Clinicoanatomic Examination of the Fibula: Anatomic Basis for Dental Implant Placement

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The advantages of the free vascularized fibular flap include its ability to be shaped with relative ease and to be grafted at the same time tumors are resected, with consequent reduction in operation time. In addition, few complications occur at donor sites. However, a large, systematic, and detailed investigation of clinicoanatomic problems of the fibula has not been performed. Therefore, in the present study, the fibula was examined morphologically and morphometrically, with special attention to regions important in the placement of dental implants. Eighty fibulae obtained from cadavers of 41 Japanese individuals aged 46 to 92 years (mean, 72.7 years) were fixed with 70% alcohol after infusion of about 6 liters of 10% formalin via the femoral artery. Morphometric examination showed the nutrient foramen was located posteriorly in 85.0% of sections, the maximal width of fibular cross sections was 13.1 mm, and the maximal cortical thickness of fibular cross sections was 4.1 mm.
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Key words: cadaver, clinicoanatomic study, dental implant, mandibular reconstruction, vascularized fibular flap

The advantages of the free vascularized fibular flap include its ability to be shaped with relative ease and to be grafted at the same time tumors are resected, with a consequent reduction in operation time. In addition, few complications occur at donor sites. Since Taylor et al[1] reported vascularized fibular grafting for reconstruction of a large tibial defect in 1975, this method has been used extensively in orthopedic and plastic surgery. Vascularized fibular grafts have been used for mandibular reconstruction, both alone[2–4] and with dental implants,[5] and have provided good restoration of masticatory function.

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Germain et al[6] reported the mean length of the usable portion of the fibula. Frodel et al[7] measured the height and width of the fibula and the thickness of cortical bone in transverse cross sections of the fibula from the viewpoint of the application of dental implants to sites of mandibular reconstruction. However, a large, systematic, and detailed investigation of clinicoanatomic problems of the fibula has not been performed. In the present study, fibula flaps from cadavers were examined morphologically and morphometrically, with special attention to regions important in the placement of dental implants.

Materials and Methods

Eighty fibulae of 41 cadavers of individuals aged 46 to 92 years (mean 72.7 years), which had been donated for anatomic study, were fixed with 70% alcohol after infusion of about 6 liters of 10% formalin via the femoral artery.

Shape of the Transverse Section of the Fibula. The apex of the fibular head and apical margin of the lateral malleolus were referred to as A and G, respectively (Fig 1). The segment A-G was divided into 6 segments of equal length, and the points between these segments were referred to as B through F. The shape of the transverse sections of

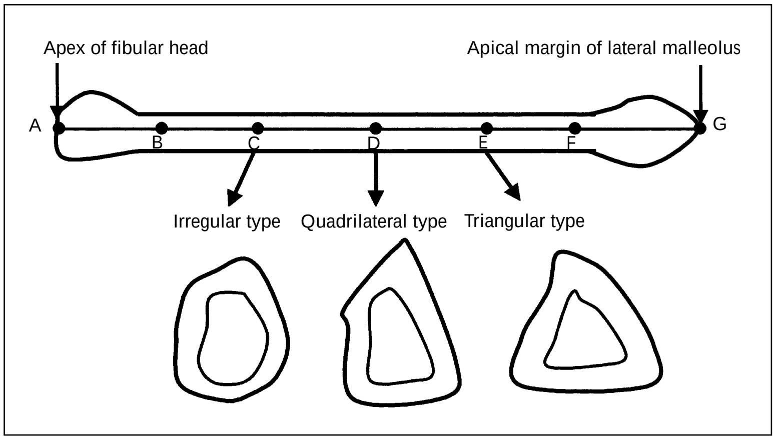

Fig 1 Transverse shape of the fibula, showing segments used as references.

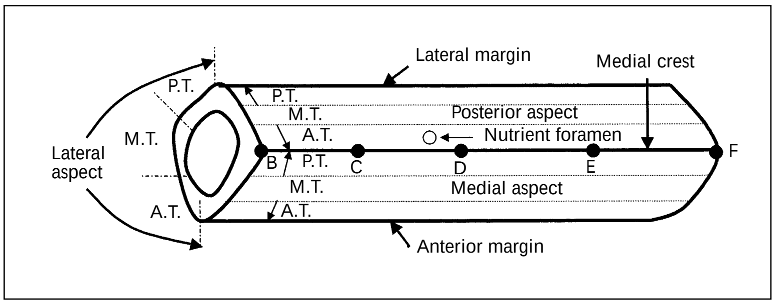

Fig 2 Model showing portions used to determine the location of the nutrient foramen. A.T. = anterior third; M.T. = middle third; P.T. = posterior third.

