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SHORT COMMUNICATION

The eligibility of the free fibula graft for masticatory rehabilitation using monocortical implants insertion—a morphologic and biomechanical study

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Abstract The use of the vascularized fibula graft has already been established for reconstruction of the mandible following ablative surgery. In order to reconstruct the vertical height of the alveolar process and improve implant position as well as angulation, some therapeutic options are available, including primary use of the fibula as a double-barrel graft and vertical distraction as well as later augmentation with avascular bone grafts. We analyzed the anatomic and morphologic features in 40 fibula bones of 20 cadavers and provided the mean cortical thickness of different transplant sites. Furthermore, we investigated the primary implant stability of dental implants inserted monocortically in harvested fibula segments using established biomechanical methods as well as Periotest®. The minimal bone height of the clinically relevant segments of the fibula transplant measured 9.06±0.45 mm, which was assessed in the most distal part. In contrast, a maximal total bone height of 15.46±0.78 was observed in the middle segment of the fibula bone. We assessed sufficient primary stability in all inserted implants as well as a reliable relative micro-movement of the implants in the fibula bone. Fibula graft as a single-barrel graft alone may provide through monocortical implant insertion a further refinement of the method to fit complex requirements and shorten prolonged therapeutic procedures. Monocortical implant insertion in the fibula graft would simplify oral rehabilitation after ablative surgery of the jaw and reduce costs as well as therapy period.

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Introduction

The use of the vascularized fibula graft has already been established for reconstruction of the mandible following ablative surgery. The authors have been using this vascularized bone graft now for more than 15 years and have recently reported on variations in the reconstructive options using this graft [1]. One of the crucial advantages of this bone transplant is the ability to shape in order to fit local anatomical structures allowing further rehabilitation using dental implants.

Although many studies provided clinical data on the eligibility of dental rehabilitation using enossal implants in transplanted fibula bone, some questions were raised during clinical follow-up of these patients including prosthetic reconstruction of the vertical height and improving oral hygiene by assessing suitable soft tissue conditions. In order to reconstruct the vertical height of the alveolar process and improve implant position and angulation, three therapeutic options have recently been introduced: primary use of the fibula as a double-barrel graft [1], later vertical distraction osteogenesis [2, 3], and rebuilding prosthesis by over-dimensioned teeth.

According to our previous experience with the latter option, we preferred bone-based solutions and therefore tended to use double-barrel grafts once feasible. In the case of long-distance defects or simultaneous elevation of a skin paddle, the double-barrel option loses its practicability due to limited transplant length or because of the risk of compromising blood supply to the skin island by kinking of the vascular pedicle.

Distraction osteogenesis may represent a further uncomfortable solution because of the anatomic limitation of this thin graft with mostly fatty spongious structures as well as complicated wound healing in mostly irradiated patients. A more convenient solution may represent an onlay iliac graft, which has to be fixed and left for healing prior to implant insertion at a later stage [4].

Monocortical insertion of dental implants in the underlying fibular bone may also represent an alternative approach in cases where anatomic conditions and local features and shape of the single-barrel fibula transplant do not allow bicortical insertion. However, the crucial prerequisite for success of this method is sufficient primary implant stability after monocortical insertion. Therefore, in order to prove the feasibility of this method, we investigated the morphological and biomechanical eligibility of the fibula graft for such a procedure using morphological and biomechanical approaches.

Material and methods

Anatomic and morphologic investigations

Forty fibula bones were harvested from the fresh cadaver of 10 males and 10 females and fixed on a special template. In order to perform the morphologic evaluation, a native CT scan was carried out in the clinically relevant segments of the fibula bone, excluding the proximal and distal 8 cm adjacent to the related joints. The first cross-sectional image derived from the middle of the fibula and three further proximal and distal sections at a distance of 4 cm were additionally carried out and evaluated. Scan data were then obtained digitally, and cross-sectional studies of all fibula bones were performed in order to measure cortical bone thickness in the various segments of the potential transplant (Fig. 1).

