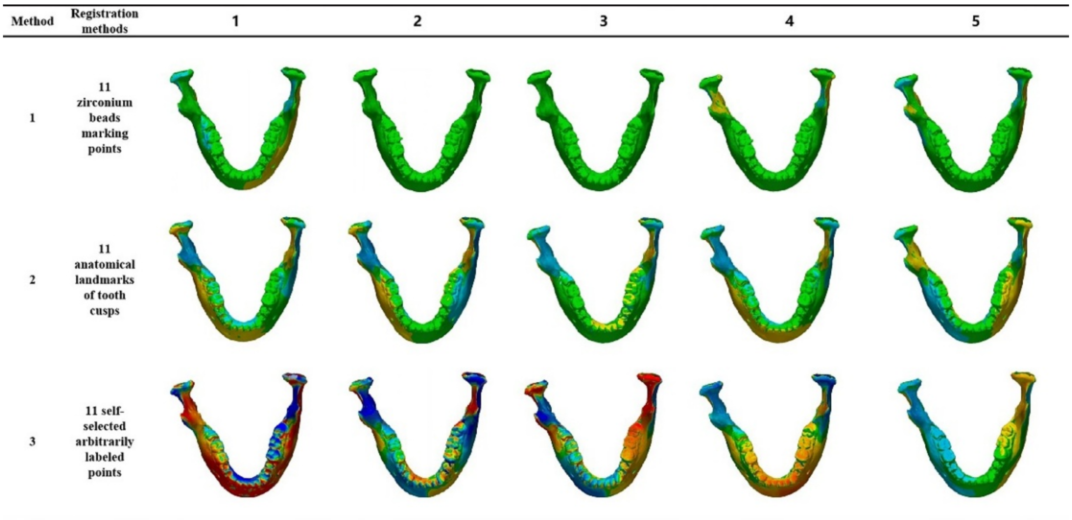

Figure 4. Three-dimensional deviation chromatograms after model registration using different registration methods.

The lowest overlap occurred in Method 3, where partial occlusal surfaces and dentition exhibited substantial deviations (Figure 5).

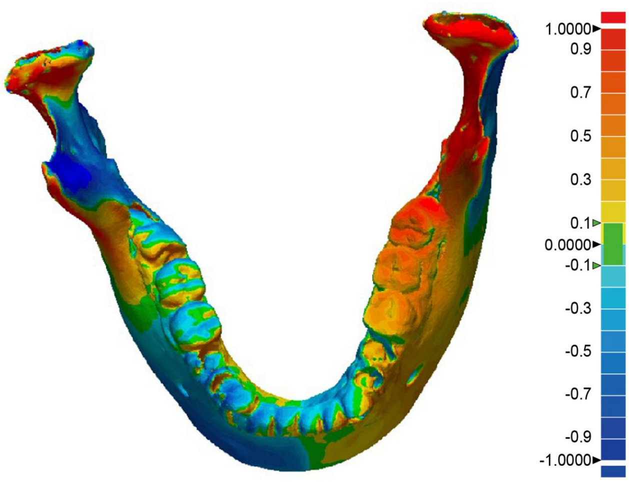

Figure 5. Distribution map of the deviation of the three-dimensional model of the mandible obtained by using the registration method of selecting any point randomly from 11 points. The color of each point is encoded according to its deviation value (unit: mm). Warm colors (yellow-red) represent positive deviations, cool colors (blue-green) represent negative deviations, and the green area indicates deviations close to 0 mm. The deviations are mainly concentrated in partial occlusal surfaces and dentition.

3.2. Reproducibility of the Register Over Time

RMS deviations after 3D model registration did not differ significantly across Time 0, 3, and 6 (p = 0.856). Pairwise comparisons also revealed no significant differences between Time 0 and Time 3 (p = 0.893) or Time 0 and Time 6 (p = 0.813). The smallest RMS deviation was observed at Time 6 (0.048 ± 0.017 mm) (Table 2).

Table 2. RMS deviation at different timepoints in method 1.