Table 1 Location of the Nutrient Foramen

	No. of limbs (%)					
Location	**B-C**	**C-D**	**D-E**	**E-F**	**Subtotal**	**Total**
Lateral margin	0	0	0	0		0
Posterior aspect						68 (85.0)
Anterior third	0	32 (40.0)	15 (18.7)	0	47 (58.7)	
Middle third	1 (1.3)	7 (8.7)	11 (13.7)	2 (2.5)	21 (26.3)	
Posterior third	0	0	0	0	0	
Medial crest	0	5 (6.3)	1 (1.3)	0		6 (7.6)
Medial aspect						6 (7.5)
Anterior third	0	0	0	0	6 (7.5)	
Middle third	0	0	0	0	0	
Posterior third	1 (1.3)	2 (2.5)	3 (3.8)	0	0	
Anterior margin	0	0	0	0		0
Lateral aspect						0
Anterior third	0	0	0	0	0	
Middle third	0	0	0	0	0	
Posterior third	0	0	0	0	0	
Total	2 (2.6)	46 (57.5)	30 (37.5)	2 (2.5)		80 (100)

the fibula at points C, D, and E was classified into 3 types—triangular, quadrilateral, and irregular—with the anterior margin, lateral margin, interosseous margin, and medial crest as apices (Fig 1).

Location of the Nutrient Foramen. Locations of the nutrient foramina 0.1 mm or greater in diameter were determined with a magnifying lens. The fibula body was divided proximodistally into 6 segments of equal length, as above, and segment B-F was divided into anterior, middle, and posterior portions clockwise from the anterior margin in the lateral aspect and counterclockwise in the medial and posterior aspects (Fig 2, Table 1).

Measurement of Cross-Sectional Width. In cross sections at points C, D, and E, which are located in the portion of the fibula used for mandibular

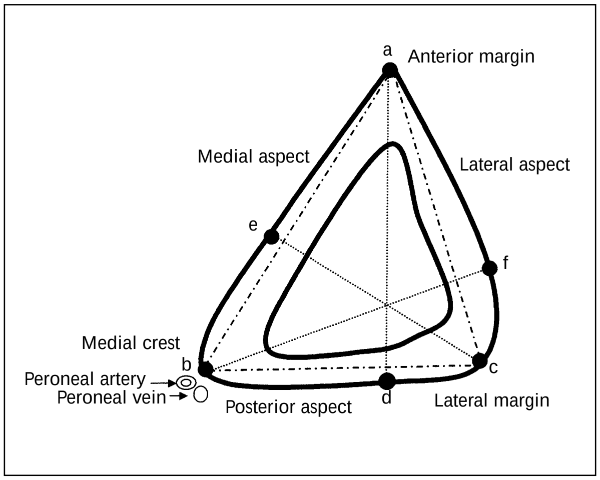

Fig 3 Model showing how cross-sectional width was determined.

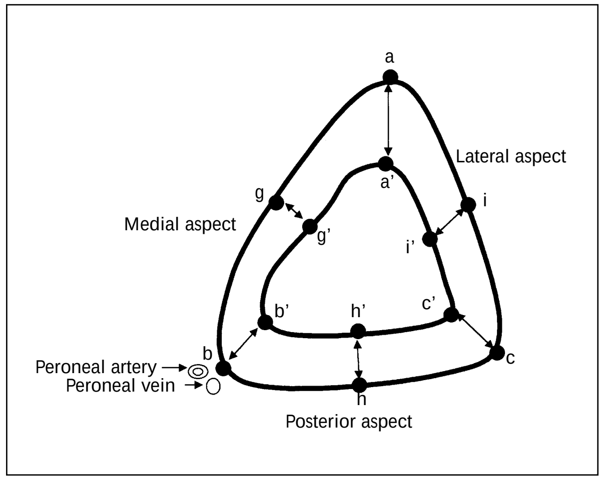

Fig 4 Model showing how cross-sectional cortical bone thickness was determined.

reconstruction, the anterior margin, medial crest, and lateral margin were referred to as points a, b, and c (Fig 3). A perpendicular line was drawn from point a to line b-c, and the intersection of its extension with the posterior aspect was referred to as point d. Similarly, a perpendicular line was drawn from point c to line a-b, and the intersection of its extension with the medial aspect was referred to as point e. A perpendicular line was drawn from point b to line a-c, and the intersection of its extension with the lateral aspect was referred to as point f. The distances a-d, c-e, and b-f were measured with calipers (Fig 3).

