Int. J. Oral Maxillofac. Surg. 2019; 48: 1009–1014
https://doi.org/10.1016/j.ijom.2019.03.008, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Clinical Paper
Reconstructive Surgery

Cortical bone resorption of fibular bone after maxillary reconstruction with a vascularized fibula free flap: a computed tomography imaging study

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Abstract. This study was performed to evaluate the cortical bone resorption of fibular bone after maxillary reconstruction with a fibula free flap. A total of 35 patients with maxillary defects that were repaired using a fibula flap (62 fibula segments) between January 2011 and January 2016 were enrolled. Computed tomography (CT) images taken 1 week and 1 year postoperative were used to evaluate cortical bone resorption. The 62 fibula segments were measured on four different surfaces in the CT images. At 1 week, the thickness of the cortical bone was 2.57 ± 0.58 mm, 2.72 ± 0.46 mm, 3.84 ± 0.98 mm, and 4.36 ± 0.90 mm for the exterior, interior, superior, and inferior sides, respectively. At approximately 1 year, the cortical bone thickness was significantly reduced to 2.00 ± 0.65 mm ($P < 0.01$), 2.25 ± 0.60 mm ($P < 0.01$), 3.37 ± 0.90 mm ($P < 0.01$), and 2.96 ± 0.84 mm ($P < 0.01$) for the exterior, interior, superior, and inferior sides, respectively. The cortical bone thickness of fibular bone is significantly reduced 1 year after the restoration of maxillary defects with a fibula free flap, most significantly on the inferior side.

Key words: maxillary reconstruction; vascularized fibula free flap; cortical bone; bone thickness; bone resorption.

Accepted for publication 12 March 2019
Available online 9 April 2019

Maxillary reconstruction after tumour resection or trauma in the head and neck region is challenging for functional and aesthetic reasons[1]. Several techniques are available for maxillary reconstruction. The use of vascularized bone grafts, including fibula[2], iliac[3], and scapula flaps[4], is one of the best solutions. The fibula free

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flap was first introduced by Hidalgo in 1989[5]. In 1993, Schusterman et al. reported the first midface reconstruction with a fibula free flap[2]. At present, fibula free flaps represent the best approach for maxillary reconstruction[6].

Many studies have shown that aesthetic problems can be satisfactorily resolved using computer-assisted surgery[7–9]. Rehabilitation of the dentition using dental implants plays an important role in the functional reconstruction of the maxilla. The use of vascularized fibula free flaps and dental implants can provide good aesthetic and functional results in the long term[10–12]. However, cortical bone thickness substantially influences the primary stability of implants[13]. The present authors observed marked cortical bone resorption in the computed tomography (CT) images of patients who had undergone maxillary reconstruction with a fibula flap. Since the fibula is a tubular bone, which contains almost no cancellous bone, only the cortical bone can provide primary stability and osseointegration. During implant surgery, a bone graft or guided bone regeneration (GBR) is required to counteract the effects of cortical bone resorption. This actually increases the cost of surgery, operation time, and number of operations. In addition, the patients suffer more pain and swelling.

This study was conducted to evaluate the cortical bone resorption of fibular bone after maxillary reconstruction with a vascularized fibula free flap, in order to know the changes in cortical bone thickness.

Materials and methods

Between January 2011 and January 2016, 113 patients underwent maxillary reconstruction with a vascularized fibula free flap in the Department of Oral and Maxillofacial Surgery, Peking University School of Stomatology, Beijing, China. The inclusion criteria for the study were (1) maxillary defect after tumour ablation or trauma requiring restoration with a fibula flap, (2) at least one fibula segment used to reconstruct the maxillary alveolus, and (3) no exposure of titanium plates or infection postoperatively. The exclusion criteria were (1) the flap did not survive, (2) the patient had a bone metabolism disease, and (3) the patient had received radiotherapy or chemotherapy. Thirty-five patients in whom 62 fibula segments were used to reconstruct the alveolus were included in this retrospective study. This study adhered to the principles of the Declaration of Helsinki in terms of medical protocols and ethics and was approved by the Institutional Ethics Committee, Peking University School and Hospital of Stomatology.