Time	Max	Min	Mean (±SD)	*p*-Value	95% Confidence Interval		F	*p*-Value
					Lower Bound	Upper Bound		
0	0.089	0.022	0.055 ± 0.030	/	/	/		
3	0.080	0.029	0.050 ± 0.018	0.893	−0.041	0.030	0.157	0.856
6	0.066	0.028	0.048 ± 0.017	0.813	−0.043	0.028		

RMS, root mean square.

Overall, model overlap remained high and stable across all time points, with complete alignment of occlusal surfaces and dentition. The greatest overlap between models was observed at Time 6 (Figure 6).

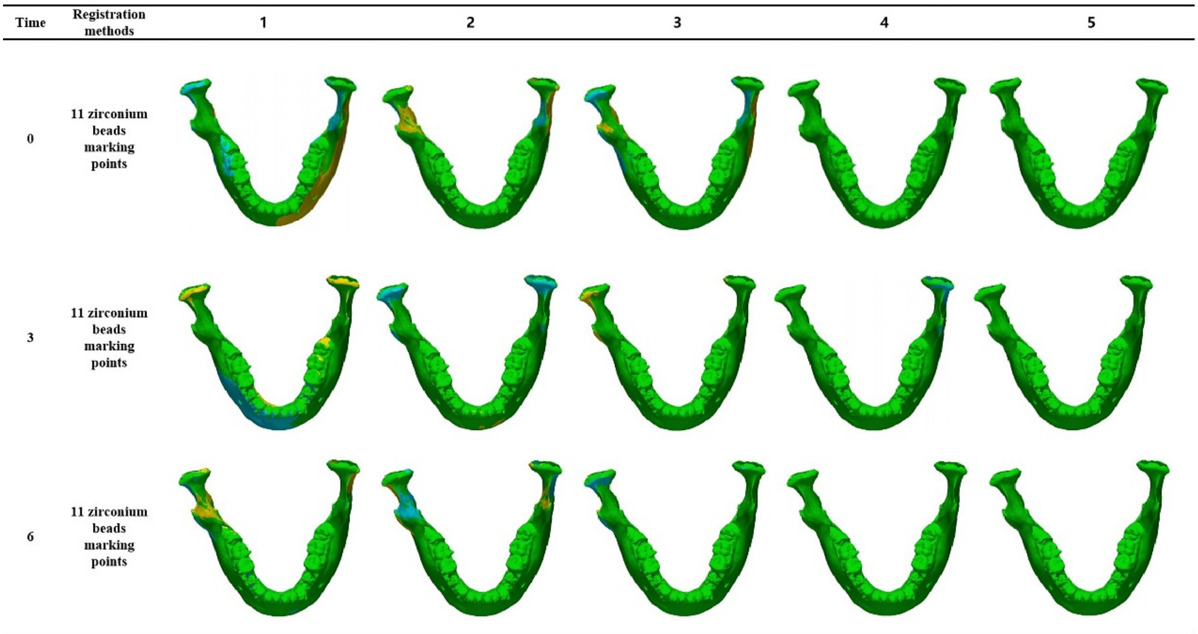

Figure 6. Three-dimensional deviation chromatograms of two model registrations performed during different periods.

3.3. Consistency of the Register among Various Examiners

The apparatus maintained excellent reproducibility over six months (p = 0.856) and showed consistent results between examiners (p = 0.441). The apparatus demonstrated good inter-examiner reproducibility. No significant differences were observed between the two examiners for Method 1 (p = 0.441) and Method 3 (p = 0.243). However, Method 2 showed a statistically significant inter-examiner difference (p = 0.018), indicating greater operator dependency when anatomical landmarks were used (Table 3).

Table 3. RMS deviation of Methods 1, 2, and 3 from two examiners.

Method	Examiner	Max	Min	Mean (±SD)	*t*	*p*-Value
1	1	0.089	0.022	0.055 ± 0.030	0.855	0.441
	2	0.079	0.030	0.049 ± 0.018		
2	1	0.239	0.074	0.171 ± 0.063	−3.900	0.018
	2	0.679	0.223	0.404 ± 0.174		
3	1	0.857	0.255	0.491 ± 0.255	−1.369	0.243
	2	1.080	0.397	0.569 ± 0.291		

RMS, root mean square.