Measurement of Cross-Sectional Cortical Bone Thickness. At points C, D, and E, the thickness of cortical bone was measured with calipers at points a, b, and c and at the midpoints of a-b (g), b-c (h), and c-a (i) (distances a-a', b-b', c-c', g-g', h-h', and i-i', respectively) (Fig 4).

Statistical Analysis of Measured Values. Each distance was measured 3 times, and mean values were calculated. For each morphometric parameter of the fibula, the differences in mean values were examined among the sites of measurement (*t* test for equality of means: upper side test) and between the right and left limbs (*t* test for equality of means: ordinary test) at the 5% significance level. Differences between the right and left limbs were examined in each of the 39 cadavers (78 bones).

Results

Shape of Cross Sections. Fibular cross sections were elliptical at point B, an obtuse triangle in points C, D, and E, and an irregular quadrilateral at point F. Points C, D, and E are located in the portion of the fibula used for mandibular reconstruction. At point C, the fibular cross section was irregular in 46.2% of specimens, quadrilateral in 40.0%, and triangular in 13.8%. At point D, the cross section was quadrilateral in 51.3% of specimens, irregular in 28.7%, and triangular in 20.0%. At point E, the cross section was triangular in 56.2% of specimens, irregular in 23.8%, and quadrilateral in 20.0% (Fig 1, Table 2).

Location of the Nutrient Foramen. The nutrient foramen was located posteriorly in 68 limbs (85.0%), medially in 6 limbs (7.5%), and laterally in no limbs (Fig 2). The nutrient foramen was located in the medial crest in 6 limbs (7.5%); on the posterior aspect, the nutrient foramen was located in the anterior third in 47 limbs (58.7%), in the middle third in 21 (26.3%), and in the posterior third in none.

The nutrient foramen was located in segment C-D in 46 limbs (57.5%), in segment D-E in 30 limbs (37.5%), in segment B-C in 2 limbs (2.5%), and in segment E-F in 2 limbs (2.5%) (Fig 2).

Segment Length at Various Cross-Sectional Levels. At point C, segment a-d was the longest at 13.8 mm, segment b-f was 10.6 mm, and segment c-e was 10.3 mm (Fig 3, Table 3). At point D, segment a-d was the longest (14.0 mm), segment b-f was 11.4 mm, and segment c-e was 10.8 mm. At point E, segment a-d was the longest (11.4 mm), segment c-e was 11.2 mm, and segment b-f was 11.0 mm. No differences were observed between right and left limbs at any measurement site.

Table 2 Shape of Cross Sections				
	Cross section			
Shape	C (%)	D (%)	E (%)	Total (%)
Irregular	37 (46.2)	23 (28.7)	16 (20.0)	76 (31.7)
Quadrilateral	32 (40.0)	41 (51.3)	19 (23.8)	92 (38.3)
Triangular	11 (13.8)	16 (20.0)	45 (56.2)	72 (30.0)
Total	80 (100.0)	80 (100.0)	80 (100.0)	240 (100.0)

Table 3 Segment Length at Various Cross-Sectional Levels (Mean ± SD)			
	Segment length		
Cross section	a-d	c-e	b-f
C	13.8 ± 1.6	10.3 ± 2.0	10.6 ± 1.2
Right side	13.7 ± 1.8	10.2 ± 1.2	10.7 ± 1.2
Left side	13.8 ± 1.3	10.3 ± 1.9	10.5 ± 1.2
Difference	NS	NS	NS
D	14.0 ± 1.6	10.8 ± 2.0	11.4 ± 1.3
Right side	14.0 ± 1.8	10.7 ± 2.0	11.6 ± 1.3
Left side	14.0 ± 1.3	10.8 ± 1.9	11.3 ± 1.2
Difference	NS	NS	NS
E	11.4 ± 1.8	11.2 ± 1.9	11.0 ± 1.4
Right side	11.6 ± 2.0	11.3 ± 2.0	11.0 ± 1.4
Left side	11.1 ± 1.6	11.2 ± 1.8	11.0 ± 1.4
Difference	NS	NS	NS
Average	13.1 ± 2.0	10.7 ± 2.0	11.0 ± 1.3
Right side	13.1 ± 2.2	10.7 ± 2.1	11.1 ± 1.4
Left side	13.0 ± 1.9	10.8 ± 1.9	10.9 ± 1.3
Difference	NS	NS	NS

NS: $P \geq .05$ (mm).
$P < .05$ at point C between a-d and c-e and between a-d and b-f; at point D, all segments.