In order to facilitate related evaluation of bone thickness in each fibula segment, a cross-sectional-based allocation of measurement was introduced as follows taking the vascular pedicle into consideration and beginning on the most proximal segment:

1. −60° represents the axis perpendicular to the antero-medial aspect.
2. 0° represents the line perpendicular to the lateral aspect.
3. +60° represents the posteriomedial aspect of the fibula bone.

The whole bone thickness was evaluated considering ipsilateral and contralateral dimensions as described in Fig. 1.

Biomechanical study

Twenty enossal implants (NobelBiocare®—Replace Select, RP 4.3×13 mm TiUnite) were inserted monocortically in harvested fibula segments. Only the apical part of the implant was inserted whereas the collar part was always left exposed as shown below (Fig. 2).

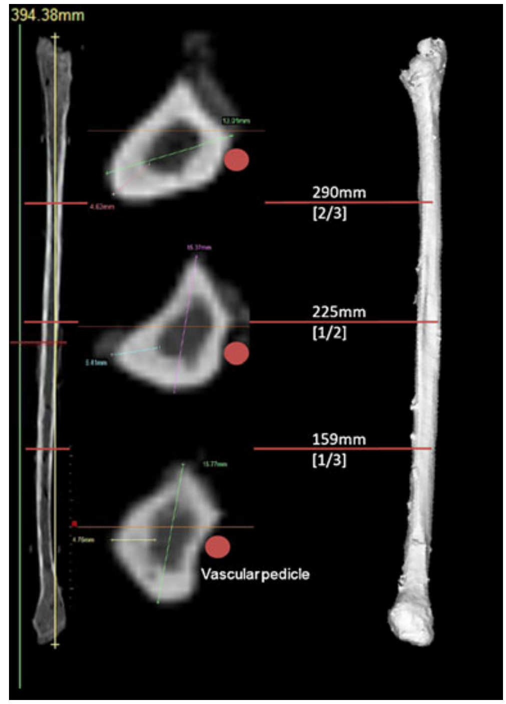


Fig. 1 Digital scan data of the fibula bone representing and explaining the radiologic evaluation method in the various regions including cross-sectional studies in order to measure cortical bone thickness

Afterward, implants and fibular bones underwent biomechanical stability tests: Following investigations were performed, the Periotest® CLASSIC (Gulden e. K. Modautal, Germany). Measurements were carried out three

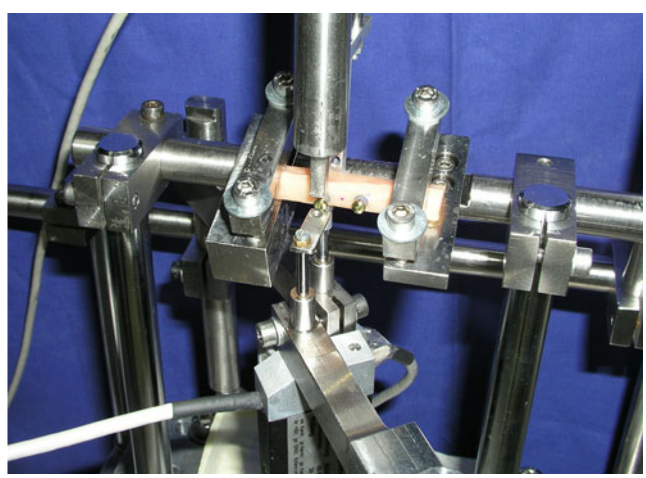


Fig. 2 Dental implants inserted monocortically in the fibula bone—here across −60° axis—which was integrated in a universal material testing machine designed for horizontal biomechanical tests using standard force of 100 N

times in each implant according to the recommended instructions of the manufacturer using standard angulation by means of a mounting device. Mean values were then registered and evaluated as follows:

$$PTV < 0 = \textit{primary stability reached};$$

$$PTV \geq 0 = \textit{insufficient primary stability of implants}.$$

These fibula segments were then integrated in a universal material testing machine (Zwick Company, Ulm, Germany) designed for biomechanical tests as previously described and underwent evaluation of distortion by horizontal mechanical stress of 200 N/cm^2 (Fig. 2) [5]. Briefly, forces were transmitted horizontally onto the neck of the abutments inserted in the fibula segments. Linear encoders (resolution 1 µm, MS30-2-LD-2; MEGATRON Elektronik AG, Putzbrunn, Germany) were used to measure the forces during compression tests. The same sensor was used to gain the bending moment during the four-point bending. All sensor signals were recorded with a sample rate of 100 Hz by the DIADEM Software (version 10, National Instruments, Munich, Germany). All tests were performed three times, without destruction of the specimen. Normal distribution was assigned for each configuration, and the Wilcoxon or Mann–Whitney test was applied. A level of $p<0.05$ was considered significant.

Results

Anatomic/morphologic results

The minimal total bone height of the clinically relevant segments of the fibula transplant measured 9.06±0.45 mm, which was assessed in the most distal part. In contrast, a maximal total bone height of 15.46±0.78 was observed in the middle segment of the fibula bone. Due to the rotation along the fibula axis beginning at the distal part of the proximal third, the site of maximal bone height underwent a wide variation, whereas the middle segment frequently provided higher osseous volume (Table 1). No significant gender-related variations in the bone length or thickness could be assessed in the samples investigated, whereas body height correlated only with total fibula length.

Taking into consideration that dental implants have to be encompassed by a minimal bone ridge of 0.5–1 mm without compromising total bone stability, regular monocortical insertion of standard implants would only be feasible within the middle third of the fibula. The position of the vascular pedicle adds a further limiting factor and leaves in the majority of cases only two feasible positions for implant insertion, namely the contralateral site at the 0° level and the ipsilateral one at the −60° level. At these sites, maximal monocortical thickness ranged from 3.24±0.21 to 3.31±0.10 mm, respectively (Table 1).

Biomechanical results

The following biomechanical results derive from implants inserted monocortically on the ipsilateral site at the −60° level in the fibula segments. Evaluation of primary stability using the Periotest® device resulted in homogenous values ranging from −3 to −4±1 PTV, indicating sufficient primary implant stability.

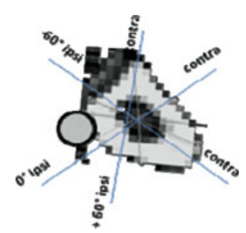
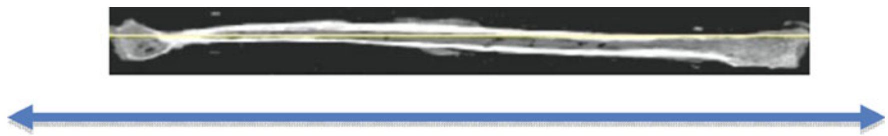
Following application of 100 N/cm^2 horizontal stress, absolute implant movement was observed and ranged from 0.113±0.083 to 0.114±0.081 mm according to the bone quality (Fig. 3). Simultaneously, associated bone movement of 0.079±0.001 to 0.079±0.001 mm was registered, so when considering the absolute implant micromotion, relative micromotion of the monocortically inserted implants could be calculated. This amounted to 0.024±0.003 to 0.026±0.002 mm. Complete regain of bone shape after elimination of applied forces was assessed in all cases as an indicator of primary biomechanical stability of the fibula segment after monocortical implant insertion. These data correlated with PT values mentioned above in regard to primary implant stability (Table 2).