Overall, Method 1 produced high overlap between models for both examiners, with complete alignment of occlusal surfaces and dentition. In contrast, Methods 2 and 3 resulted in lower overall overlap, with substantial deviations observed in occlusal surfaces and dentition (Figure 7).

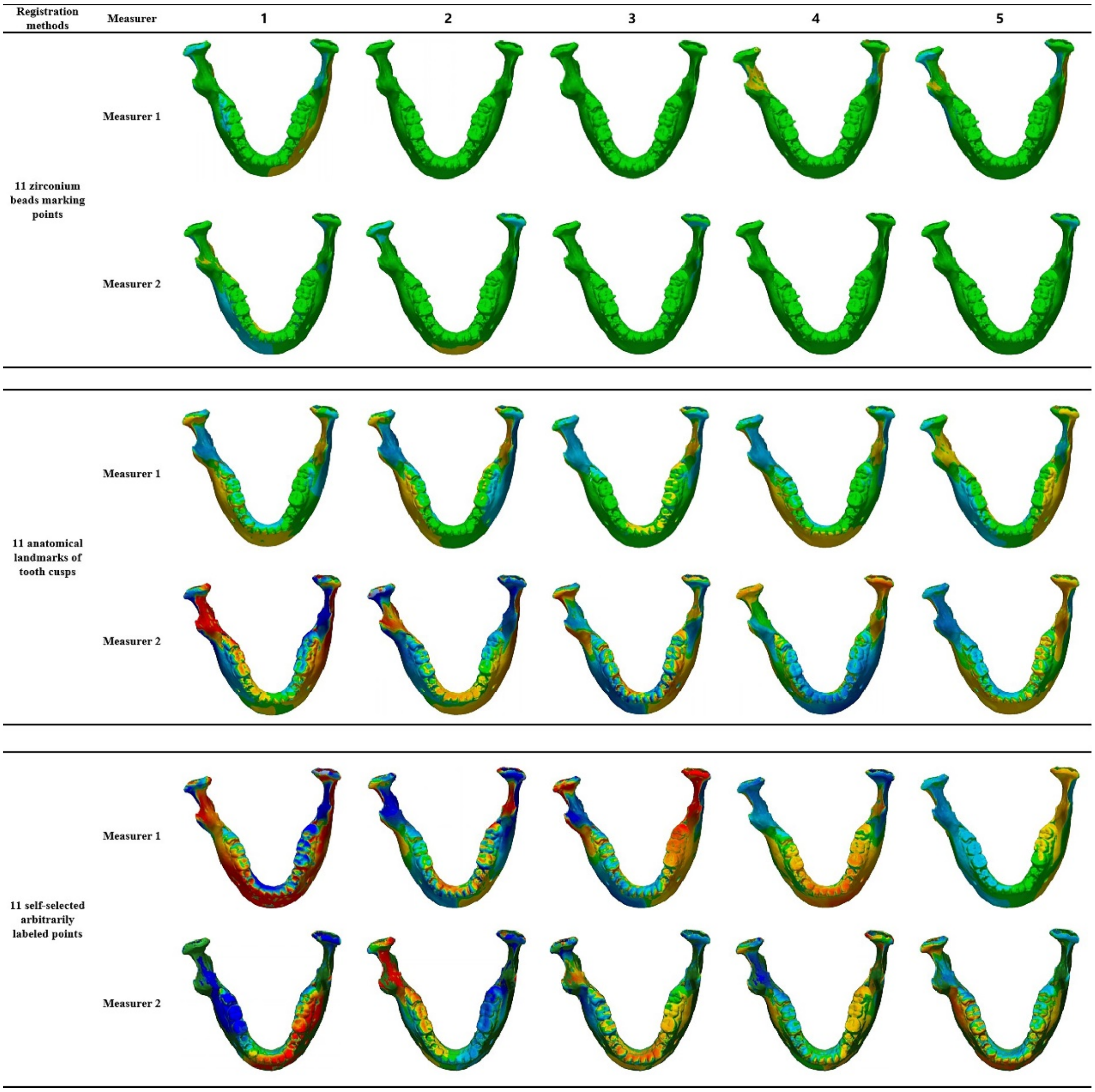

Figure 7. Three-dimensional deviation chromatograms after model registration using three registration methods by two examiners.

