A small number of residual teeth after the mandibular resection of oral cancer is associated with titanium reconstruction plate exposure

Hiromi Hirohata\textsuperscript{1,2} | Toru Yanagawa\textsuperscript{3,4} | Shohei Takaoka\textsuperscript{1} | Kenji Yamagata\textsuperscript{3} | Kaoru Sasaki\textsuperscript{5} | Yoichiro Shibuya\textsuperscript{5} | Fumihiko Uchida\textsuperscript{3} | Satoshi Fukuzawa\textsuperscript{3} | Katsuhiko Tabuchi\textsuperscript{6} | Shogo Hasegawa\textsuperscript{7} | Naomi Ishibashi-Kanno\textsuperscript{3} | Mitsuru Sekido\textsuperscript{5} | Hiroki Bukawa\textsuperscript{3}

\textsuperscript{1}Oral and Maxillofacial Surgery, Clinical Sciences, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tsukuba, Japan
\textsuperscript{2}Department of Oral and Maxillofacial Surgery, Tsukuba Central Hospital, Ushiku, Japan
\textsuperscript{3}Department of Oral and Maxillofacial Surgery, Faculty of Medicine, University of Tsukuba, Tsukuba, Japan
\textsuperscript{4}Department of Oral and Maxillofacial Surgery, Ibaraki Prefectural Central Hospital, Kasama, Japan
\textsuperscript{5}Department of Plastic and Reconstruction Surgery, Faculty of Medicine, University of Tsukuba, Tsukuba, Japan
\textsuperscript{6}Department of Neurohealth Innovation, Institute for Biomedical Sciences Interdisciplinary Cluster for Cutting Edge Research, Department of Molecular & Cellular Physiology, Shinshu University School of Medicine, Matsumoto, Japan
\textsuperscript{7}Department of Oral and Maxillofacial Surgery, Department of Maxillofacial Surgery, School of Dentistry, Aichi Gakuin University, Nagoya, Japan

Correspondence
Toru Yanagawa, Department of Oral and Maxillofacial Surgery, Faculty of Medicine, University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi, Ibaraki-ken 305-8575, Japan.
Email: ytony@md.tsukuba.ac.jp

Funding information
JSPS KAKENHI, Grant/Award Number: 19H03846

Abstract

Objective: Reconstruction plates are used to treat patients with a segmental mandibular defect after oral cancer surgery. Reconstruction plate failure analysis has rarely focused on occlusion, which conducts a mechanical force to the mandible and the plate. To determine the prognostic factors, we retrospectively evaluated patients who underwent reconstruction of a mandibular segmental defect with a reconstruction plate and assessed the number of residual paired teeth.

Material and Methods: From among 390 patients with oral cancer who visited University of Tsukuba Hospital (Tsukuba, Japan) between 2007 and 2017, we selected and analyzed the data of 37 patients who underwent segmental resection of the mandible and reconstruction with reconstruction plates. Prognostic factors evaluated were patient age, sex, TNM classification, plate manufacturer, treatment with radiotherapy or chemotherapy, whether the patient had diabetes or smoked, and whether the patient had a small number of residual paired teeth, plate length, and use of a fibular-free flap. Among these 37 patients, eight reconstruction plates had intraoral or extraoral exposure and were removed in 5 years.

Results: Kaplan–Meier and log-rank analyses revealed that the prognosis for the 5-year plate exposure-free rate was significantly poorer for patients with a small number of residual teeth than for patients with no teeth or those with a large number of residual teeth (p=0.01). Univariate Cox regression analysis revealed that a small number of residual teeth was a significant prognostic factor in the loss of a reconstruction plate (hazard ratio: 5.63; 95% confidence interval [1.10, 25.85]; p=0.04).