Significant differences were observed between segments a-d and c-e and between segments a-d and b-f at point C, among all segments at point D, and between no 2 segments at point E (Fig 3, Table 3).

Thickness of Cortical Bone in Various Cross-Sectional Levels. Among the apices, the thickness of cortical bone was 4.0 mm at a, 3.5 mm at b, and 3.4 mm at c at point C; 4.1 mm at a, 3.6 mm at b, and 3.5 mm at c at point D; and 4.2 mm at a, 3.5 mm at c, and 3.4 mm at b at point E. Among the midpoints, cortical thickness was 2.9 mm at h, 2.2 mm at g, and 2.2 mm at i at point C; 2.7 mm at h, 2.2 mm at i, and 2.1 mm at g at point D; and 2.6 mm at h, 2.5 mm at g, and 2.5 mm at i at point E. No differences were observed between the right and left limbs at any measurement site.

Among the apices, significant differences were observed between a and b and between a and c at point C, between a and b and between a and c at point D, and between a and b and between a and c at point E. Among the midpoints, significant differences were observed between h and g and between h and i at point C, between h and g and between h and i at point D, and between no 2 points at point E. No significant difference was observed in the thickness of cortical bone at any apex or midpoint among the 3 cross sections (Fig 4, Table 4).

Discussion

Shape of Cross Sections. One textbook of anatomy[8,9] describes the fibular body as a triangular column and states that the cross section of the fibula has 4 apices; namely, the anterior margin, lateral margin, interosseous margin, and medial crest. However, a simpler classification would be more practical for evaluating procedures for reconstruction, such as collecting tissue grafts and selecting sites for dental implantation. Therefore, in the present study, cross sections of the fibular body were classified at points C, D, and E into triangular, quadrilateral, and irregular types in consideration of clinical reports involving use of the fibula for mandibular reconstruction, the distances from the fibular head and the lateral malleolus, and determination of morphometric points in central cross sections.

In the present study, quadrilateral cross sections were observed most frequently, as in earlier reports, followed by irregular and triangular shapes. The quadrilateral type was observed less frequently in the distal fibula, probably because the interosseous margin and medial crest fuse distally and increase the frequency of the triangular type. These findings should be useful for selecting donor sites for fibular grafts and placement of dental implants after mandibular reconstruction.

Table 4 Thickness of Cortical Bone in Various Cross-Sectional Levels

Cross section	Thickness (mm) a	b	c	g	h	i	Average
C							
Mean ± SD	4.0 ± 1.2	3.5 ± 0.9	3.4 ± 1.0	2.2 ± 0.9	2.9 ± 0.8	2.2 ± 0.8	3.0 ± 1.2
Right side	3.9 ± 1.1	3.5 ± 0.9	3.3 ± 0.9	2.1 ± 0.6	2.8 ± 0.9	2.1 ± 0.7	3.0 ± 1.1
Left side	4.1 ± 1.2	3.5 ± 0.9	3.5 ± 1.1	2.3 ± 1.0	3.0 ± 0.8	2.3 ± 0.8	3.1 ± 1.2
Difference	NS	NS	NS	NS	NS	NS	NS
D							
Mean ± SD	4.1 ± 1.1	3.6 ± 1.1	3.5 ± 0.9	2.1 ± 0.7	2.7 ± 0.8	2.2 ± 0.8	3.0 ± 1.1
Right side	4.1 ± 1.1	3.6 ± 1.1	3.5 ± 0.9	2.1 ± 0.7	2.6 ± 0.8	2.1 ± 0.8	3.0 ± 1.2
Left side	4.4 ± 1.2	3.7 ± 1.1	3.6 ± 0.7	2.2 ± 0.8	2.7 ± 0.8	2.2 ± 0.8	3.2 ± 1.1
Difference	NS	NS	NS	NS	NS	NS	NS
E							
Mean ± SD	4.2 ± 1.2	3.4 ± 0.9	3.5 ± 1.2	2.5 ± 0.8	2.6 ± 0.9	2.5 ± 0.8	3.1 ± 1.2
Right side	4.1 ± 1.1	3.4 ± 1.0	3.4 ± 1.3	2.4 ± 0.8	2.5 ± 0.8	2.5 ± 0.9	3.1 ± 1.2
Left side	4.4 ± 1.2	3.4 ± 0.9	3.6 ± 1.2	2.6 ± 0.8	2.5 ± 0.8	2.4 ± 0.8	3.2 ± 1.2
Difference	NS	NS	NS	NS	NS	NS	NS
Average							
Mean ± SD	4.1 ± 1.2	3.5 ± 1.0	3.5 ± 0.9	2.3 ± 0.8	2.7 ± 0.8	2.2 ± 0.8	
Right side	4.0 ± 1.1	3.5 ± 1.0	3.4 ± 1.0	2.2 ± 0.8	2.6 ± 0.9	2.2 ± 0.9	
Left side	4.2 ± 1.2	3.5 ± 1.0	3.6 ± 1.0	2.4 ± 0.8	2.7 ± 0.9	2.2 ± 0.8	
Difference	NS	NS	NS	NS	NS	NS	