4. Discussion

In dental implantology, bone augmentation is an essential procedure for repairing alveolar bone defects, and accurate 3D assessment of postoperative bone changes is crucial for implant planning and outcome evaluation. However, current image registration methods in clinical practice still face challenges, such as image noise, artifacts, and operator-dependent variability. To address these issues, this study developed a non-destructive registration device that integrates zirconia beads into a customized dental template, enabling precise, repeatable, and user-friendly 3D measurements. In recent years, spherical zirconia beads have been demonstrated to exhibit high radiodensity and excellent imaging contrast, allowing clear visualization and differentiation from bone tissue on CBCT image [22,23]. Compared with conventional registration methods based on anatomical landmarks or arbitrarily selected points, this register achieves higher registration accuracy, mainly due to its individualized design, stable fixation on the dentition, and high radiographic visibility of the zirconia markers. Repeated measurements at different time points confirmed the temporal stability and inter-operator consistency of the register.

The main advantage of register lies in its ability to minimize systematic errors inherent in traditional image registration. Image quality is a critical factor that influences registration accuracy. Ketcha et al. reported that a low signal-to-noise ratio (SNR) and large voxel size markedly increase registration errors, especially in fine or marginal structures [24]. Under low-dose CT or suboptimal CBCT scanning conditions, registration stability tends to decrease. In contrast, the high-contrast zirconia markers used in register remain clearly identifiable under various scanning parameters, thereby enhancing robustness in low-SNR environments.

Patient-related factors also have a considerable impact on registration performance. Variations in patient positioning, respiration, or soft-tissue movement during CT acquisition can cause inter-scan misalignment [25]. In addition, metal artifacts frequently occur in dental imaging. Orthodontic attachments, restorations, implants, and metallic fillings may cause beam hardening, photon starvation, and scattering, resulting in streak artifacts that markedly reduce the accuracy of registration [26]. This registration approach overcomes these limitations by locating the registration points on the external dental surface, away from high-density metallic structures, thereby effectively minimizing artifact interference. In contrast, registration methods that rely on dental anatomical landmarks—such as cusp tips—are often unusable in edentulous patients or in cases of severe occlusal wear, which considerably limits their clinical applicability.

Furthermore, discrepancies in scanning parameters and operator performance represent additional sources of error. Variations in the field of view (FOV) or scanning angle between two CT scans reduce the overlapping registration region, compromising stability [27]. Manual landmark identification and boundary delineation may also introduce subjective bias [25]. Moreover, inconsistencies in evaluation metrics—such as target registration error (TRE), Hausdorff distance, and Dice coefficient—make cross-study comparisons difficult [28]. In the present study, the use of a fixed, individualized template minimized operator dependency, achieving consistent registration results across different observers and time points.

In experimental validation, two identical 3D datasets were repeatedly registered using various methods, and RMS deviation values were compared to evaluate accuracy. This device with zirconia markers achieved significantly higher registration precision than internal feature-based methods, with lower registration errors than those reported in previous studies [20,21,29–31]. This superior performance can be attributed to the stable and well-defined physical markers and the rigid coupling between the customized template and the dental arch. Additionally, the transparent resin material used for the template introduced no imaging artifacts, providing an optimal support medium for zirconia beads.

Beyond accuracy, time efficiency and clinical applicability are also important considerations for registration techniques. Although advanced non-rigid algorithms theoretically achieve higher accuracy, they are computationally complex and time-consuming, making them unsuitable for intraoperative or real-time applications [32]. Traditional manual correction or landmark-based methods also increase operator workload and subjectivity [25]. This registration device achieves physical alignment through mechanical fixation and radiopaque markers, combining high precision with superior efficiency and clinical feasibility.

From a clinical perspective, the primary value of this registration method lies in enabling accurate three-dimensional comparison of bone morphology before and after augmentation procedures. This allows clinicians to quantitatively assess bone gain in both horizontal and vertical dimensions, thereby supporting implant planning and outcome evaluation.