Conclusions: A small number of residual teeth after the segmental resection of oral cancer is significantly involved in reconstruction plate survival and may be important in predicting reconstruction plate prognosis.
1 | BACKGROUND

Treating advanced oromandibular cancer often requires resecting mandibular and alveolar bones and soft tissues such as the oral mucosa, muscles, or external skin of the mandible. Mandibular reconstruction with a plate, with or without a vascularized free flap, is a common treatment to deliver acceptable function and cosmesis to maintain the postoperative quality of life. The role of the reconstruction plate is very important because an unreconstructed mandibular defect may cause deformation of the remaining mandible in association with several problems for the patients such as insufficient sealing of the lips and feeding (van der Rijt, Noorlag, Koole, Abbink, & Rosenberg, 2015). However, many postsurgery complications occur with reconstruction plates, and the rates of reported complications with reconstruction plates range from 28% to 39% and include loosening of the osteosynthesis screws, plate fracture, and intraoral or extraoral exposure or infection (Kammerer, Klein, Moergel, Gemmel, & Draenert, 2014; Maurer, Eckert, Kriwalsky, & Schubert, 2010). A recent systematic review and meta-analysis (Sadr-Eshkevari et al., 2013) demonstrated that the failure rate was 30.8% at the 32-month follow-up and discussed the risk factors of reconstruction plate failure from various viewpoints. Many reports discuss the influencing factors for reconstruction plate survival and list many factors such as physical factors such as whether an individual has diabetes mellitus (van der Rijt et al., 2015), smoking habit (Maurer et al., 2010; van der Rijt et al., 2015), whether an individual has had a blood transfusion (Fanzio et al., 2015), and surgical infection site (Wood, Shinn, Amin, Rohde, & Sinard, 2018), hardware factors such as plate length and location of a mandibular defect (Arden, Rachel, Marks, & Dang, 1999; Ettl et al., 2010; Mariani, Kowalski, & Magrin, 2006; Okura, Isomura, Iida, & Kogo, 2005; Poli, Ferrari, Bianchi, & Sesenna, 2003; Prasad et al., 2018; Shibahara, Noma, Furuya, & Takaki, 2002), and treatment factors such as radiation therapy and chemotherapy (Okura et al., 2005; Ryu et al., 1995; Shibahara et al., 2002; Wang, Zhang, & Mendenhall, 2005). Most reports have focused on the shape of the mandibular bone defect after resection and hardware-related complications; however, few reports have analyzed risk factors for plate failure from the viewpoint of dental occlusion (i.e., the mechanical force exerted on the reconstructed mandible and plate).

The maxillomandibular occlusal state differs depending on the relationship between the upper and lower teeth. Disharmony of chewing motion after surgery is caused by the resection of the mandibular bone and the masticatory and facial muscles. The load of the stress then alters depending on whether a stable stop position of occlusion does or does not exist. In this study, we investigated the predictive factors of reconstruction plate exposure by using the number of paired teeth as a variable to define prognostic factors for reconstruction plate loss and to improve future treatment planning.

2 | METHODS

2.1 | Patient characteristics

From among 390 patients with oral cancer who consulted serially in the Department of Oral and Maxillofacial Surgery at the University of Tsukuba Hospital (Tsukuba City, Japan) between 2007 and 2017, out of 390 oral cancers, 134 cases include mandibular regions (lower gingiva, buccal mucosa, and so on) and 77 patients received surgery. Among them, we selected 37 patients who underwent segmental resection of mandibular and reconstruction with reconstruction plates and analyzed the data. The patients included 21 men and 16 women with a mean age (standard deviation) of 65.8 (10.4) years. Each case of oral cancer was staged, using the International Union against Cancer system (Sobin, Wittekind, & Gospodorowicz, 2009). Prognostic factors determined from the patients’ medical records were as follows: the patients’ age and sex; stage of the cancer; number of screws; number of residual paired teeth; plate manufacturer (MODUS 2.5-mm locking reconstruction plate [Mediartis, Basel, Switzerland]; Lorenz 2.4-mm locking reconstruction plate [Biomet, Jacksonville, USA]; CMF 2.4-mm titanium locking reconstruction plate [Synthes GmbH, Oberdorf Switzerland]); type of flap (i.e., no flap, fibular-free flap, rectus abdominis myocutaneous flap, nasolabial flap, latissimus dorsi flap); infection site; stage; whether the patient had diabetes or smoked; and whether the patient had received chemotherapy or radiotherapy. Residual paired teeth meant teeth that can stably maintain a vertical dimension of occlusion. Therefore, if the mobility of the opposite tooth was substantial, which included mobility occurring with severe periodontitis, we did not include it as a residual paired tooth. By using Eichner’s index, which is a system for classification of partial edentulous arches based on occlusal contact between the premolar and molar regions, II dental arches that had residual paired teeth were classified as Eichner’s index B3 (Eichner, 1995), and dental arches that had no residual paired teeth were classified as Eichner’s index C1–C3 (Eichner, 1995). The clinical features of the patients are presented in Table 1. The patients were treated by surgical excision alone (23 patients) or by surgical excision plus chemoradiotherapy (14 patients). The 14 patients were treated by linear accelerator radiosurgery (mean dose, 52.4 ± 9.4 Gy; range, 37.3–60 Gy). The study protocol was reviewed and approved by the Research Ethics Committee of the University of Tsukuba (Tsukuba, Japan; approval no., H29-258).