CT images (120 kV, 25 mAs, section width (SW) = 1.25 mm) taken 1 week and approximately 1 year postoperative were used to evaluate the cortical bone thickness of fibula segments. The cortical bone thickness of fibula segments was viewed in a bone window (800 HU) and measured manually using PACS software (Carestream Health, Inc., Rochester, NY, USA). Cortical bone thickness was measured in three cross-sections, which were at 25%, 50%, and 75% of the maximum length of the fibula segment[14]. Four points were measured in each cross-section. By adjustment of the observation planes before measurement, the axial plane was made to coincide with the longest diameter of the cross-section of the fibula segment. The exterior and interior sides were then measured in the axial plane. The coronal plane was made parallel to the long axis of the fibula segment and passed through the most prominent point. The superior and inferior sides were measured in the coronal plane. These planes were all relative to the maxilla position (Fig. 1). The images were evaluated by two investigators; the time interval between each measurement session was 1 week.

All statistical analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). Measurement results were recorded as the mean $\pm$ standard deviation. The intraclass correlation coefficient (ICC) was used to evaluate inter-observer reliability. The 1-year resorption rate was calculated by dividing the reduction in cortical bone thickness by the cortical bone thickness at 1 week postoperative. A linear mixed-effects model with zero intercept was adopted to investigate whether the resorption rate on the four sides was equal to zero and whether the resorption rate differed between the four sides. The covariance structure was specified as unstructured. Also, pairwise comparisons were conducted using the paired *t*-test to investigate which two sides were different. The Wilcoxon signed-rank test was used to investigate the difference in cortical bone thickness among the time points 1 week, 1 year, and 2 years postoperative. The four variables sex, age, defect type, and number of fibula segments used were assessed by linear regression analysis to determine the factors associated with cortical bone resorption. The defect type was subdivided into Brown class II or class III[15]. *P*-values of less than 0.05 were considered statistically significant.

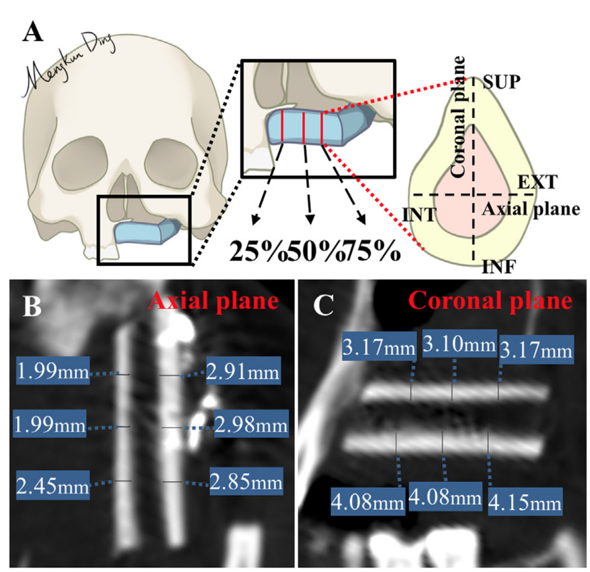

Fig. 1. The measurement method. (A) Cortical bone thickness was measured in three cross-sections, which were at 25%, 50%, and 75% of the maximum length of the fibula segment. Four points were measured in each cross-section. By adjustment of the observation planes before measurement, the axial plane was made to coincide with the largest diameter of the cross-section of the fibula segment. The exterior and interior sides were then measured in the axial plane. The coronal plane was made parallel to the long axis of the fibula segment and passed through the most prominent point. The superior and inferior sides were measured in the coronal plane. These planes were all relative to the maxilla position. Measurements in the (B) axial and (C) coronal planes in CT images. (EXT = exterior side; INT = interior side; SUP = superior side; INF = inferior side.).

Table 1. Patient characteristics.