In particular, this method may be applied in scenarios such as evaluating the outcomes of alveolar ridge preservation or guided bone regeneration, assessing augmented bone volume prior to implant placement, and longitudinal monitoring of peri-implant bone changes.

In the present study, we focused on validating the accuracy and reproducibility of the registration method using controlled datasets. Although direct comparison of pre- and post-augmentation clinical data was not performed, this methodological validation is a necessary prerequisite to ensure that future measurements reflect true biological changes rather than registration errors. Future clinical studies will apply this method to longitudinal patient data to further establish its clinical utility.

Nevertheless, the accuracy of this registration device may still be influenced by CBCT imaging parameters, algorithmic performance, and marker quality [33]. The present study was conducted on cadaveric specimens, which do not fully represent the dynamic conditions of living patients. Future clinical trials with larger sample sizes are needed to further validate its stability and applicability, especially in complex oral conditions such as edentulous jaws or severe periodontal bone loss. In addition, the precise seating and stability of this device depend on the morphology of the dentition and the number of the remained teeth. In edentulous patients or those with extensive tooth loss and insufficient occlusal support, it is hardly to install the device precisely and fix it, thereby limiting its clinical applicability. The long-term mechanical and material stability of the customized template also warrant further investigation. In particular, the material must withstand continuous masticatory forces, temperature fluctuations, and moisture in the oral environment, which may affect their physical properties and dimensional stability.

In addition, the dimensional stability of the thermoplastic material and the durability of the adhesive used to fix zirconia beads should be considered when translating this device into clinical practice. In an intraoral environment, thermoplastic materials may be affected by temperature fluctuations, moisture absorption, and repeated masticatory loading, which could lead to creep deformation or minor dimensional changes over time. Similarly, the adhesive interface may be susceptible to hydrolytic degradation, potentially influencing long-term bonding stability.

Although no significant differences in registration accuracy were observed across the 6-month period in this study, the experimental conditions did not fully simulate intraoral aging. Therefore, future studies incorporating artificial aging protocols, such as thermal cycling and mechanical loading, as well as long-term clinical validation, are necessary to further assess the durability and stability of the device.

5. Conclusions

The registration device provides high accuracy, stability, and reproducibility for assessing bone augmentation in implant dentistry. The device demonstrated consistent performance over time and reliable inter-examiner measurements, supporting its repeatability and robustness. These findings suggest that this device is a practical and reliable tool for precise 3D image registration, with potential applications in evaluating bone volume changes following various augmentation procedures or over different time intervals.

6. Clinical Implications

This study introduces a novel approach utilizing transparent orthodontic retainers with radiopaque zirconia beads to evaluate bone augmentation. The method's exceptional accuracy, evidenced by high reproducibility and low root mean square (RMS) deviations, allows for the precise quantification of bone volume changes throughout implant treatment. By optimizing 3D image registration, this technique enhances the reliability of surgical planning and long-term implant prognosis. The current design is particularly suitable for partially dentate patients with sufficient remaining teeth to ensure stable fixation. Its application in fully edentulous patients remains limited and requires further design modifications.

Author Contributions

The individual contributions of each author are specified below: Z.S.: conceptualization, methodology, investigation, data curation, formal analysis, writing—original draft preparation; J.Z.: investigation, data curation, methodology, writing—review and editing; X.X.: formal analysis, validation, data interpretation, writing—review and editing; L.W.: literature review, visualization, preparation of figures and tables; C.X.: methodology, supervision, project administration, writing—review and editing; D.Y.: conceptualization, supervision, data interpretation, writing—review and editing, correspondence. Both C.X. and D.Y. are the corresponding authors for this manuscript, ensuring communication with the journal and addressing reviewers' comments during the revision process. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was approved by the ethics committee of the Shanghai Ninth People's Hospital (NO. SH9H-2023-T91-1) in Shanghai, China, and was conducted according to the Helsinki Declaration of 1964, as revised in 2008.

Informed Consent Statement

Not applicable.

Data Availability Statement

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

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized in the preparation of this manuscript.

