Received: 24 August 2020 | Revised: 19 November 2020 | Accepted: 21 November 2020
DOI: 10.1111/clr.13694

ORIGINAL RESEARCH

CLINICAL ORAL IMPLANTS RESEARCH WILEY

The migration of neighboring and antagonist teeth three months after implant placement in healed single tooth-missing sites

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Abstract

Objectives: To quantify the neighboring and antagonist teeth migration of a single posterior tooth-missing site within 3 months using digital scanning and measuring techniques.

Materials and Methods: Intraoral scans (IOS) were made in 40 patients presenting a single posterior tooth-missing gap and receiving implant therapy. IOS were obtained at the day of and three months after implant surgery rendering a digital baseline model (BM) and a digital follow-up model (FM). Digital models were superimposed using the implant scan body as reference. Antagonist models were processed by the best fit alignment. Dimensional change between anatomical landmarks on neighboring teeth and that of featuring points on antagonistic teeth were measured using a three-dimensional analysis software. The Mann–Whitney *U* test was applied to compare the tooth-moving distance between the mesial and distal neighboring teeth. The Kruskal–Wallis one-way ANOVA was used to test the difference in dimensional change in tooth-missing site among age subgroups.

Results: The mean dimensional change in the tooth-missing site was −37.62 ± 106.36 μm (median: −28.33 μm, Q_{25} −72.65/Q_{75} 38.97) mesial-distally and −67.91 ± 42.37 μm (median: −61.50 μm, Q_{25} −88.25/Q_{75} −36.75) occlusal-gingivally. Eighteen out of 40 mesial neighboring teeth and 24 out of 40 distal neighboring teeth showed migration towards the implants. When patients were grouped according to age, the mesial-distal reduction in the tooth-missing site was significantly larger in patients younger than 30 years compared with those older than 50 years ($p < .05$).

Conclusions: The dimensions of posterior tooth-missing sites decreased over an observation period of 3 months.

KEYWORDS
dental implants, digital, three-dimensional, tooth migration, tooth movement

1 | INTRODUCTION

The reports about migration of neighboring and antagonist teeth after natural tooth extraction remain inconsistent. A variety of clinical studies revealed that the integrity and stability of natural dentition could be affected for a long time after tooth extraction if the space was left without restoration (Christou & Kiliaridis, 2007; Craddock et al., 2007; Garcia-Herraiz et al., 2012, 2017).

Drifting and tipping of the neighboring teeth (Weinstei, 1967) and overeruption of the antagonist teeth (Lyka et al., 2001) are typical phenomena observed 5–12 years after tooth loss (Christou & Kiliaridis, 2007; Lindskog-Stokland et al., 2012). Nevertheless, other studies showed that the incidence of adjacent teeth moving toward edentulous area was not always the same (Kiliaridis et al., 2000; Love & Adams, 1971), and the probability and distance of teeth movement could be small. The mean reduction in the mesial-distal tooth-missing gap did not exceed 1 mm six years after tooth extraction (Gragg et al., 2001; Shugars et al., 2000). With the tooth-missing time prolonged, the risk of dimensional edentulous gap changes decreased (Garcia-Herraiz et al., 2017; Gragg et al., 2001).

Most of the studies investigating dimensional change in tooth-missing gap after tooth extraction generally had a 5- to 20-year observation time (Christou & Kiliaridis, 2007; Gragg et al., 2001; Kiliaridis et al., 2000; Love & Adams, 1971; Shugars et al., 2000). Only one study compared the change in tooth-missing gap between 1 and 3 months after tooth extraction by analyzing stone models with confocal laser scanning microscopy technique (Garcia-Herraiz et al., 2017). They reported 0.35-mm and 0.67-mm mean gap reduction 1 and 3 months following tooth extraction.

Different outcomes may come from different timing and measurement techniques. Methods of measurement used in prior studies included the following: clinical examination (Kiliaridis et al., 2000; Love & Adams, 1971), questionnaire (Kiliaridis et al., 2000), radiographic evaluation (Gragg et al., 2001; Lindskog-Stokland et al., 2012; Shugars et al., 2000), and stone model measurement (Garcia-Herraiz et al., 2017). Some of these methods were qualitative techniques (Kiliaridis et al., 2000; Love & Adams, 1971), while others were quantitative techniques (Garcia-Herraiz et al., 2017; Gragg et al., 2001; Lindskog-Stokland et al., 2012; Shugars et al., 2000). These quantitative techniques have some limitations such as lacking fixed reference markers, using two-dimensional (2D) radiographies, involving too many manual interventions in data acquisition, or failing to standardize the reference points. All of these factors may have an influence on the results.

Novel digital technology has been adopted to improve dimensional measurement accuracy. Recent studies showed that the fully digital workflow in the restoration of posterior single implant crowns was highly effective and efficient (Joda et al., 2017; Muhlemann et al., 2018). Intraoral scanners with an accuracy of up to 12.7 µm (Moreira et al., 2015) can generate digital model which can be easily stored, transmitted, and utilized repeatedly without information loss over time (Shah et al., 2004). Compared with 2D radiographic measurement, linear measurement of three-dimensional (3D) digital model and quantitative analysis using inspection software can reduce patients' X-ray exposure and the error caused by image deformation.