Variable	
Number of patients	35
Sex, *n* (%)	
Male	18 (51.4%)
Female	17 (48.6%)
Age (years), median (range)	37 (17–72)
Disease, *n* (%)	
Benign tumour	14 (40.0%)
Malignant tumour	18 (51.4%)
Trauma	3 (8.6%)
Defect, *n* (%)	
Brown class II	26 (74.3%)
Brown class III	9 (25.7%)
Number of fibula segments, *n* (%)	62 (100%)
1	11 (31.4%)
2	21 (60%)
3	3 (8.6%)
Follow-up time (months), median (range)	12 (9–26)

Table 2. Postoperative cortical bone thickness of fibular bone (mean ± SD, millimetres).

Location	Postoperative time		*P*-value
	1 week	1 year	
Exterior side	2.57 ± 0.58	2.00 ± 0.65	<0.01
Interior side	2.72 ± 0.46	2.25 ± 0.60	<0.01
Superior side	3.84 ± 0.98	3.37 ± 0.90	<0.01
Inferior side	4.36 ± 0.90	2.96 ± 0.84	<0.01

Results

A total of 35 patients, 18 male and 17 female, were included in this study, and cortical bone thickness was measured for 62 fibula segments (Table 1). Twenty-six patients had Brown class II defects and nine had Brown class III defects. The median patient age was 37 years (range 17–72 years) and the median follow-up time was 12 months (range 9–26 months). The inter-observer reliability was good (ICC = 0.91).

At 1 week postoperative, the thicknesses of the cortical bone was 2.57 ± 0.58 mm, 2.72 ± 0.46 mm, 3.84 ± 0.98 mm, and 4.36 ± 0.90 mm for the exterior, interior, superior, and inferior sides, respectively. At 1 year postoperative, there was a significant reduction in cortical bone thickness. The thickness of the cortical bone decreased to 2.00 ± 0.65 mm ($P <$ 0.01), 2.25 ± 0.60 mm ($P <$ 0.01), 3.37 ± 0.90 mm ($P <$ 0.01), and 2.96 ± 0.84 mm ($P <$ 0.01) for the exterior, interior, superior, and inferior sides, respectively (Table 2, Fig. 2). The cortical bone resorption rate was 21 ± 24%, 17 ± 21%, 10 ± 20%, and 31 ± 17% for the exterior, interior, superior, and inferior sides, respectively (Fig. 3). The linear mixed-effects model showed that the resorption rates at 1 year differed significantly among the four sides ($P <$ 0.01). The pairwise comparison results showed that the resorption rate differed significantly between any two sides ($P <$ 0.05), except between the exterior side and the interior side ($P =$ 0.063). The most obvious cortical bone resorption occurred on the inferior side of the fibula segments.

Of the 35 patients included in the study, five who were treated with seven fibula segments were followed up at 1 week, 1 year, and 2 years postoperative. There was an obvious resorption at the first year compared to 1 week postoperative ($P <$ 0.05) and the inferior side ($P <$ 0.05). In contrast, the cortical bone on the exterior side showed marked resorption between the first year and the second year postoperative ($P <$ 0.05). Furthermore, there was no significant difference in cortical bone thickness on the interior side between the first and second year postoperative (Fig. 4).

Linear regression analysis showed none of four variables (sex, age, defect type, and number of fibula segments used) to be factors associated with cortical bone resorption ($P >$ 0.05).

Case report

A 26-year-old male patient was treated for left maxillary ossifying fibroma. Three segments of vascularized fibula free flap were used to repair the defect, two of which were used for alveolar reconstruction. The cortical bone of the fibula segments showed obvious resorption at 2 years postoperative compared with 1 week postoperative in the CT images. During implant surgery, it was found that the cortical bone of the fibula segments was very thin, and the initial stability of the implants was about 10 N·cm. GBR and an onlay bone graft were performed to obtain sufficient bone for osseointegration (Fig. 5).