2.2 | STATISTICAL ANALYSIS

For the univariate analysis, we used Kaplan–Meier analysis, evaluated by the log-rank test, and the Cox proportional hazard regression model. Statistical analyses were conducted using the software package JMP 12.0.1 for Mac (SAS Institute Inc., Cary, NC, USA).
TABLE 1  Clinical feature of patients

| Variables                              | Age   | SD    |
|----------------------------------------|-------|-------|
| Age                                    | Mean = 65.83 | SD = 10.42 |
| Sex                                    | Male 21 | Female 16 |
| Plate length (mm)                      | Median = 128 | Range = 72–240 |
| Number of screws                       | Median = 8 | Range = 4–14 |
| Number of residual paired teeth        | Median = 5 | Range = 0–12 |
| Manufacturer                           | Mediartis MODUS 2.5-mm locking reconstruction plate 16 |
|                                        | Biomet Lorenz 2.4-mm locking reconstruction plate 18 |
|                                        | Synthes CMF 2.4-mm Titanium locking reconstruction plate 3 |
| Flap                                   | No flap 12 | Fibular-free flap 19 |
|                                        | Rectus abdominis myocutaneous flap 4 |
|                                        | Nasolabial flap 1 |
|                                        | Latissimus dorsi flap 1 |
| Site infection                         | Yes 5 | No 32 |
| TNM classification stage               | 1 3 | 2 3 |
|                                        | 3 4 | 4a 26 |
|                                        | 4b 1 |
| Diabetes mellitus                      | Yes 8 | No 29 |
| Smoking                                | Yes 18 | No 19 |
| Chemotherapy                           | Yes 12 | No 25 |
| Radiation therapy                      | Yes 14 | No 23 |

TABLE 2  5-year exposure free rate by Kaplan–Meier analysis and log-rank test

| Variable                              | 5-year plate exposure free ratio | Log-rank test (p value) |
|----------------------------------------|----------------------------------|-------------------------|
| Age                                    | ≦65 0.71 | .29 |
|                                        | <65 0.66 |
| Sex                                    | Male 0.65 | .24 |
|                                        | Female 0.80 |
| Plate length                           | ≦128 0.74 | .83 |
|                                        | <128 0.66 |
| Number of screws                       | ≦8 0.74 | .19 |
|                                        | <8 0.66 |
| Number of residual paired teeth        | Small tooth number group (<0, ≦5) 0.00 | .01 |
|                                        | The others 0.79 |
| Manufacturer                           | Mediartis 0.64 | .44 |
|                                        | Biomet + Synthes 0.85 |
| Flap                                   | Fibular-free flap 0.74 | .67 |
|                                        | The others 0.67 |
| Site infection                         | Yes 0.80 | .84 |
|                                        | No 0.68 |
| TNM classification Stage               | 1–3 0.76 | .59 |
|                                        | 4a,b 0.69 |
| Diabetes mellitus                      | Yes 0.73 | .71 |
|                                        | No 0.72 |
| Smoking                                | Yes 0.80 | .65 |
|                                        | No 0.65 |
| Chemotherapy                           | Yes 0.49 | .24 |
|                                        | No 0.81 |
| Radiation therapy                      | Yes 0.58 | .46 |
|                                        | No 0.79 |
3 | RESULTS

3.1 | Univariate analysis of the 5-year exposure-free rate based on Kaplan–Meier analysis and the log-rank test