The latest research showed that optical impression could be taken immediately after implant placement, and posterior single implant crown could be successfully delivered three months after the surgery (Guo et al., 2019; Pan et al., 2019). However, it is still unclear if there are dimensional changes in the tooth-missing site during the 3 months following implant placement.

Therefore, the aim of the present clinical study was to analyze position changes in neighboring and antagonist teeth of single posterior tooth-missing site, between the day of implant placement and 3 months later using digital scanning and measuring techniques (CONSORT 2010 checklist). The null hypothesis was that there were no dimensional changes in single posterior tooth-missing sites between implant placement and 3 months later.

2 | MATERIALS AND METHODS

2.1 | Participants

This study was conducted in the Department of Prosthodontics, Peking University School and Hospital of Stomatology.

The study was reviewed and approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (Ethical approval No: PKUSSIRB-201732002). The study had been registered in Chinese Clinical Trial Registry (ChiCTR; ChiCTR No: INR-17014092). The Consolidated Standards of Reporting Trials (CONSORT) guidelines were used as the framework for this study.

This study was undertaken with the understanding and written consent of each subject and according to the World Medical Association Declaration of Helsinki (version 2013).

The inclusion criteria were as follows:

1. Age ≥ 18 years old
2. Missing single posterior premolar or first molar for at least 3 months
3. Mesial and distal teeth / fixed restorations present and intact
4. Sufficient bone height and width at implant site (vertical bone height ≥ 10 mm, buccal-lingual bone width ≥ 6 mm)
5. Sufficient prosthetic space (vertical height ≥ 5 mm, mesial-distal distance ≥ 6 mm)
6. Willing to receive implant treatment

The exclusion criteria were as follows:

1. Local or systemic contraindication for implant therapy (i.e., uncontrolled diabetes, hemophilia, metabolic bone disorder, history of renal failure, radiation treatment to the head or neck region, current chemotherapy, and pregnancy)

2. Smoking ≥ 10 cigarettes per day
3. In need for major guided bone regeneration (GBR) / submucosal implant healing

2.2 | Clinical examination and implant placement

The surgical procedure of implant placement was described in a previous article reporting on the same patient cohort (Pan et al., 2019). In brief, at the first visit a clinical and radiographic examination (CBCT, VGi evo, NewTom) was performed. An intraoral scan (IOS) including both jaws and a bite registration (3Shape Trios® Standard-P11, 3Shape A/S) was made. At the second appointment, the implant (Straumann Bone Level or Tissue Level, Institut Straumann AG) was placed according to the manufacturers' instructions.

2.3 | Digital model acquisition

Immediately after implant placement, an implant-specific scan body (Institut Straumann AG) was connected onto the implant, and the intraoral scan acquired during the first visit was updated with the scan body (Figure 1a). Three months following implant placement, a second intraoral scan was taken including both jaws, the implant site with the scan body in the same alignment as during the first scan, and the bite registration (Figure 1b).

Digital models were generated from the optical impression datasets and saved in stereolithography (STL) format by means of a computer-aided design (CAD) software (3Shape Designer, 3Shape A/S). Digital models obtained at the day of surgery were considered as the baseline models (BM), and digital models generated 3 months following implant placement were considered as the follow-up models (FM). The two digital models were imported into a 3D analysis software (Geomagic Qualify 2012, 3D SYSTEMS) for the dimensional measurements.

2.4 | Three-dimensional measurement of neighboring teeth migration

2.4.1 | Determination of reference lines on the neighboring teeth

On the BM, a buccal plane was generated according to a buccal line connecting the most prominent point on the buccal surface of the mesial and distal neighboring teeth and paralleling to the central axis of the scan body, and then, a reference plane (RP) was determined parallel to the buccal plane and running through the central axis of the scan body (Figure 2a). Two reference lines were obtained in the RP by drawing lines parallel to the central axis of the scan body and tangential to the mesial and distal outline of the neighboring teeth (Figure 2b). The scan body of the FM was superimposed on the scan body of the BM using best fit alignment. The RP in the BM was replicated in the FM and used to determine the mesial and distal reference lines in the FM.

2.4.2 | Measurement of neighboring tooth movement in the RP

The distances between the central axis of the scan body and the parallel reference lines were measured mesially (D1) and distally (D2)

