Original

Morphological Study on the Fibula in Japanese: Basic Anatomical Study for Maxillofacial Reconstruction

Hidetomo Hirouchi\(^1\), Yoshiaki Shimoo\(^2\), Masashi Suzuki\(^3\), Satoru Matsunaga\(^4\), Masahito Yamamoto\(^5\), Kento Odaka\(^6\), Kei Kitamura\(^7\), Kazuto Koresawa\(^8\), Nobuki Yanagisawa\(^9\), Koji Sakiyama\(^9\), Takeshi Takayama\(^9\), Katsuhiko Hayashi\(^9\), Wei-Jen Chang\(^10,11\) and Shinichi Abe\(^10\)

\(^1\) Department of Anatomy, Tokyo Dental College, Tokyo, Japan
\(^2\) Malo Clinic Tokyo, Tokyo, Japan
\(^3\) Ginza Yanagidori Dental Clinic, Tokyo, Japan
\(^4\) Multidisciplinary Research Center for Jaw Disease (MRCJD), Tokyo Dental College, Tokyo, Japan
\(^5\) Department of Oral and Maxillofacial Radiology, Tokyo Dental College, Tokyo, Japan
\(^6\) Department of Anatomy, Tokyo Dental College, Tokyo, Japan
\(^7\) Division of Oral Health Sciences, Department of Health and Social Services, Saitama Prefectural University, Koshigaya, Japan
\(^8\) Division of Anatomy, Meikai University School of Dentistry, Saitama, Japan
\(^9\) Department of Dentistry, Jikei University School of Medicine, Tokyo, Japan
\(^10\) School of Dentistry, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan
\(^11\) Dental Department, Taipei Medical University, Taipei, Taiwan

Correspondence to: Dr. Hidetomo Hirouchi, Department of Anatomy, Tokyo Dental College, 2-9-18 Kandamisaki-eko, Chiyoda-ku, Tokyo 101-0061, Japan; Tel: +81-3-6380-9592; Fax: +81-3-6380-9664; E-mail: hirouchihideto@tdc.ac.jp

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Abstract: Free vascularized fibular flaps (FVFF) have an advantage in their applicability for extensive bone defects in the maxillofacial region after surgery, and have therefore been employed in maxillofacial reconstruction in Western countries. For successful application of FVFF, anatomical understanding of the fibula is necessary. Many studies on the fibula of patients and autopsied bodies have been reported. An increase in demand is predicted in Japan, but few studies on the morphological characteristics of the fibula of Japanese have been reported. Many unclear points remain and no study has focused on sex differences. In this study, the 3-dimensional morphology of the fibula of Japanese was observed, the previously unreported distribution and location of the feeding blood vessels were examined, and the region containing sufficient bone mass for maxillofacial reconstruction was anatomically evaluated. Images of the excised fibula were acquired using CT for medical use and subjected to 3-dimensional reconstruction. Prior to measurement, the fibula was divided into 6 parts between the apex of the fibular head and apex of the lateral malleolus. The 4 central regions were set as regions of interest and the diameters of the fibular cross sections were 3-dimensionally measured. In addition, the distribution of the feeding blood vessels to the fibula was macroscopically observed and classified. On 3-dimensional bone morphology measurement, the width (diameter) of fibula cross section between the anterior margin and posterior aspect was the largest, followed by that between the medial crest and lateral aspect. In the regions of interest, the mean width between the anterior margin and posterior aspect, which corresponded to the grafted bone height, exceeded 10 mm, and the mean width between the medial crest and lateral aspect and between the posterior margin and medial aspect, which became the buccolingual width of the grafted bone, exceeded 6 mm, confirming that the graft thickness is sufficient for grafting. Furthermore, the blood vessels feeding the fibula entered the bone in the central one-third region in all preparations. Inclusion of the central one-third region was suggested to be effective for vascularized fibular grafting.