Kaplan–Meier analysis was used to estimate each factor's 5-year exposure-free rate (i.e., 5-year survival rate of the reconstruction plate). During this term, reconstruction plate exposure occurred in eight (21.6%) of 37 patients. The overall 5-year exposure-free rate was 0.71, as estimated using Kaplan–Meier analysis. Table 2 presents the 5-year exposure-free rate and log-rank test results based on Kaplan–Meier analysis. Figures 1 and S1–S13 present the survival curves for each factor. The 5-year exposure-free rate was significantly different between the null tooth group (i.e., zero teeth), small number of teeth group (i.e., 1–5 residual paired teeth), and large number of teeth group (i.e., six residual paired teeth or more); the rate was 0.81, 0.00, and 0.79 for the null group, small number of teeth group, and large number of teeth group, respectively (p = .04; Figure S5). We then divided the tooth groups into two groups: (Arden et al., 1999) small number of teeth group and (Coletti, Ord, & Liu, 2009) large number of teeth group and null teeth group combined (i.e., other group). We divided the type of flap into two groups: (Arden et al., 1999) the fibular-free flap group and (Coletti et al., 2009) other type of flap group. The TNM classification stage was classified into two groups: (Arden et al., 1999) Stages 1–3 group and (Coletti et al., 2009) Stages 4a and 4b group. The 5-year exposure-free rate was insignificantly associated with age (≥65 years, 0.71; <65 years, 0.66; p = .29), sex (male, 0.65; female, 0.80; p = .24), plate length (<128 mm, 0.74; ≥128 mm, 0.66; p = .83), number of screws (≥8, 0.66; p = .19), manufacturer (Medartis, 0.64; Biomet + Synthes, 0.85; p = .44), type of flap (fibular-free flap, 0.74; other flap type, 0.67; p = .67), infection site (yes, 0.80; no, 0.68; p = .84), cancer stage (1–3, 0.76; 4a and 4b, 0.69; p = .59), diabetes mellitus (yes, 0.73; no, 0.72; p = .71), smoking status (yes, 0.80; no, 0.65; p = .65), chemotherapy (yes, 0.49; no, 0.81; p = .24), and radiation therapy (yes, 0.58; no, 0.79; p = .46). However, a significant difference in the 5-year exposure-free rate existed between the small number of teeth group and the other group (small number of teeth group, 0.00; other group, 0.79; p = .01).

3.2 | Univariate analysis by using the Cox proportional hazard regression model

Table 3 presents the univariate analysis results based on the Cox proportional hazard regression model. The univariate analysis of each factor revealed a significant difference between the small number of teeth group and the other group (hazard ratio, 5.63; 95% confidence interval [1.10, 25.85]; p = .04). There was no significant association with age, sex, plate length, number of screws, manufacturer, type of flap, infection site, stage, diabetes mellitus, smoking, chemotherapy, and radiation therapy.

4 | DISCUSSION

In the present study, we retrospectively investigated the prognostic factors for the loss of reconstruction plates in patients with a mandibular segmental defect. In univariate analysis, conducted using Kaplan–Meier analysis evaluated by log-rank test, the 5-year exposure-free rate showed no significant association with the clinical factors (i.e., age, sex, plate length, number of screws, manufacturer, type of flap, infection site, diabetes mellitus, smoking, chemotherapy, and radiation therapy). However, the 5-year exposure-free rate of the small number of teeth group was significantly less than that of the other group (small number of teeth group, 0.00; the other group, 0.79; p = .011). The univariate analysis using the Cox proportional hazard regression model revealed a significant association in the small number of teeth group (hazard ratio, 5.63; 95% confidence interval [1.10, 25.85]; p = .04). These findings indicated that a small number of teeth may be a poor predictive factor for reconstruction plate survival.

A recent systemic review and meta-analysis of alloplastic mandibular reconstruction has been reported (Sadr-Eshkevari et al., 2013). In this study, the failure rate of the reconstruction plate was 30.8% (interquartile range, 11.7–48.1%). In our study, reconstruction plate exposure occurred in eight (21.6%) of 37 patients, and the
Overall 5-year exposure-free rate was 70.6%. Thus, our clinical outcome was comparable with previous reports (Arden et al., 1999; Fanzio et al., 2015; Maurer et al., 2010; Okura et al., 2005). In various studies, many predictive factors have been presented, and physical factors (Fanzio et al., 2015; Maurer et al., 2010; van der Rijt et al., 2015; Wood et al., 2018), hardware factors (Arden et al., 1999; Ettl et al., 2010; Mariani et al., 2006; Okura et al., 2005; Poli et al., 2003; Prasad et al., 2018; Shibahara et al., 2002), and treatment factors (Okura et al., 2005; Ryu et al., 1995; Shibahara et al., 2002; Wang et al., 2005) have been reported. Among these factors, plate length and the location of a mandibular defect influenced the prognosis of plate survival. Many reports show various predictive factors of the reconstruction plate; however, only a few reports are presented from the viewpoint of occlusion. Kammerer et al. (2014) presented the concept of the tooth unit. A small tooth unit is associated with a poor survival rate of reconstruction plates. Coletti et al. (2009) demonstrated that postoperative dentition is associated with poor prognosis of the plates. These studies showed the number of teeth was an indicator of length of survival of the plate, but the studies did not discuss occlusion, which determines the mechanical stress applied to the resected mandible and reconstruction plate.