Discussion

Oral rehabilitation using dental implants in fibula transplants has been frequently used following reconstruction of the upper and lower jaw and proven to be a reliable method in such cases [1, 4]. If multilayer reconstruction in the oral cavity—floor of the mouth or tongue—is planned, we prefer to harvest an osteocutaneous fibula transplant from the contralateral side and vice versa once applicable. This rather facilitates positioning of the skin island in the oral cavity. Mere bony reconstruction using an osseous fibula graft would, however, be more independent of structural conditions of the neck and therefore offers more flexibility.

While several anatomical and surgical aspects of vascularized fibula transplant for orofacial reconstruction as well as the possibility of implant insertion in this bone graft have been thoroughly investigated [6, 7], very little is known about the primary stability of dental implants when placed monocortically. Until now, we have preferred to postpone implant insertion till at least 1 year after radiotherapy in oncologic patients. This has the advantage to allow operating in a rather recovered soft tissue and definitively healed fibula bone but also rule out an early recurrence of tumor. At this stage, we consider either

Table 1 Mean of cortical as well as total thickness of the fibular bone measured at the three aspects of the triangle shape at each of the seven evaluated sites from proximal to distal expressed in millimeters

	 proximal						distal
0° ipsilateral cortical thickness	2.99±0.12	3.01±0.31	2.51±0.32	3.58±0.38	2.39±0.35	2.03±0.21	2.17±0.19
0° contralateral cortical thickness	*2.86±0.11*	*2.89±0.28*	*2.51±0.31*	*2.54±0.19*	*2.43±0.18*	*3.24±0.21*	*2.62±0.26*
0° total thickness	9.56±0.35	9.64±0.32	10.08±0.79	10.19±0.66	9.75±0.42	9.17±0.48	9.06±0.45
60° ipsilateral cortical thickness	2.53±0.22	2.74±0.21	2.51±0.35	3.84±0.29	3.52±0.31	3.12±0.36	3.43±0.24
60° contralateral cortical thickness	3.87±0.23	3.43±0.26	4.49±0.61	6.33±0.27	4.76±0.34	4.15±0.22	3.12±0.31
60° total thickness	11.67±0.44	12.16±0.92	12.95±0.87	15.46±0.78	14.54±0.49	13.71±0.51	13.97±0.55
–60° ipsilateral cortical thickness	*3.31±0.10*	*2.73±0.27*	*2.56±0.26*	*3.19±0.28*	*2.54±0.19*	*2.03±0.22*	*2.58±0.27*
–60° contralateral cortical thickness	4.21±0.13	3.88±0.54	3.62±0.29	5.12±0.36	4.11±0.23	4.14±0.41	3.82±0.35
–60° total thickness	12.83±0.37	13.27±0.89	13.23±0.77	14.74±0.64	13.46±0.51	12.51±0.67	11.97±0.48

Italicized data represent clinically relevant sites for implant insertion

bicortical insertion or augmentation with an avascular iliac crest graft according to bone height available.

In order to decrease the treatment period, monocortical or simultaneous implant insertion and onlay bone place-

Table 2 Biomechanical data of 20 implants inserted monocortically in clinically relevant sites in harvested fresh fibular bone segments, evaluated by biomechanical horizontal stress measurements at 100 N as well as Periotest®

	Absolute implant movement (mm)	Absolute bone movement (mm)	Relative implant movement in fibula (mm)	Mean Periotest® value
1st measurement	0.114±0.081	0.088±0.001	0.025±0.002	−3±1 PT
2nd measurement	0.113±0.083	0.079±0.001	0.026±0.002	−3±1 PT
3rd measurement	0.113±0.080	0.085±0.002	0.024±0.003	−4±1 PT