Key words: Ameloblastoma, Contrast-enhanced MRI, Diagnostic imaging, FLAIR, MRI

Introduction

After Taylor et al.\(^1\), initially used vascularized free fibular flaps (FVFF) for tibial reconstruction in 1975, this method was widely adopted. FVFF is also used for the maxillofacial region because it is superior to iliac and scapular grafts for reconstruction of the dental arc, oral cavity function, and facial reconstruction\(^2\).\(^3\). Dental implant placement in FVFF is routinely performed\(^4\), and has improved the outcomes of mastication, conversation, and swallowing functions\(^5\).\(^6\). For jaw bone reconstruction, the fibula is measured in the upward direction from the lateral malleolus, and the bone is excised from the donor site based on the measurement results. In general, for the region to be cross-sectioned in the fibula, the region at 8-10 cm above the lateral malleolus is excised in order to maintain ankle joint stability\(^7\).\(^8\).

For successful FVFF grafting, an understanding of the fibular anatomy is necessary. Many studies on the fibula of patients and autopsied bodies have been reported\(^9\).\(^10\). Germain et al. reported the mean usable...
length of the fibula for grafting, and Matsuura et al. measured the fibular diameter, observed the morphology of cross section, measured the cortical bone thickness, and observed the nutrient foramen, in which the nutrient foramen was present on the posterior aspect in the central one-third of the fibula in 85%, the maximum diameter was 13.1 mm, and the maximum cortical bone thickness was 4.1 mm. Ide et al. acquired and 3-dimensionally reconstructed CT images of the fibula of adult patients, and then measured the fibular diameter, observed the morphology of cross sections, and measured the fibular length based on 2 types of implant placement. Lee et al. examined the distribution and radiographic characteristics of the nutrient canal in the fibula, in which many nutrient canals were present on the posterior and medial aspects of the fibula, comprising 2 types. Frodel et al. measured the height, width, and cortical bone thickness of fibular cross sections from the viewpoint of placing dental implants in the reconstructed region of the mandible, and clarified that the fibula is appropriate for reconstruction of the anterior region of the mandible. Moscoso et al. measured the fibular height, width, and cross-sectional area by area measurement using a computer, and demonstrated that the fibula is appropriate for grafting following the iliac crest and scapula. Hoon et al. evaluated the fibular cancellous bone density, bone-implant interface density, and cortical bone thickness by simulating endosseous implant placement, in which the fibular cancellous bone density was low, but the cortical bone thickness and bone-implant interface density were high. Bernd et al. measured the cortical bone thickness and density in fibular cross sections using radiography, and confirmed that the fibula is also appropriate for reconstructing extensive bone defects. Regarding the feeding blood vessels of the fibula, the fibula is fed by the main feeding blood vessel (bone marrow branch) entering through the nutrient foramen at one-third of the entire fibular length and the periosteal branch, and it has been reported that grafted bone smoothly engrafted when one of these vessels was conserved. The demand for this grafting may increase in the future in Japan, but there are only a few reports on the morphological characteristics of the fibula of Japanese, with many points remaining unclear. Moreover, no study discussing sex differences has been reported. In this study, the 3-dimensional morphology of the fibula of Japanese was observed, the previously unreported distributions and positions of feeding blood vessels were examined, and the region with a sufficient bone mass for maxillofacial reconstruction was anatomically evaluated.

The objective of this study was to clarify the anatomical structure of the fibula of Japanese by morphological observation, 3-dimensional measurement, and examination of the distribution and position of feeding blood vessels for use in maxillofacial reconstruction.

Materials and methods

Specimens

Cadavers of 84 adult Japanese (mean age: 79.9 years old) for practice from the department of anatomy of Tokyo Dental College were used (58 cadavers were male [mean age: 77.8 years old (range: 53-97 years old)]; 26 cadavers were female [mean age: 84.7 years old (range: 66-101 years old)]. This study was approved by the Ethics Committee of Tokyo Dental College (No. 785). The fibulae were excised from the cadavers, fixed in 10% neutral buffered formalin solution, dehydrated with ethanol, and subjected to experiments.