Discussion

Peng et al. suggested that maxillary reconstruction should achieve the following aims: obliteration of the defect; restoration

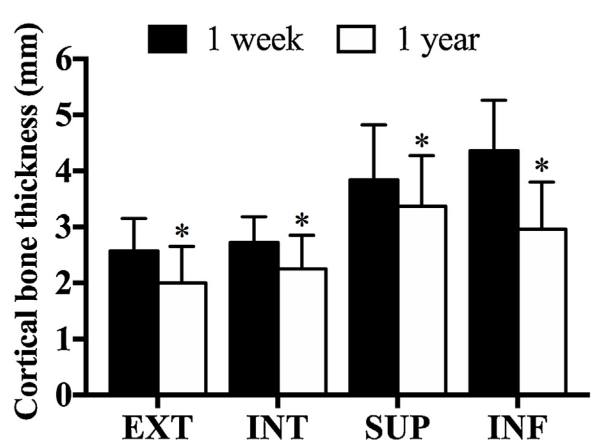

Fig. 2. Cortical bone thickness of 62 fibula segments (in millimetres) on the exterior, interior, superior, and inferior sides at 1 week and at 1 year postoperative. There was a significant reduction in cortical bone thickness between 1 week and 1 year postoperative on all four sides. The main bar and error bar represent the mean and standard deviation, respectively. *$P <$ 0.01. (EXT = exterior side; INT = interior side; SUP = superior side; INF = inferior side).

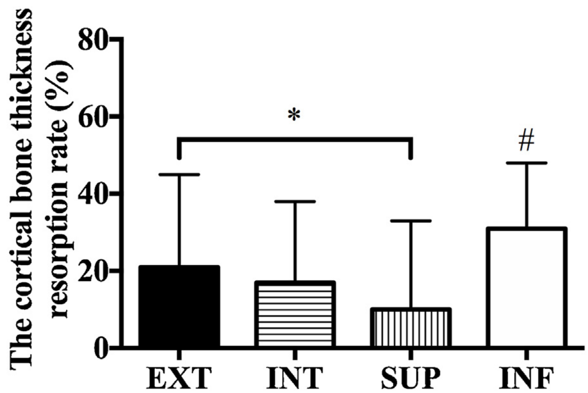

Fig. 3. Cortical bone thickness resorption rates at 1 year postoperative on the exterior, interior, superior, and inferior sides. The most obvious cortical bone resorption occurred on the inferior side of the fibula segments. The main bar and error bar represent the mean and standard deviation, respectively. *EXT vs. SUP, $P < 0.05$. #INF vs. EXT, INF vs. INT, and INF vs. SUP, $P < 0.05$. (EXT = exterior side; INT = interior side; SUP = superior side; INF = inferior side).

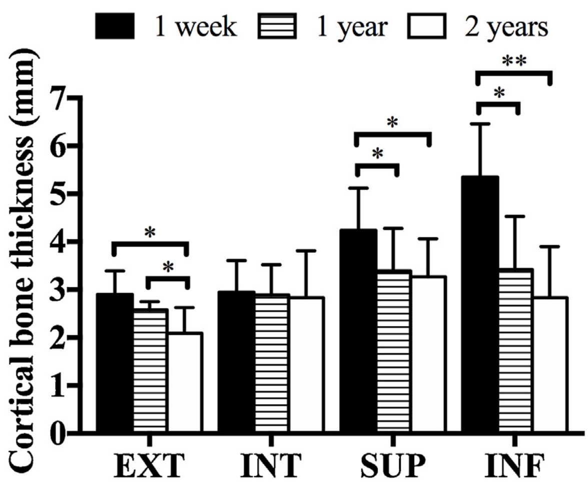

Fig. 4. Cortical bone thickness of seven fibula segments (in millimetres) on the exterior, interior, superior, and inferior sides at 1 week, 1 year, and 2 years postoperative. There was obvious resorption on the superior side and inferior side at the first year compared to 1 week postoperative. The cortical bone on the exterior side show marked resorption at the second year postoperative. There was no significant difference in the cortical bone thickness between the first and second years on the interior side. The main bar and error bar represent the mean and standard deviation, respectively. *$P < 0.05$. **$P < 0.01$. (EXT = exterior side; INT = interior side; SUP = superior side; INF = inferior side).