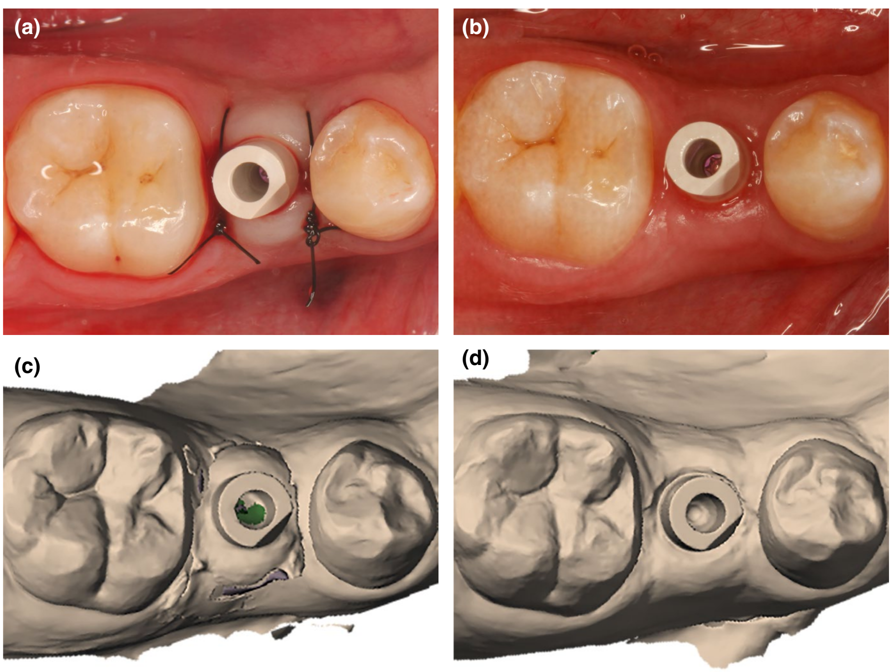

FIGURE 1 IOS digital model acquisition. (a) Intraoral scan made immediately after implant placement. (b) Intraoral scan made 3 months following implant placement. (c) Digital baseline model (BM). (d) Digital follow-up model (FM)

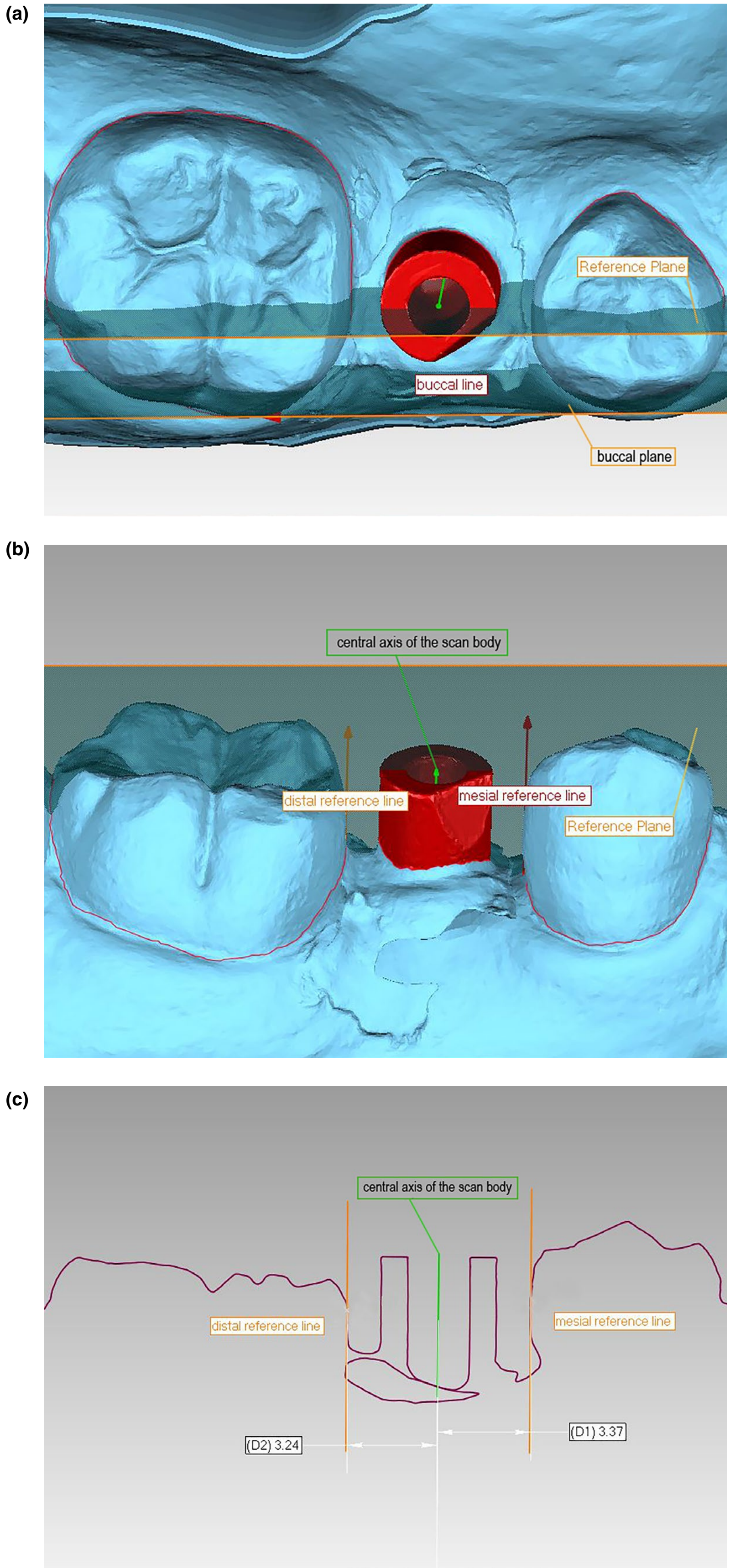

FIGURE 2 Measurement of neighboring teeth movement. (a) Parallel buccal plane and reference plane (RP) generated with RP running through central axis of scan body. (b) Reference lines in the RP parallel to central axis of scan body and tangential to mesial and distal neighboring teeth. (c) Distances between central axis of scan body and reference lines measured mesially (D1) and distally (D2)

in both the BM and the FM (Figure 2c). The total mesial-distal dimensional change in the tooth-missing site [($D1_{FM} + D2_{FM}$) − ($D1_{BM} + D2_{BM}$)], the mesial neighboring tooth migration ($D1_{BM} - D1_{FM}$), and the distal neighboring tooth migration ($D2_{BM} - D2_{FM}$) were calculated.