CT scanning

The collected specimens were imaged using CT for medical use (SOMATOM Definition AS, SIEMENS Corporation, Japan) under the following acquisition conditions: 120 kV, eff.mAs 90 mA. The raw data were reconstructed using the reconstruction kernels B70f, and slice thickness were 1.0 mm; matrix size, 0.25×0.25 mm. Using 3D structure analysis software, Mimics (Mimics 19.0, Materialise Corporation, Japan), 3-dimensional reconstructed images were prepared and the inner structure was observed.

Cross-sectional measurement

The apex of the fibular head and that of the lateral malleolus were designated as points A and G, respectively. The distance between these 2 points was divided into 6 parts, and the divided points were designated as B, C, D, E, and F from the apex of the fibular head. Cross sections were placed on the long axis of the fibula were prepared at B, C, D, and E. and these cross sections were designated as cross sections B, C, D, and E. 3D structure analysis software, Mimics (Mimics 19.0, Materialise Corporation, Japan), was used to define these cross sections and acquire the images described below.

Length of fibula

As the entire fibular length, the distance between the apex of the fibular head (point A) and apex of the lateral malleolus (point G) was measured (Fig. 1). To confirm that cross sections B, C, D, and E were included in the bone graft region, the distances of these points from the apex of the lateral malleolus were calculated from the entire fibular length.

Widths from the margins of the fibula to their opposing aspects

To acquire the entire view of the fibula, the length was measured in the fibular cross sections (B, C, D, and E) employing the measurement system used by Matsuura and Ide. As shown in Fig. 2, the anterior margin was designated as point a, the medial crest was designated as point b, and the posterior margin was designated as point c. A perpendicular line was drawn from point a to line segment b-c, and the intersecting point with the posterior aspect was designated as point d. Similarly, a perpendicular line was drawn from point c to line segment a-b, and the intersecting point with the medial aspect was designated as point e. A perpendicular line was drawn from point b to line segment a-c and the intersecting point with the lateral aspect was designated as point f. Distances a-d, c-e, and b-f were measured.

Shapes of cross sections

According to the methods reported by Matsuura et al. and Ide et al., the shapes of cross sections B, C, D, and E in the bone graft donor region were classified into 3 types: triangular, quadrilateral, or irregular (Fig. 3).

Statistical analysis

Statistical analysis was performed using statistics software SPSS 18.0 (SPSS, Chicago, IL). Differences between the cross sections and between the measured regions were compared. The t-test was employed to evaluate sex difference, and differences in the mean between the 2 groups were calculated. A p-level below 0.05 was considered significant.

Blood vessels feeding the fibula

Blood vessels feeding the fibula were dissected out. The nutrient foramen through which the bone marrow branch of the fibular artery entered the fibula was observed (Fig. 4).
Hidetomo Hirouchi et al.: Morphological Study on the Fibula

Results

Length of the fibula

The results of fibular length measurement are shown in Fig. 5. The length from the apex of the fibular head (point A) to the apex of the lateral malleolus (point G) was measured. Similarly, the distances between the apex of the lateral malleolus, and cross sections B, C, D, and E were measured. The mean length was 345.98 mm in males and 315.11 mm in females, demonstrating that the length was significantly longer in males than in females.

Widths from margins of the fibula to the opposing aspects

Figs. 6 and 7 show the results of comparison of the widths between the margin (anterior margin, medial crest, and posterior margin) and the opposing aspect (medial aspect, lateral aspect, and posterior aspect) respectively. The widths were measured at each margin, and the diameters were calculated.

The distances from the apex of the lateral malleolus to cross sections B, C, D, and E of the bone graft region were classified into 3 types: triangular, quadrilateral, or irregular.