NS = $P \geq .05$ (mm).
Among apices, significant differences ($P < .05$) were observed between a and b and a and c at point C, between a and b and a and c at point D, and between a and b and a and c at point E. Among midpoints, significant differences ($P < .05$) were observed between h and i and h and g at point C, between h and g and h and i at point D, and between no 2 points at point E. No significant differnce was seen at any apex or midpoint among the 3 cross sections.

Location of the Nutrient Foramen. Anatomy textbooks[8] state that one branch of the fibular artery reaches the posterior aspect of the fibula through a nutrient foramen in the proximal or middle third of the fibula. Kaneko[9] found that the nutrient foramen was located in the posterior aspect of the fibula, slightly proximal to the midpoint of the shaft. In the present study, it was found that the nutrient foramen was located most frequently in the posterior aspect (85%), followed by the medial and lateral aspects. These findings agree with those of earlier reports, in which the nutrient foramen was located most frequently in the anterior third of the posterior aspect, followed by the middle and posterior thirds. On the basis of proximal-distal classification of the fibula body, Shimada and Yoshimura[10] reported that the nutrient foramen was located in the middle third in 80.3% of specimens, followed by the central (proximal) and peripheral (distal) thirds. Chen et al[11,12] found that the nutrient foramen was located most often in the middle third (96%), followed by the central (proximal) and peripheral (distal) thirds. In the present study, the nutrient foramen was located most frequently in segments C-D (57.5%) and D-E (37.5%), and infrequently in segments B-C and E-F (2.5%).

These findings should be helpful for harvesting vascularized fibular grafts, layering them for mandibular reconstruction, and manipulating them, eg, bending by creating fissures.

Segment Lengths in Various Cross Sections. Previously described surgical procedures were reviewed to study how the fibula has been used in mandibular reconstruction. The anterior margin of the fibula is often used to reconstruct the alveolar crest, and the lateral surface of the fibula is used to reconstruct the labiobuccal aspect. Zlotolow et al[4] implanted artificial dental roots after mandibular reconstruction involving the anterior margin of the fibula, which formed the alveolar crest of the reconstructed jaw, to the cortical bone in the posterior portion of the fibula.

As mentioned above, few clinicoanatomic investigations have reported results of mandibular reconstruction involving dental implantation to the reconstructed areas. Reported segment lengths at various cross sections of the fibula, maximal diameters, minimal diameters, and girths at the center of the fibula have ranged from 14.0 mm to 16.0 mm, 10.4 mm to 11.5 mm, and 35.8 to 46.1 mm, respectively. Frodel et al[7] studied the fibula, ilium, scapula, and radius clinicoanatomically, and they reported the height and width of the fibula at its central cross section to be 15.0 mm and 10.9 mm. However, morphometric points or methods of measurements have not been well described in earlier reports.

In the present study, the greatest distances from base to apex were found in segment a-d (13.1 mm), followed by b-f and c-e. Segment a-d, which is along the sagittal plane of the fibula, was the longest in cross sections at C, D, and E. These findings should be useful for mandibular reconstruction and determining sites of dental implant placement.

Thickness of Cortical Bone in Various Cross Sections. Frodel et al[7] found that the central cross-sectional thickness of fibular cortical bone on the side of the fibular artery and vein ranged from 3.0 to 4.2 mm. They suggested that the cortex of the fibula was as thick as that of other bones used for grafts. Moscoso et al[13] reported that approximately 66.7% of the cross-sectional area of the fibula is cortical bone, a percentage similar to that in the ilium, scapula, and radius, and sufficient for placement of dental implants. However, previous studies have not precisely defined morphometric points or measured the thickness of cortical bone in detail at various sites.

In the present study, among the apices the cortical bone was thickest at apex a (4.1 mm) in cross sections at C, D, and E. Among the 3 midpoints in the 3 cross sections, cortical bone was thickest at point h (2.7 mm). Little difference was observed in the thickness of cortical bone among various cross sections.

In conclusion, the present findings should be of assistance in the placement of dental implants at sites of fibular grafting after mandibular reconstruction.

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