References

1. Gargallo-Albiol, J. How to Enhance Dental Implant Therapies and Definitive Restoration Outcomes to Reduce Complications and Improve Patient Well-Being. *Materials* **2023**, *16*, 3730.
2. Bassir, S.H.; Alhareky, M.; Wangsrimongkol, B.; et al. Systematic Review and Meta-Analysis of Hard Tissue Outcomes of Alveolar Ridge Preservation. *Int. J. Oral. Maxillofac. Implants* **2018**, *33*, 979–994.
3. Stumbras, A.; Kuliesius, P.; Januzis, G.; et al. Alveolar Ridge Preservation after Tooth Extraction Using Different Bone Graft Materials and Autologous Platelet Concentrates: A Systematic Review. *J. Oral. Maxillofac. Res.* **2019**, *10*, e2.
4. Tan, W.L.; Wong, T.L.; Wong, M.C.; et al. A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans. *Clin. Oral. Implants Res.* **2012**, *23*, 1–21.
5. MacBeth, N.; Trullenque-Eriksson, A.; Donos, N.; et al. Hard and soft tissue changes following alveolar ridge preservation: A systematic review. *Clin. Oral. Implants Res.* **2017**, *28*, 982–1004.
6. D'haese, J.; Ackhurst, J.; Wismeijer, D.; et al. Current state of the art of computer-guided implant surgery. *Periodontol. 2000* **2017**, *73*, 121–133.
7. Sethi, A.; Kaus, T.; Sharma, N. Clinical record-keeping for monitoring treatment outcomes in implant dentistry: A case study. *Prim. Dent. J.* **2013**, *2*, 39–43.
8. MacBeth, N.D.; Donos, N.; Mardas, N. Alveolar ridge preservation with guided bone regeneration or socket seal technique. A randomised, single-blind controlled clinical trial. *Clin. Oral. Implants Res.* **2022**, *33*, 681–699.
9. Lutz, R.; Neukam, F.W.; Simion, M.; et al. Long-term outcomes of bone augmentation on soft and hard-tissue stability: A systematic review. *Clin. Oral. Implants Res.* **2015**, *26*, 103–122.
10. El-Gamal, F.E.Z.A.; Elmogy, M.; Atwa, A. Current trends in medical image registration and fusion. *Egyptian Informatics Journal* **2016**, *17*, 99–124.
11. Park, J.H.; Hwang, C.J.; Choi, Y.J.; et al. Registration of digital dental models and cone-beam computed tomography images using 3-dimensional planning software: Comparison of the accuracy according to scanning methods and software. *Am. J. Orthod. Dentofacial Orthop.* **2020**, *157*, 843–851.
12. Flügge, T.; Derksen, W.; Te Poel, J.; et al. Registration of cone beam computed tomography data and intraoral surface scans—A prerequisite for guided implant surgery with CAD/CAM drilling guides. *Clin. Oral. Implants Res.* **2017**, *28*, 1113–1118.
13. Zou, J.; Gao, B.; Song, Y.; et al. A review of deep-based deformable medical image registration. *Front. Oncol.* **2022**, *12*, 1047215.
14. Yang, S.; Dong, B.; Zhang, Q.; et al. An Indirect Digital Technique to Transfer 3D Printed Casts to a Mechanical Articulator with Individual Sagittal Condylar Inclination Settings Using CBCT and Intraoral Scans. *J. Prosthodont.* **2022**, *31*, 822–827.
15. Porter, B.C.; Rubens, D.J.; Strang, J.G.; et al. Three-dimensional registration and fusion of ultrasound and MRI using major vessels as fiducial markers. *IEEE Trans. Med. Imaging* **2001**, *20*, 354–359.
16. Lan, K.; Tao, B.; Wang, F.; et al. Accuracy evaluation of 3D-printed noninvasive adhesive marker for dynamic navigation implant surgery in a maxillary edentulous model: An in vitro study. *Med. Eng. Phys.* **2022**, *103*, 103783.
17. Wang, J.; Shen, Y.; Yang, S. A practical marker-less image registration method for augmented reality oral and maxillofacial surgery. *Int. J. Comput. Assist. Radiol. Surg.* **2019**, *14*, 763–773.
18. Lee, W.; Lee, S.; Chong, S.; et al. Radiation dose reduction and improvement of image quality in digital chest radiography by new spatial noise reduction algorithm. *PLoS ONE* **2020**, *15*, e0228609.
19. Naik, R.R.; Hoblidar, A.; Bhat, S.N.; et al. A Hybrid 3D-2D Image Registration Framework for Pedicle Screw Trajectory Registration between Intraoperative X-ray Image and Preoperative CT Image. *J. Imaging* **2022**, *8*, 185.
20. Fang, S.B.; Yang, G.J.; Kang, Y.F.; et al. Method and accuracy of determining the jaw position of repositioning splint with the aid of digital technique. *Beijing Da Xue Xue Bao Yi Xue Ban* **2020**, *53*, 76–82.
21. Swennen, G.R.; Barth, E.L.; Eulzer, C.; et al. The use of a new 3D splint and double CT scan procedure to obtain an accurate anatomic virtual augmented model of the skull. *Int. J. Oral. Maxillofac. Surg.* **2007**, *36*, 146–152.
22. Zheng, R.; Ye, J.; Zhang, X.; et al. Influence factors on registration of three-dimensional contrast-enhanced ultrasound fusion imaging in evaluating the ablative margin—A phantom study. *Clin. Hemorheol. Microcirc.* **2023**, *83*, 117–128.
23. Blokker, A.M.; Wood, R.; Milner, J.C.; et al. Novel quantification of the regional strain distribution in the anterior