Occlusion involves bringing the opposing surfaces of the teeth of the two jaws into contact in association with complicated chewing motion. During surgery for oromandibular cancer, surgeons resect the mandibular bone and peripheral soft tissues, including the masticatory and facial muscles. Furthermore, resection includes sensory nerves such as a branch of the trigeminal nerve. A disharmony in chewing motion may produce an unexpected overload on the reconstruction plate owing to irregular movement and a patient's unawareness of the stress overload. The maxillomandibular occlusal state differs based on the relationship between the upper and lower teeth. The stress load is altered if the area of the stable stop position that bears the occlusal force is different. Markwardt, Pfeifer, Eckelt, and Reitemeier (2007) attempted to analyze the risk factors for complications by using Eichner's classification; however, they could not find a significant difference among the factors examined. Markwardt did not conduct a long-term observation; therefore, they may not have been able to determine a significant difference. However, some reports (Hoefert & Taier, 2018; Park, Lee, & Noh, 2018; Yi et al., 1999) present analysis results from a biomechanical viewpoint and demonstrate that reconstruction plates and screws are often subjected to excessive stress produced by functional loading, moment, and shear forces. From these reports, the reconstruction plate bridging mandibular bone can be estimated to burden excessive load by the shape of bone defect and the loading points (Hoefert & Taier, 2018; Park et al., 2018; Yi et al., 1999). In particular, Park et al., 2018 divided patients into three groups—unilateral molar clenching, group function clenching, and incisal clenching—and measured the von Mises stress, a value used to determine if a given material will yield or fracture, occurring on the reconstruction plate. The maximum von Misess stress on the reconstruction plate of patients with unilateral molar clenching was larger than in that of group function clenching (Park et al., 2018). Unilateral molar clenching group in their analysis resembles the small number of teeth group in our study, and the group function clenching in their study resembles large number of teeth group in our study.

| Variable                  | Hazard ratio | 95% confidence interval | p value |
|---------------------------|--------------|-------------------------|---------|
| Age                       |              |                         |         |
| ≥65                       | 0.43         | [0.06, 1.88]            | .27     |
| <65                       |              |                         |         |
| Sex                       |              |                         |         |
| Male                      | 2.55         | [0.58, 17.52]           | .22     |
| Female                    |              |                         |         |
| Plate length              |              |                         |         |
| ≤128                      | 0.85         | [0.19, 3.76]            | .83     |
| 128<                      |              |                         |         |
| Number of screws          |              |                         |         |
| ≤8                        | 0.73         | [0.66, 0.17]            | .66     |
| <8                        |              |                         |         |
| Number of residual paired teeth | 5.63 | [1.10, 25.85] | .04     |
| The others                |              |                         |         |
| Manufacturer              |              |                         |         |
| Mediartis                 | 1.77         | [0.41, 8.85]            | .44     |
| Biomet + Synthes          |              |                         |         |
| Flap                      |              |                         |         |
| Fibular-free flap         | 0.76         | [0.18, 3.23]            | .70     |
| The others                |              |                         |         |
| Site infection            |              |                         |         |
| Yes                       | 0.80         | [0.04, 4.55]            | .83     |
| No                        |              |                         |         |
| TNM classification stage  |              |                         |         |
| 1–3                       | 0.64         | [0.09, 2.84]            | .58     |
| 4a,b                      |              |                         |         |
| Diabetes mellitus         |              |                         |         |
| Yes                       | 1.36         | [0.20, 6.06]            | .72     |
| No                        |              |                         |         |
| Smoking                   |              |                         |         |
| Yes                       | 1.14         | [0.27, 4.83]            | .86     |
| No                        |              |                         |         |
| Chemotherapy              |              |                         |         |
| Yes                       | 2.27         | [0.53, 9.71]            | .26     |
| No                        |              |                         |         |
| Radiation therapy         |              |                         |         |
| Yes                       | 1.68         | [0.39, 7.17]            | .47     |
| No                        |              |                         |         |
Our results may theoretically be supported from the viewpoint of biomechanical analysis. However, there is no point in loading an occlusal force in an edentulous jaw. The mechanical stress caused by occlusal movement such as twisting torsions may be reduced.