The distances from the apex of the lateral malleolus to cross sections E, D, C, and B were 115.33, 172.99, 230.65, and 288.32 mm, respectively, in males and 105.03, 157.55, 210.07, and 262.59 mm, respectively, in females after surveying the position of each cross section. When an FVFF is prepared, a region with a length of approximately 20 cm is excised while conserving the region at 8-10 cm from the apex of the lateral malleolus to maintain stability of the ankle joint (12). Cross sections B, C, D, and E were suitable for grafting in both male and female patients.
opposing aspect (posterior, medial, and lateral aspects) among cross sections B, C, D, and E.

In male, the diameter of the fibula cross section decreased in the order of widths between the anterior margin and posterior aspect (a-d), between the medial crest and lateral aspect (b-f), and between the posterior margin and medial aspect (c-e) in the region of cross sections B-D. However, the diameters of the fibula cross sections with widths between the medial crest and lateral aspect (b-f) show lower values than one of widths between the posterior margin and medial aspect (c-e) in the region of cross sections B-C and D-E.

Female

In female, the diameter of the fibula cross section decreased in the order of widths between the anterior margin and posterior aspect (a-d), between the medial crest and lateral aspect (b-f), and between the posterior margin and medial aspect (c-e) in the region of cross sections C-D. However, the diameters of the fibula cross sections with widths between the medial crest and lateral aspect (b-f) show lower values than one of widths between the posterior margin and medial aspect (c-e) in the region of cross sections B-C and D-E.

Figure 5. Fibular length (mm) Full length: Length from the apex of the lateral malleolus (G) to the apex of the fibular head. B-G: Length from the apex of the lateral malleolus (G) to cross section B. C-G: Length from the apex of the lateral malleolus (G) to cross section C. D-G: Length from the apex of the lateral malleolus (G) to cross section D. E-G: Length from the apex of the lateral malleolus (G) to cross section E. The mean fibular length was significantly longer in males than in females (*p < 0.05).

Figure 6. Comparison of the fibular diameter (a-d, b-f, and c-e). The results of measurement of the widths between the margins (anterior margin, medial crest, and posterior margin) and opposing aspects (posterior, medial, and lateral aspects) are presented. The diameter of the fibular cross sections in B-E decreased in the order of anterior margin-posterior aspect (a-d), medial crest-lateral aspect (b-f), and posterior margin-medial aspect (c-e) in both sexes.

Figure 7. Comparison of the fibular diameter in B, C, D, and E *(p < 0.05). The widths between the anterior margin and posterior aspect (a-d) in sections B and C were significantly larger in males than in females. The widths between the medial crest and lateral aspect (b-f) in sections B, C, D, and E were significantly larger in males. The widths between the posterior margin-medial aspect (c-e) in sections C, D, and E were significantly larger in males.
When sex differences were evaluated at each measurement point, the widths between the anterior margin and posterior aspect in all cross sections, between the medial crest and lateral aspect in all cross sections, and between the posterior margin and medial aspect in cross sections C and D were significantly greater in males (Fig. 7).

Thus, a-d was found to be the largest compared with the widths of the other regions in cross sections B, C, D, and E (bone graft regions). The values were significantly greater in males in all B, C, D, and E cross sections (p < 0.05).

**Shapes of cross sections**

Fig. 8 shows the shape-based evaluations of cross sections B, C, D, and E. In males, triangular, quadrilateral, and irregular shapes of cross section B were observed in 3, 5, and 91%, respectively, those of cross section C were observed in 14, 33, and 53%, respectively, those of cross section D were 16, 59, and 26%, respectively, and those of cross section E were observed in 57, 0, and 43%, respectively. In females, triangular, quadrilateral, and irregular shapes of cross section B were observed in 8, 8, and 85%, respectively, those of cross section C were observed in 8, 100%, and 0%, respectively, those of cross section D were 14, 33, and 53%, respectively, and those of cross section E were observed in 57, 0, and 43%, respectively.
27, and 65%, respectively, those of cross section D were observed in 8, 65, and 27%, respectively, and those of cross section E were observed in 46, 8, and 46% respectively. The frequencies of irregular shape in cross sections B and C and of quadrilateral shape in cross section D were high in both sexes. In cross section E, the frequency of triangular shape was high in males, and frequencies of triangular and irregular shapes were high in females.