of function, particularly speech and mastication; and structural support for the reconstruction of facial features[16]. To achieve these aims, multiple reconstructive methods are available. The reconstruction team must choose the best approach based on each patient's individual situation[17]. We prefer the use of a fibula free flap to other options. For complex maxillary defects, the fibula flap has several advantages over other vascularized free flaps, including the long vascular pedicle, wide diameter of peroneal vessels, types and volumes of tissues, and suitability for dental implants[18]. We consider it the best option for maxillary reconstruction.

The thickness of cortical bone has been shown to have a substantial influence on the primary stability of implants[13]. Cortical bone thickness greatly increases implant stability in humans. An experimental study consistently demonstrated that the removal torque of implants in the fibula, iliac crest, and scapula of cadavers was related to cortical rather than total bone thickness[19]. Furthermore, Ivanoff et al. evaluated the removal torque and bone tissue response to implants supported by one or two cortical layers in the rabbit tibia[20]. Their results showed that the removal torque was two times higher after 6 weeks and three times higher after 12 weeks for bicortical implants than for monocortical implants. Thus, the feasibility of the bicortical fixation of implants, which provides greater stability and a higher chance of osseointegration[21], makes the use of the fibula flap most appropriate for maxillary reconstruction.

As maxillary reconstruction is challenging, studies on bone resorption in fibula flaps used for maxillary reconstruction are rare. In contrast, there are many studies on bone resorption in fibula flaps used for mandibular reconstruction[22–26], the results of which are very similar: fibula flaps used for mandibular reconstruction are stable and bone resorption is low, even after radiotherapy. However, maxillary reconstruction is more complicated than mandibular reconstruction, and may require more segments and more complex structures. The degree of bone resorption in fibula flaps used for maxillary reconstruction remains unclear.

These studies on mandibular reconstruction focused on the total thickness of the fibula segments, but cortical bone resorption was not examined. In addition, the use of panoramic radiograph measurements to evaluate bone resorption in these studies may have resulted in errors related to image magnification: the fibula segments used in maxillary reconstruction have multiple directions that may cause larger errors when images are magnified. Wilkman et al. used multi-slice CT to calculate the volumes of fibula segments[22], which is more reliable than two-dimensional measurement. The change in volume represents total bone resorption, but is not informative about cortical bone resorption. The measurements in the present study were based on two-dimensional CT images. To reduce error, the axial plane was made to coincide with the longest diameter of the cross-section of the fibula segments. The coronal plane was made parallel to the long axis of the fibula segments and passed through the most prominent point. Also, four different surfaces were measured in three cross-sections, meaning that the technique used was more comprehensive than panoramic radiograph measurement. Currently, the direct measurement of cortical bone thickness on CT images is the best option. New approaches are needed to evaluate cortical bone thickness more easily and objectively.

According to Wolff's law, the morphology of bone is affected by mechanical loading, and bone has a self-optimizing