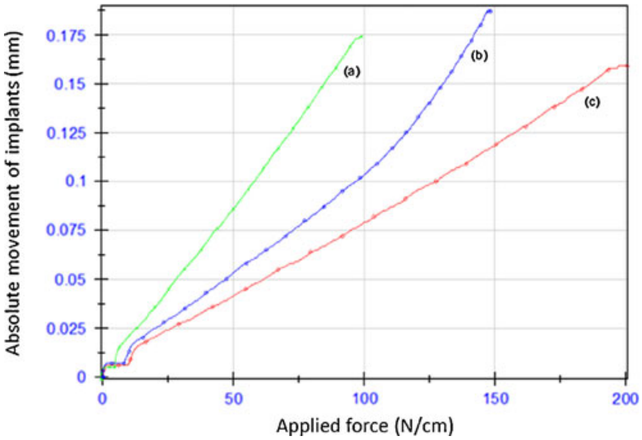


Fig. 3 Mean values of absolute implant movement in fixed fibula bone segments during application of increasing horizontal force reaching a maximum of 200 N/cm which is usual to launch orthopedic implants using the material testing machine. Grafts with poor bone quality are represented in the *green a-curve*, fibula segments with moderate bone quality are shown in the *blue b-curve*, and fibula bone with good high quality are given in the *red c-curve*. Criteria applied for classifying bone quality derived from the maximal value measured in relation to the absolute distortion of the fibula segments during stress loading. Since the poorest bone quality also provided sufficient stability (at 100 N/cm), this classification is specific to the experimental setting but has no clinical relevance

ment may hence be applicable if implants inserted monocortically show sufficient primary stability. The clinical relevance of this approach arises from the potential application of short implant design to ensure stable implant-borne rehabilitation in patients with a long-distance single-barrel fibula graft and reasonably reduced bone height. Bicortical implant insertion in these critical cases may attenuate total bone stability and hazard graft fracture.

The radiomorphologic results presented above indicate that once the vascular pedicle is localized either caudally or medially toward the oral cavity—representing the usual clinical situation—only the contralateral site at the 0° level and the ipsilateral one at the −60° level are feasible for implant insertion. This requires special attention to incline or decline one of the two levels during the reconstruction procedure, since later implant angulation will play a crucial role in this case. Further, as seen in Table 1, these two differentially located implantation plateaus converging at an angle of more than 90° enable axial rotation of the fibula graft to fit local anatomic features and simultaneously allow monocortical implant insertion.

Since initial implant stability is considered an important prerequisite for further osseointegration [8], which correlates significantly with bone quality and implant length as well as implant features and Periotest value [9], we also investigated this aspect in harvested fibular bones. As a parameter of primary implant stability, we used the Periotest® device, which represents a reliable method with strong correlation with implant stability and compared derived data with a further objective biomechanical investigation using standard equipment and precisely reproducible forces.

Considering that patients with osseointegrated implants are lacking periodontal receptors thus having a special type of masticatory performance of holding and biting forces ranging from 2 to 30 N [10], the study design chosen here represents an adequate method by applying horizontal stress of 100 N/cm^2. Although we used only a single implant system (Replace Select® with TiUnite surface), comparable results are expected since diameter and implant length as well as surface features used for this study strongly correlate with most standard implant designs. Furthermore, the biomechanical data derived show very reliable and improved values exceeding corresponding clinical data for primary stability of dental implants in the mandible.

In comparable experimental works, criteria of success for implants inserted in fibula transplants were defined as follows: absence of pain, absence of peri-implant infection, absence of mobility, absence of continuous peri-implant radiolucency, and less than 1.5 peri-implant bone resorption after 1 year of function [11]. In order to get final clinical results of this procedure, more patients have to be included in a clinical study with prolonged follow-up period. This would allow definitive recommendation of the method. Until then, this procedure has to be strictly indicated and kept for patients with a lower risk profile and good compliance.

Conclusion

Anatomic features of the fibular bone are subject to a wide range of variation leading to the necessity of changing of surgical planning in regard to reconstruction and functional rehabilitation. According to the results presented here, fibula graft as a single-barrel graft alone may provide through monocortical implant insertion a further refinement of the method to fit complex requirements and shorten prolonged therapeutic procedures.

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Conflict of interest No potential conflicts of interest were disclosed.

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