**Blood vessels feeding the fibula**

The fibula-feeding artery was macroscopically observed. The nutrient foramen through which the fibular artery branched from the posterior or tibial artery entered was present in the central region of the fibula, C-E, in all fibulae (Fig. 9). The nutrient foramen was normally present on the posterior aspect of the fibula, but it was present close to the anterior margin on the medial aspect in some cases (Fig. 10).

**Discussion**

FVFF with osseointegrated implant placement is routinely applied for jaw bone reconstruction, and a high success rate and favorable functional recovery have been reported\(^{6-11}\). To improve the outcome of treatment with fibular implants, surgeons must understand the characteristics of the fibular shape before surgery.

In this study, we performed morphological measurements based on data collected from medical CT images of the fibulae in practice cadavers of Japanese adults. CT image data-based measurement is advantageous in that the shapes of cross sections of regions of interest maybe easily observed using a non-destructive method, and a wide measurement range can be set. As values are measured under the same conditions, comparison among measured values is possible. Statistical analysis was performed for differences in different regions to compare the cadavers between sexes and to examine the characteristics of the fibular shape.

**Length of the fibula**

When an FVFF is prepared, the region at 8-10 cm from the lateral malleolus is conserved to maintain stability of the ankle joint\(^{12-13}\). The positions of cross sections B, C, D, and E from the lateral malleolus were measured. The position of cross section E was 115.33 mm in males and 105.03 mm in females, and that of cross section B was 288.32 and 262.59 mm in males and females, respectively, demonstrating that cross sections B, C, D, and E were within the flap donor region. Thus, we closely examined cross sections B, C, D, and E.

Ide et al. studied the fibula in Canadians, in which the position of cross section E was 129.1±7.9 mm in males and 120.5±4.1 mm in females, and that of cross section B was 322.3±19.7 and 301.3±10.2 mm, respectively\(^{14}\). The fibular length in Japanese males was shorter than that in Canadian females.

Germain et al. examined the fibula in the French\(^{13}\), and found the mean length of the fibular region excisable for grafting to be 25 cm. Bernd et al. examined the fibula in Germans\(^{28}\), in which the mean length of the fibular region excisable for grafting was 22.2±2.5 cm. In our study, the mean length of the fibular region excisable for grafting (between B and E) was 230.65 mm in males and 210.07 mm in females.

Based on our study, the range of the fibular graft donor region is slightly shorter in Asians than in Western people, but the fibula is appropriate for repair of extensive tissue defects in Asians.

**Widths from the margins of the fibula to the opposing aspects**

In general, B-E of the 6 parts of the fibula is used for fibular grafting. Vascularized bone grafts for jaw bone reconstruction are required to have a 10-mm or greater height and a 6-mm or larger width to maintain the morphology against mastication loads and support implant fixtures\(^{29}\). A region with a mean width between the anterior margin and posterior aspect corresponding to the graft bone height reaching 10 mm, and regions with widths between the medial crest and lateral aspect and between the posterior margin and medial aspect corresponding to the buccolingual width of the graft bone\(^{30}\) reaching 6 mm were present in all cases, suggesting that mandibular body reconstruction with the fibula alone is an effective surgical procedure based on the assumption of subsequent prosthetic treatment. When the measured values in each region were compared between sexes, significant differences were noted in many regions. The width between the anterior margin and posterior aspect corresponding to the graft bone height was the maximum at point D and minimum at point B.

In male, the widths between the medial crest and lateral aspect and between the posterior margin and medial aspect corresponding to the graft bone width were the maximum at point D and minimum at point E. On the other hand, in women, the widths between the medial crest and lateral aspect were the maximum at point D and minimum at point E. However, the widths between the posterior margin and medial aspect were the maximum at point B and minimum at point E.