Our findings showed a close relationship between a small number of residual teeth and reconstruction plate prognosis. To clarify this causal relationship, a biomechanical analysis of the stress load to the mandible and reconstruction plate is needed. However, if this problem can be clarified, the prognosis of the reconstruction plate can be determined, and countermeasures to reduce the stress can be established. The stress generated by occlusion should be analyzed from multiple perspectives in future studies.

5 CONCLUSIONS

The 5-year exposure-free survival of a mandibular plate was poorer for patients with a small number of residual paired teeth than for patients with no teeth or those with a large number of residual paired teeth. Thus, stress burden on the reconstruction plate appears to differ based on the number of residual paired teeth. To accurately specify the cause of this stress burden and utilize it for treatment, future in vivo studies on the stress load on the reconstruction plate are needed.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI (Tokyo, Japan; grant number, 19H03846).

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

ORCID

Toru Yanagawa https://orcid.org/0000-0003-0868-2563
Shohei Takaoaka https://orcid.org/0000-0001-7690-9120

REFERENCES

Arden, R. L., Rachel, J. D., Marks, S. C., & Dang, K. (1999). Volume-length impact of lateral jaw resections on complication rates. Archives of Otolaryngology - Head and Neck Surgery, 125, 68–72. https://doi.org/10.1001/archotol.125.1.68

Coletti, D. P., Ord, R., & Liu, X. (2009). Mandibular reconstruction and second generation locking reconstruction plates: Outcome of 110 patients. International Journal of Oral and Maxillofacial Surgery, 38, 960–963. https://doi.org/10.1016/j.ijoms.2009.03.721

Eichner, K. (1995). A group classification of missing teeth for prosthotodontics. Deutsche zahnärztliche Zeitschrift, 10, 1831–1834.

Ettl, T., Driemel, O., Dresp, B. V., Reichert, T. E., Reuther, J., & Pister, H. (2010). Feasibility of alloplastic mandibular reconstruction in patients following removal of oral squamous cell carcinoma. The Journal of Craniofacial Surgery, 38, 350–354. https://doi.org/10.1016/j.jcsm.2009.04.011

Fanzio, P. M., Chang, K. P., Chen, H. H., Hsu, H. H., Gorantla, V., Solari, M. G., & Kao, H. K. (2015). Plate exposure after anterolateral thigh free-flap reconstruction in head and neck cancer patients with composite mandibular defects. Annals of Surgical Oncology, 22, 3055–3060. https://doi.org/10.1245/s10434-014-4322-1

Hoefert, S., & Taier, R. (2018). Mechanical stress in plates for bridging reconstruction mandibular defects and purposes of double plate reinforcement. The Journal of Craniofacial Surgery, 46, 785–794. https://doi.org/10.1016/j.jcsm.2018.01.016

Kammerer, P. W., Klein, M. O., Moergel, M., Gemmel, M., & Draenert, G. F. (2014). Local and systemic risk factors influencing the long-term success of angular stable alloplastic reconstruction plates of the mandible. The Journal of Craniofacial Surgery, 42, e271–e276. https://doi.org/10.1016/j.jcsm.2013.10.004

Mariani, P. B., Kowalski, L. P., & Magrin, J. (2006). Reconstruction of large defects postmandibulectomy for oral cancer using plates and myocutaneous flaps: A long-term follow-up. International Journal of Oral and Maxillofacial Surgery, 35, 427–432. https://doi.org/10.1016/j.ijom.2005.10.008

Markwardt, J., Pfeifer, G., Eckelt, U., & Reitemeier, B. (2007). Analysis of complications after reconstruction of bone defects involving complete mandibular resection using finite element modelling. Onkologie, 30, 121–126. https://doi.org/10.1159/000098848