cruciate ligament in response to simulated loading using micro-CT imaging. *J. Exp. Orthop.* **2021**, *8*, 95.
24. Ketcha, M.D.; de Silva, T.; Han, R.; et al. Fundamental limits of image registration performance: Effects of image noise and resolution in CT-guided interventions. *Proc. SPIE Int. Soc. Opt. Eng.* **2017**, *10135*, 62–69.
25. Luu, H.M.; Klink, C.; Niessen, W.; et al. Non-Rigid Registration of Liver CT Images for CT-Guided Ablation of Liver Tumors. *PLoS ONE* **2016**, *11*, e0161600.
26. Kim, C.; et al. An additional tilted-scan-based CT metal-artifact-reduction method for radiation therapy planning. *J. Appl. Clin. Med. Phys.* **2019**, *20*, 237–249.
27. Brock, K.K.; Mutic, S.; McNutt, T.R.; et al. Use of image registration and fusion algorithms and techniques in radiotherapy: Report of the AAPM Radiation Therapy Committee Task Group No. 132. *Med. Phys.* **2017**, *44*, e43–e76.
28. Gooding, M.J.; Eccles, C.L.; Fuss, M.; et al. Assessing The Quality of Deformable CT-MR Registration for the Purpose of Multimodal Radiotherapy Contouring. *Int. J. Radiat. Oncol. Biol. Phys.* **2011**, *81*, S812–S813.
29. Swennen, G.R.; Mommaerts, M.Y.; Abeloos, J.; et al. A cone-beam CT based technique to augment the 3D virtual skull model with a detailed dental surface. *Int. J. Oral. Maxillofac. Surg.* **2009**, *38*, 48–57.
30. Berry, J.; O'Malley, B.W, Jr.; Humphries, S.; et al. Making image guidance work: Understanding control of accuracy. *Ann. Otol. Rhinol. Laryngol.* **2003**, *112*, 689–692.
31. Schaefer, O.; Watts, D.C.; Sigusch, B.W.; et al. Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: A three-dimensional analysis of accuracy and reproducibility. *Dent. Mater.* **2012**, *28*, 320–326.
32. Elhawary, H.; Oguro, S.; Tuncali, K.; et al. Multimodality non-rigid image registration for planning, targeting and monitoring during CT-guided percutaneous liver tumor cryoablation. *Acad. Radiol.* **2010**, *17*, 1334–1344.
33. Mehl, A.; Reich, S.; Beuer, F.; et al. Accuracy, trueness, and precision—A guideline for the evaluation of these basic values in digital dentistry. *Int. J. Comput. Dent.* **2021**, *24*, 341–352.