2.5 | Three-dimensional measurement of antagonist teeth migration

2.5.1 | Determination of reference points on antagonist tooth

Five featuring points were selected on the occlusal surface of the antagonist tooth opposite to the tooth-missing site (Figure 3). In case of two antagonist teeth opposing the site, the one with the larger occlusal area exposed to the tooth-missing gap was chosen as the antagonist of interest.

2.5.2 | Measurement of antagonist tooth migration

A 3D coordinate system was established on the BM of the opposing dentition by defining a horizontal plane with three landmark points: the incisal point of mesial interproximal contact of the central incisors and the two mesial buccal cusp tips of the first molar on each side. Then, the *z*-axis was set perpendicular to the horizontal plane. The BM and the FM of the opposing dentition were superimposed using best fit alignment of the neighboring teeth to the antagonist tooth. The standard of best fit registration was as follows: After the best fit alignment of the selected area with 100 000 sampling size, the root mean square error (RMS) was <30 μm (Peters et al., 1999).

The vector change in the *z*-axis direction of the five featuring points on the antagonist tooth between the BM and the FM was recorded, and the mean vector change in the five points was calculated to represent the migration distance of the antagonist tooth (Figure 3a-c). This is also the occlusal-gingival dimensional change in the tooth-missing site. Average occlusal-gingival change in the tooth-missing site in the cohort was then calculated.

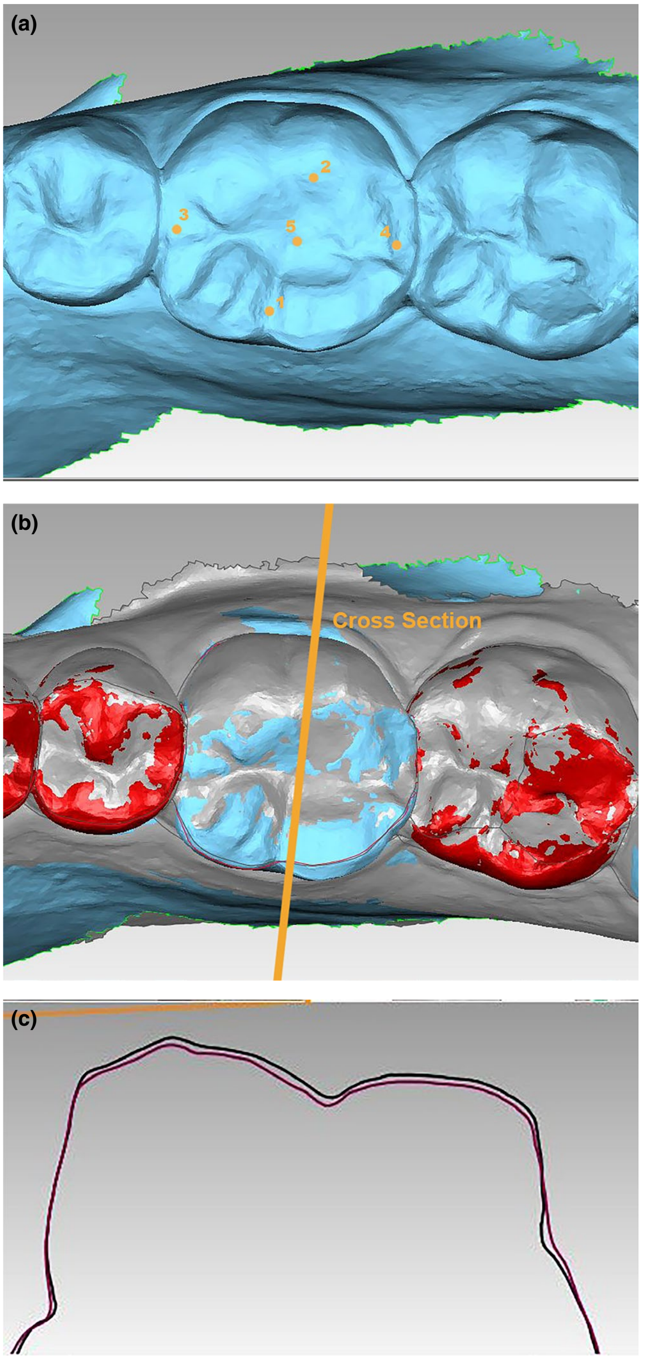

FIGURE 3 Measurement of antagonist teeth extrusion. (a) Five featuring points on antagonist tooth. (b) Superimposition of BM and FM using best fit alignment of neighboring teeth. (c) Vector change in reference points between BM (purple line) and FM (black line) was measured

2.6 | Statistical analysis

A power analysis was performed using the data originated from a previous study assessing mesial-distal dimensional change in tooth-missing gap 3 months postextraction. The power analysis was based on an independent *t* test. A sample size of 22 will have 90% power to detect a gap reduction of 613 μm, assuming a standard deviation of 698 μm (Garcia-Herraiz et al., 2012). Considering the possibility of 20% loss of follow-up rate, the sample size of this study was set at 40.