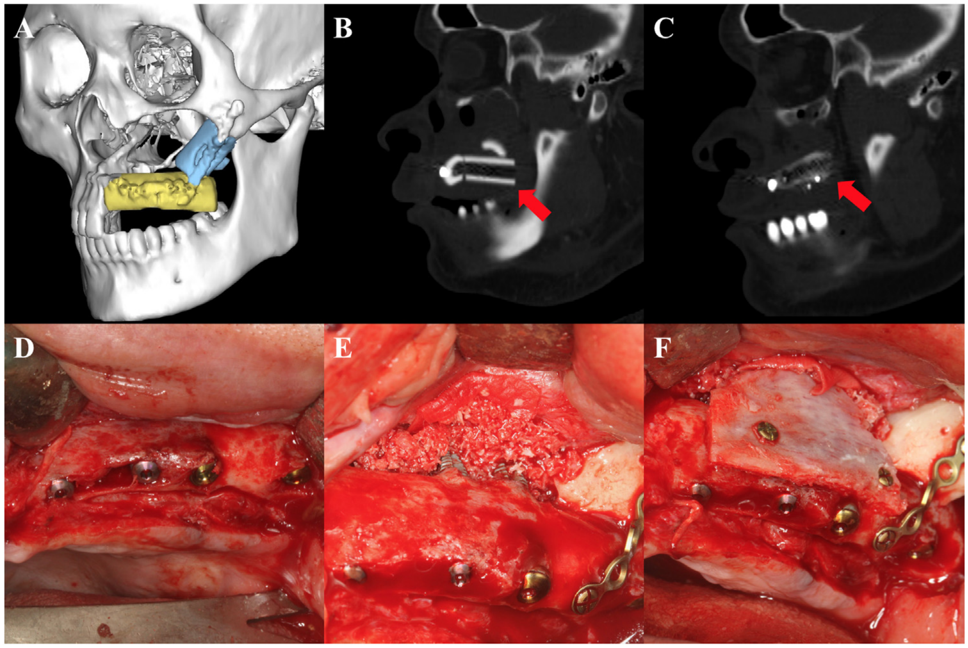

Fig. 5. A 26-year-old male was treated for left maxillary ossifying fibroma. (A) Two of the three fibula segments were used for alveolar reconstruction (yellow). CT images at (B) 1 week and (C) 2 years postoperative. (D) The cortical bone of the fibula segments was very thin during implant surgery. (E) Guided bone regeneration and (F) an onlay bone graft were used to augment the bone volume (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

capability[27]. Wolff also suggested that bone obtains maximum mechanical efficiency with minimum mass[27]. In brief, bone is remodelled along the main stress trajectories. When the fibula is in the leg, the direction of stress is parallel to its long axis. After maxillary reconstruction, the orientation of the fibula segments may be the same as the direction of stress. Thus, bone remodelling occurs after reconstruction. Frost elaborated on Wolff's law, stating that there are threshold stress values for the resorption and strengthening of bone[28]. Furthermore, Frost demonstrated that bone is absorbed when microstrain is less than 50–100 or stress is less than 1–2 MPa. The fibula segments used in maxillary reconstruction are stationary relative to the skull and lack functional stimulation. Thus, it is suggested that the strain and stress acting on the fibula segments is reduced, which results in bone resorption. However, proving this hypothesis will require more patients and finite element analysis to simulate the stress conditions of the fibula segments.

The following aspects require further study in the future. First, the correlation between time and bone resorption remains unclear. The results of this study showed that the different sides of the fibula segments exhibited different changes in cortical bone thickness over time. With a larger sample size, it may be possible to obtain more specific results on the rate of bone resorption to determine the optimum time range for dental implant placement. Second, the correlation between age and bone resorption requires further clarification. It would be useful to confirm the age range in which patients are eligible for dental implants.

In conclusion, the cortical bone thickness of fibular bone was significantly reduced 1 year after the restoration of maxillary defects with a vascularized fibula free flap. The most significant bone resorption was evident on the inferior side of the fibular cortical bone. Based on the existing data, performing dental implant surgery as soon as possible after maxillary reconstruction with a fibula flap might be a good choice to avoid low primary implant stability resulting from severe bone resorption. This is because cortical bone thickness undergoes a significant reduction during the first postoperative year and is absorbed constantly over time. The rehabilitation of occlusion may give the fibula segments sufficient functional stimulation to reduce bone resorption.

Funding

This work was supported by The National Key Research and Development Program of China (grant number 2016YFC1102902) and Beijing Municipal Development Foundation in China (grant number Z161100000516016).

Competing interests

None.

Ethical approval

Peking University School and Hospital of Stomatology Institutional Ethics Committee (PKUSSIRB – 201412028).

Patient consent

Not required.

Acknowledgements. The authors thank Dr Meng-Kun Ding for the illustration used in Fig. 1.

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