They suggest that for jaw bone reconstruction with the fibula in females, the risk of insufficient height is high when the proximal region of the bone is grafted, and the risk of insufficient width is high when the distal region of the bone is grafted. Our findings are slightly different from the study reported by Matsuura et al.\(^{14}\), in which the diameters of cross sections C, D, and E were measured. In their study, the width between the anterior margin and posterior aspect reached the maximum at point D and minimum at point E. The widths between the medial crest and posterior aspect and between the posterior margin and medial aspect were the minimum at point C. Bernd et al.\(^{29}\) divided the region from a site 5 cm distal to the fibular head to a site 8 cm proximal to the lateral malleolus into 4 parts as regions of interest in the fibula of Germans, and the fibular diameter was measured. The mean fibular diameter was 10.6±2.0 mm at the proximal one-fourth, 11.0±2.0 mm at the central one-fourth, and 11.1±1.5 mm at the distal one-fourth, revealing that the fibular diameter in Asians is comparable with that in Western people, and that the fibula is appropriate for jaw bone reconstruction with dental implants in Asians.

**Shapes of cross sections**

In anatomical text books\(^{13}\), the fibular body is described as a triangular prism, and 4 vertexes are present in cross sections of the fibula, i.e., the anterior, posterior, and interosseous margins and medial crest. To perform practical evaluation, using the evaluation method reported by Matsuura et al.\(^{14}\) and Ide et al.\(^{15}\), cross sections B, C, D, and E were classified into 3 types: triangular, quadrilateral, or irregular. Understanding the tendency of the shape of each region is useful to plan fibular grafting and subsequent implant placement in the fibula graft. In the present study, cross section E was triangular in many cases and cross section B tended to have an irregular shape, i.e., the shape of cross sections close to the fibula head is irregular in many cases, whereas the shape of cross sections close to the lateral malleolus tends to become triangular. A quadrilateral shape was not frequently observed in the distal fibula, which may have been due to fusion of the interosseous margin and medial crest in the distal region, thereby increasing cross sections with a triangular shape. These findings are consistent with those reported by Matsuura et al.\(^{14}\). In contrast, Ide et al. reported that the shape of...
fibular cross sections becomes irregular in the direction toward the lateral malleolus\(^{16}\). These findings suggest that the fibula is different between Asians and Western people in not only the length and diameter, but also in the morphology of cross sections. Furthermore, the triangular angle was sharp at the anterior margin compared with in the quadrilateral and irregular shapes. The triangular shape is preferable for selective osteotomy of the anterior margin of the fibula for implant placement. The bone crest is trimmed (resected) to prepare a bone foundation appropriate for implant placement.

**Sex differences**

All measured values were larger in males than in females. Accordingly, it is necessary to consider the sex difference in the usable bone volume. Regarding bones with a sex difference, Wu et al.\(^{17}\) discovered that the length and width of the humerus were larger in males, and Zubin et al.\(^{18}\) reported that the length, width, and thickness of the clavicle were larger in males.

**Blood vessels feeding the fibula**

The fibula-feeding blood vessel penetrated the fibular cortical bone in the central region of the fibula, C-E, and branched into a blood vessel feeding the bone marrow. This was consistent with reports by Shimada in the central region of the fibula, C-E, and branched into a blood vessel into the fibular cross sections becomes irregular in the direction toward the lateral malleolus. These findings suggest that the fibula is effective for vascularized fibular grafting. Asians and Western people in not only the length and diameter, but also in the morphology of cross sections. Furthermore, the triangular angle was sharp at the anterior margin compared with in the quadrilateral and irregular shapes. The triangular shape is preferable for selective osteotomy of the anterior margin of the fibula for implant placement. The bone crest is trimmed (resected) to prepare a bone foundation appropriate for implant placement.

**Conflict of Interest**

The authors have declared that no COI exists.

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