All statistical analyses were conducted in SPSS software (IBM SPSS Statistics v22; IBM Corp). The results of Shapiro–Wilk test showed that some of the data were not normally distributed; therefore, the nonparametric Mann–Whitney *U* test was used to compare tooth-moving distance between the mesial and distal neighboring teeth groups, male and female, premolar and molar, and upper and lower jaws. The Kruskal–Wallis one-way ANOVA was used to test the difference in dimensional change in tooth-missing site among age subgroups. The level of significance was set at .05.

3 | RESULTS

Forty participants with 21 females and 19 males were recruited in this study, and the mean age was 45.1 years. The tooth-missing position and numbers are shown in Table 1. The mean tooth-missing time was 14 months (range: 3–84 months).

Three months after implant surgery, the mean mesial-distal dimensional change in the tooth-missing site was −37.62 ± 106.36 μm (median: −28.33 μm, Q_{25} −72.65/Q_{75} 38.97, the negative value represents a distance reduction). In 25 participants, the mesial-distal distance of the tooth-missing site decreased, while in the other 15 patients, the mesial-distal distance increased.

For the mesial neighboring teeth, 18 migrated toward while 22 away from the implant. For the distal neighboring teeth, 24 migrated towards and 16 away from the implant. Table 2 shows the median, the Q_{25}, and the Q_{75} of the mesial- and distal-moving distance of the mesial and distal neighboring teeth. The distal-moving distance of the mesial neighboring teeth was significantly larger than that of the distal neighboring teeth ($p = .003$).

The antagonist teeth extrude towards the tooth-missing sites in all forty patients, and the average occlusal-gingival change in the tooth-missing site was −67.91 ± 42.37 μm (median: −61.50 μm, Q_{25} −88.25/Q_{75} −36.75, the negative value represents a distance reduction).

Participants were divided into three age subgroups (under 30 years, 30–50 years, and above 50 years), the mesial-distal reduction in the tooth-missing site was significantly larger in patients younger than 30 years compared with those older than 50 years (Table 3, Figure 4). No significant difference was found in occlusal-gingival dimensional change in the tooth-missing site among the three subgroups (Table 3, Figure 4).

There was no significant difference in the mesial-distal and occlusal-gingival dimensional change in tooth-missing site between sexes (male or female), tooth positions (molar or premolar), and jaws (maxilla or mandible) during the three months after implant placement (Table 4).

4 | DISCUSSION

The null hypothesis stating that there were no dimensional changes in single posterior tooth-missing sites between implant placement and 3 months later was rejected. The mean mesial-distal dimensional change in posterior single tooth-missing sites was −37.62 ± 106.36 μm, with 25 out of 40 participants demonstrating mesial-distal distance reduction while 15 participants showing mesial-distal distance increase. The occlusal-gingival distance reduction in the posterior single tooth-missing site was observed in all 40 patients with a mean change in −67.91 ± 42.37 μm.

This study investigated the short-term dimensional changes in single posterior tooth-missing site. A conventional loading protocol of taking impression three months after implant placement has been adopted in this study. According to the systematic review (Gallucci et al., 2018) reported on the 6th ITI consensus conference, when implants were placed in healed sites, the loading protocols (early or conventional loading) have not influenced the survival or success rate. Conventional loading of implants placed in healed sites was the most documented study protocol and remains the standard of care. The results indicated that minor dimensional changes in the posterior single tooth gap were inevitable during the 3 months following implant placement. Minor antagonist tooth extrusion happened in all the cases, while the mesial-distal distance

TABLE 1 Tooth-missing position and number of teeth in each position

Tooth-missing position	14	15	16	24	26	35	36	45	46	Total
Number of teeth	1	2	7	1	4	2	13	1	9	40

TABLE 2 Moving distance of mesial and distal neighboring teeth (absolute value, μm)

Neighboring teeth	Moving mesially			Moving distally		
	n	Median (Q_{25}/Q_{75}; μm)	*p*	*n*	Median (Q_{25}/Q_{75}; μm)	*p*
Mesial	22	41.92 (19.58/69.98)	.071	18	85.17 (51.87/99.20)	.003*
Distal	24	58.74 (35.21/99.28)		16	49.95 (17.33/64.65)	

*$p < .05$.