Maurer, P., Eckert, A. W., Kriwalsky, M. S., & Schubert, J. (2010). Scope and limitations of methods of mandibular reconstruction: A long-term follow-up. British Journal of Oral and Maxillofacial Surgery, 48, 100–104. https://doi.org/10.1016/j.bjoms.2009.07.005

Okura, M., Isomura, E. T., Iida, S., & Kogo, M. (2005). Long-term outcome and factors influencing bridging plates for mandibular reconstruction. Oral Oncology, 41, 791–798. https://doi.org/10.1016/j.oraloncology.2005.03.006

Park, S. M., Lee, J. W., & Noh, G. (2018). Which plate results in better stability after segmental mandibular resection and fibula free flap reconstruction? Biomechanical analysis. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, 126, 380–389. https://doi.org/10.1016/j.oooo.2018.05.048

Poli, T., Ferrari, S., Bianchi, B., & Sesenna, E. (2003). Primary oromandibular reconstruction using free flaps and thorp plates in cancer patients: A 5-year experience. Head and Neck, 25, 15–23. https://doi.org/10.1002/hed.10181

Prasad, J., Sahovaler, A., Theurer, J., Yeh, D. H., Fung, K., MacNeil, S. D., ... Nichols, A. C. (2018). Predictors of plate extrusion in oromandibular free flap reconstruction. Microsurgery, 38, 682–689. https://doi.org/10.1002/micr.30349

Ryu, J. K., Stern, R. L., Robinson, M. G., Bowers, M. K., Kubo, H. D., Donald, P. J., ... Fu, K. K. (1995). Mandibular reconstruction using a titanium plate: The impact of radiation therapy on plate preservation. International Journal of Radiation Oncology and Biological Physics, 32, 627–634. https://doi.org/10.1016/0360-3016(95)00074-9

Sadr-Eshkevari, P., Rashad, A., Vahdati, S. A., Garajei, A., Bohluli, B., & Maurer, P. (2013). Alloplastic mandibular reconstruction: A systematic review and meta-analysis of the current century case series. Plastic and Reconstructive Surgery, 132, 413e–427e. https://doi.org/10.1097/PRS.0b013e318292dd0d9

Shibahara, T., Noma, H., Furuya, Y., & Takaki, R. (2002). Fracture of mandibular reconstruction plates used after tumor resection. Journal of Craniofacial Surgery, 100. https://doi.org/10.1053/joms.2002.29817

Sobin, L. H., Wittekind, C., & Gospodarowicz, M. K. (2009). TNM classification of malignant tumours (7th ed.). New York: Wiley-Blackwell.

van der Rijt, E. E., Noorlag, R., Koole, R., Abink, J. H., & Rosenberg, A. J. (2015). Predictive factors for premature loss of Martin 2.7 mandibular reconstruction plates. British Journal of Oral and Maxillofacial Surgery, 53, 121–125. https://doi.org/10.1016/j.bjoms.2014.10.010
Wang, Z. H., Zhang, Z. Y., & Mendenhall, W. M. (2005). Postoperative radiotherapy after titanium plate mandibular reconstruction for oral cavity cancer. *American Journal of Clinical Oncology, 28*, 460–463. https://doi.org/10.1097/01.coc.0000178836.68782.b5

Wood, C. B., Shinn, J. R., Amin, S. N., Rohde, S. L., & Sinard, R. J. (2018). Risk of plate removal in free flap reconstruction of the mandible. *Oral Oncology, 83*, 91–95. https://doi.org/10.1016/j.oraloncology.2018.06.008

Yi, Z., Jian-Guo, Z., Guang-Yan, Y., Ling, L., Fu-Yun, Z., & Guo-Cheng, Z. (1999). Reconstruction plates to bridge mandibular defects: A clinical and experimental investigation in biomechanical aspects. *International Journal of Oral and Maxillofacial Surgery, 28*, 445–450. https://doi.org/10.1016/S0901-5027(99)80058-7

**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

*How to cite this article:* Hirohata H, Yanagawa T, Takaoka S, et al. A small number of residual teeth after the mandibular resection of oral cancer is associated with titanium reconstruction plate exposure. *Clin Exp Dent Res*. 2019;5:469–475. https://doi.org/10.1002/cre2.208