TABLE 3 Mesial-distal and occlusal-gingival dimensional change in the tooth-missing site among the three age subgroups (the negative value represents a distance reduction)

Age subgroups (years)	Mesial-distal dimensional change		Occlusal-gingival dimensional change	
	n	Median (Q_{25}/Q_{75}; μm)	*n*	Median (Q_{25}/Q_{75}; μm)
<30	8	−102.42 (−218.78, −54.04)	8	−63.5 (−95.50, −40.50)
30–50	18	−13.68 (−73.41, 41.96)	18	−51.50 (−92.75, −33.00)
>50	14	−6.35 (−36.73, 57.25)	14	−62.5 (−81.50, −52.50)
p	.03*		.74	

*$p < .05$.

of the tooth-missing site showed a tendency to decrease. These results partially confirmed the outcomes of some previous studies (Garcia-Herraiz et al., 2017; Gragg et al., 2001). With a single tooth loss, the remaining teeth especially the neighboring and antagonist teeth had a tendency to rearrange to establish a new equilibrium state, which might lead to the reduction in the tooth-missing gap (Garcia-Herraiz et al., 2012). Even after implant restoration, the dynamic position change in neighboring and antagonist teeth could cause implant infraposition (IIP) and proximal contact point (PCP) loss (Papageorgiou et al., 2018), and should be monitored constantly at patients' follow-up.

In the present study, the mean mesial-distal distance reduction in the tooth-missing site (37.62 μm) 3 months following implant placement was significantly smaller than that observed 3 months following natural tooth extraction (672.30 μm; Garcia-Herraiz et al., 2017). The difference could be explained by different time points chosen for the baseline. In this study, the baseline of measurement was set at equal to or more than three months after tooth extraction, and in most of the participants, the posterior teeth have already been missing for several years. Therefore, the period of significant dimension change due to active bone remodeling following tooth extraction was avoided in this study (Garcia-Herraiz et al., 2017; Gragg et al., 2001).

To our knowledge, the present study is the first of its kind using intraosseous implants as reference and a digital method to quantitatively analyze the movement of neighboring teeth. The implant provided a fixed reference point to define reproducible reference planes for precise measurements. Three-dimensional registration technology was used to duplicate the reference plane in the same position in both the baseline and follow-up digital models to further improve measurement accuracy. Thus, the migration of neighboring and antagonist teeth relative to the implant position can be analyzed separately on the scale of microns. Compared with stone models, the digital models can be stored for a long time without information loss and can be used to analyze the change in dentition for this group of patients in the future. The digital measurement protocol using

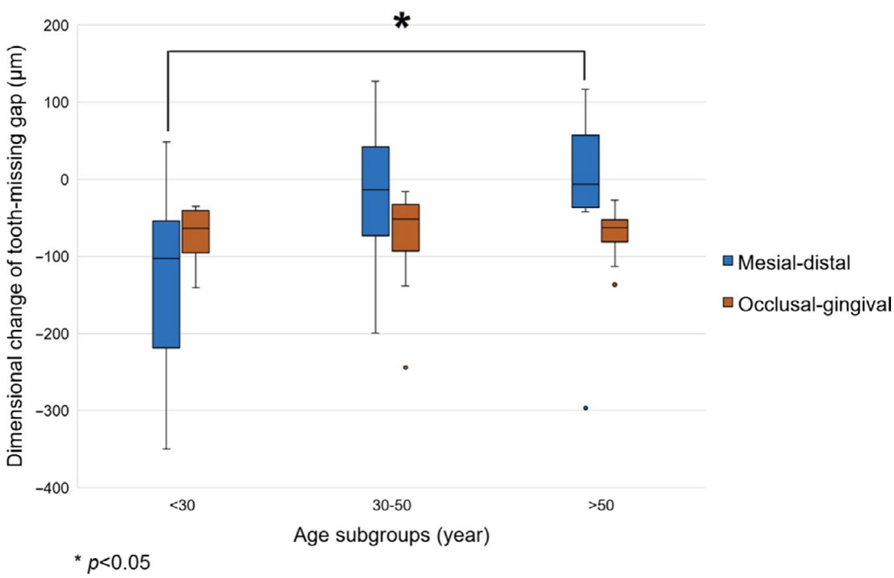

FIGURE 4 Mesial-distal reduction in tooth-missing site was significantly larger in patients younger than 30 years compared with those older than 50 years. No significant difference was found in occlusal-gingival dimensional change in the tooth-missing site among three age subgroups

TABLE 4 Mesial-distal and occlusal-gingival dimensional change in the single posterior tooth-missing site according to sex, tooth-missing position, and jaw position

		Mesial-distal dimensional change			Occlusal-gingival dimensional change		
Factors		*n*	Median (Q_{25}/Q_{75}; μm)	*p*	*n*	Median (Q_{25}/Q_{75}; μm)	*p*
Sex	Male	19	−20.86 (−38.60, 39.97)	.27	19	−61.00 (−79.00, −36.00)	.45
	Female	21	−41.84 (−129.58, 32.58)		21	−66.00 (−110.50, −37.00)	
Tooth-missing position	Premolar	7	−38.60 (−129.93, 8.55)	.58	7	−41.00 (−62.00, −27.00)	.05
	Molar	33	−21.25 (−69.70, 44.05)		33	−63.00 (−93.50, −41.50)	
Jaw position	Upper	15	−20.87 (−63.00, 35.97)	.98	15	−63.00 (−79.00, −41.00)	.80
	Lower	25	−36.57 (−88.94, 50.01)		25	−58.00 (−95.50, −35.50)	

engineering software program has been proved to be an acceptable form of measurement with statistical validation (Zeller et al., 2019).

For the 18 mesial neighboring teeth moving distally, the average moving distance was significantly larger than that of the 16 distal neighboring teeth moving distally. The lack of support in-between the mesial and distal neighboring teeth could be the reason for this difference.

In this study, more than 75% of the neighboring and antagonist teeth showed <100 μm linear tooth migration (Table 2). The mesial-distal dimensional change in the tooth-missing sites was minimal. These findings provided evidence for clinical adoption of a more time-efficient fully digital workflow in implant restoration of single posterior missing tooth (Guo et al., 2019; Pan et al., 2019). It has been shown that the single implant crown can be fabricated from digital impressions taken immediately after implant surgery by means of a model-free, laboratory-based fully digital workflow, and delivered three months after implant placement. The chairside time for the crown delivery was similar to that of implant crowns made from conventional impression taken three months after implant placement (Pan et al., 2019). With the data from this study, it was clarified that the fit of the implant crown was not affected by the minor migration of the neighboring and antagonist teeth during the 3 months. The clinical relevance of the findings from this study was to provide appropriate designing parameters for implant crown in fully digital workflow, and the fit of the single implant crowns can be further improved.

Participants' sexes and upper or lower jaw did not significantly affect the dimensional change in the tooth-missing site, and this was similar to the result of Garcia-Herraiz et al., (2017).

When participants were divided into three age subgroups, the mesial-distal dimensional change in tooth-missing site in the younger-than-30-years subgroup was significantly larger than that in the older-than-50-years group ($p = .023$). The present results are in accordance with a previous study showing a more pronounced bone remodeling in a young population resulting in larger mesial-distal tooth-missing gap reduction (Verna, 2016).

It should be noted that this study is a single-group prospective cohort study based on a previous randomized controlled clinical trial (RCT); therefore, it is a spin-off use of data from a RCT (Pan et al., 2019). Both the registration and randomization aspects of this study pertain to the primary research question. Limitations of the present study include that intraoral scan, registration process, and definition of reference lines on different digital models could introduce errors in the measurement, and these errors were not assessed in this study. Due to the definitions of the reference lines and the central axis of the scan body, the distance values were automatically displayed by the digital analysis software instead of manual measurement, and the repeated measurement was not performed. This study only evaluated the linear change between fixed reference lines/points on neighboring and antagonist teeth, without indicating the rotational and inclination movement. In addition, the influence of the type of interocclusal relationship was not tested because of the low number of patients.

5 | CONCLUSION

The dimensions of posterior tooth-missing sites decreased over an observation period of 3 months.

ACKNOWLEDGEMENTS

The authors express their gratitude to Dai Tong (Clinical professor, Department of Prosthodontics, Peking University School and Hospital of Stomatology), Bing Wang, Pengfei Wang, and Wenhui Gao (Dental Technicians, Laboratory Center, Peking University School and Hospital of Stomatology) for the acquisition of the digital model.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Danni Guo: Data curation (equal); Formal analysis (equal); Investigation (equal); Writing – original draft (equal). **Shao-Xia Pan:** Conceptualization (lead); Formal analysis (equal); Investigation (lead); Methodology (lead); Resources (lead); Writing – original draft (lead). **Sven Mühlemann:** Conceptualization (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Writing – review and editing (lead). **yongsheng zhou:** Conceptualization (equal); Formal analysis (equal); Methodology (lead); Resources (equal); Supervision (lead); Writing – review and editing (equal). **Ronald Ernst Jung:** Conceptualization (lead); Formal analysis (supporting); Methodology (lead); Supervision (lead); Writing – review and editing (equal).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

Christou, P., & Kiliaridis, S. (2007). Three-dimensional changes in the position of unopposed molars in adults. *European Journal of Orthodontics*, *29*(6), 543–549. https://doi.org/10.1093/ejo/cjm036

Craddock, H. L., Youngson, C. C., Manogue, M., & Blance, A. (2007). Occlusal changes following posterior tooth loss in adults. Part 2. Clinical parameters associated with movement of teeth adjacent to the site of posterior tooth loss. *Journal of Prosthodontics*, *16*(6), 495–501. https://doi.org/10.1111/j.1532-849X.2007.00223.x

Gallucci, G. O., Hamilton, A., Zhou, W., Buser, D., & Chen, S. (2018). Implant placement and loading protocols in partially edentulous patients: A systematic review. *Clinical Oral Implants Research*, *29*(Suppl 16), 106–134. https://doi.org/10.1111/clr.13276

Garcia-Herraiz, A., Leiva-Garcia, R., Canigral-Ortiz, A., Silvestre, F. J., & Garcia-Anton, J. (2012). Confocal laser scanning microscopy for the study of the morphological changes of the postextraction sites. *Microscopy Research and Technique*, *75*(4), 513–519. https://doi.org/10.1002/jemt.21085

Garcia-Herraiz, A., Silvestre, F. J., Leiva-Garcia, R., Crespo-Abril, F., & Garcia-Anton, J. (2017). Post-extraction mesio-distal gap reduction assessment by confocal laser scanning microscopy - A clinical 3-month follow-up study. *Journal of Clinical Periodontology*, *44*(5), 548–555. https://doi.org/10.1111/jcpe.12706

Gragg, K. L., Shugars, D. A., Bader, J. D., Elter, J. R., & White, B. A. (2001). Movement of teeth adjacent to posterior bounded edentulous spaces. *Journal of Dental Research*, *80*(11), 2021–2024. https://doi.org/10.1177/00220345010800111401

Guo, D. N., Liu, Y. S., Pan, S. X., Wang, P. F., Wang, B., Liu, J. Z., & Zhou, Y. S. (2019). Clinical efficiency and patient preference of immediate digital impression after implant placement for single implant-supported crown. *The Chinese Journal of Dental Research: The Official Journal of the Scientific Section of the Chinese Stomatological Association (CSA)*, *22*(1), 21–28. https://doi.org/10.3290/j.cjdr.a41771

Joda, T., Ferrari, M., & Bragger, U. (2017). Monolithic implant-supported lithium disilicate (LS2) crowns in a complete digital workflow: A prospective clinical trial with a 2-year follow-up. *Clinical Implant Dentistry and Related Research*, *19*(3), 505–511. https://doi.org/10.1111/cid.12472

Kiliaridis, S., Lyka, I., Friede, H., Carlsson, G. E., & Ahlqwist, M. (2000). Vertical position, rotation, and tipping of molars without antagonists. *International Journal of Prosthodontics*, *13*(6), 480–486. https://doi.org/10.1046/j.1365-2591.2000.00365.x

Lindskog-Stokland, B., Hansen, K., Tomasi, C., Hakeberg, M., & Wennstrom, J. L. (2012). Changes in molar position associated with missing opposed and/or adjacent tooth: A 12-year study in women. *Journal of Oral Rehabilitation*, *39*(2), 136–143. https://doi.org/10.1111/j.1365-2842.2011.02252.x

Love, W. D., & Adams, R. L. (1971). Tooth movement into edentulous areas. *Journal of Prosthetic Dentistry*, *25*(3), 271–278. https://doi.org/10.1016/0022-3913(71)90188-0

Lyka, I., Carlsson, G. E., Wedel, A., & Kiliaridis, S. (2001). Dentists' perception of risks for molars without antagonists. *Swedish Dental Journal*, *25*(2), 67–73.

Moreira, A. H., Rodrigues, N. F., Pinho, A. C., Fonseca, J. C., & Vilaca, J. L. (2015). Accuracy comparison of implant impression techniques: A systematic review. *Clinical Implant Dentistry and Related Research*, *17*(Suppl 2(S2)), e751–764. https://doi.org/10.1111/cid.12310

Muhlemann, S., Kraus, R. D., Hammerle, C. H. F., & Thoma, D. S. (2018). Is the use of digital technologies for the fabrication of implant-supported reconstructions more efficient and/or more effective than conventional techniques: A systematic review. *Clinical Oral Implants Research*, *29*(Suppl 18), 184–195. https://doi.org/10.1111/clr.13300

Pan, S., Guo, D., Zhou, Y., Jung, R. E., Hammerle, C. H. F., & Muhlemann, S. (2019). Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: A double-blind self-controlled clinical trial. *Clinical Oral Implants Research*, *30*(7), 617–626. https://doi.org/10.1111/clr.13447

Papageorgiou, S. N., Eliades, T., & Hammerle, C. H. F. (2018). Frequency of infraposition and missing contact points in implant-supported restorations within natural dentitions over time: A systematic review with meta-analysis. *Clinical Oral Implants Research*, *29*(Suppl 18), 309–325. https://doi.org/10.1111/clr.13291

Peters, M. C., Delong, R., Pintado, M. R., Pallesen, U., Qvist, V., & Douglas, W. H. (1999). Comparison of two measurement techniques for clinical wear. *Journal of Dentistry*, *27*(7), 479–485. https://doi.org/10.1016/s0300-5712(99)00027-5

Shah, S., Sundaram, G., Bartlett, D., & Sherriff, M. (2004). The use of a 3D laser scanner using superimpositional software to assess the accuracy of impression techniques. *Journal of Dentistry*, *32*(8), 653–658. https://doi.org/10.1016/j.jdent.2004.07.005

Shugars, D. A., Bader, J. D., Phillips, S. W. Jr, White, B. A., & Brantley, C. F. (2000). The consequences of not replacing a missing posterior tooth. *Journal of the American Dental Association*, *131*(9), 1317–1323. https://doi.org/10.14219/jada.archive.2000.0385

Verna, C. (2016). Regional Acceleratory Phenomenon. *Frontiers of Oral Biology*, *18*, 28–35. https://doi.org/10.1159/000351897

Weinstei, S. (1967). Minimal forces in tooth movement. *American Journal of Orthodontics*, *53*(12), 881–903. https://doi.org/10.1016/0002-9416(67)90163-7

Zeller, S., Guichet, D., Kontogiorgos, E., & Nagy, W. W. (2019). Accuracy of three digital workflows for implant abutment and crown fabrication using a digital measuring technique. *Journal of Prosthetic Dentistry*, *121*(2), 276–284. https://doi.org/10.1016/j.prosdent.2018.04.026

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Guo D, Pan S, Mühlemann S, Zhou Y, Jung R. The migration of neighboring and antagonist teeth three months after implant placement in healed single tooth-missing sites. *Clin Oral Impl Res*. 2021;32:233–241. https://doi.org/10.1111/clr.13694