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ORIGINAL ARTICLE

Three-dimensional evaluation of the different donor sites of the mandible for autologous bone grafts

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Abstract
Objectives For effective placement of endosseous implants, a sufficient volume of bone is required at the recipient site. The aim of this study is to evaluate the density and maximum amount of harvestable bone graft required from the mandible symphysis, coronoid process, and ascending ramus, depending on dentition.
Materials and methods CT data from 42 patients (13 females and 29 males) in DICOM format were read using special planning software. Three different virtual bone grafts were created, and the dimension outcomes, surface, volume, and density were measured in a dentate group (n=22) and a total edentulous group (n=20).
Results Comparisons between corresponding bone grafts showed no difference for the symphysis and coronoid process in relation to dentition, and no difference in bone density was observed. However, significant changes between the average values of the ramus were found between the two groups (p<0.0001).
Conclusions Appropriate software and CT data can deliver more accurate examinations of the mandible in relation to potential donor sites. Atrophy primarily affects the ascending ramus; the symphysis and coronoid process are only slightly influenced.
Clinical relevance Using appropriate software in conjunction with implant planning, it is possible to analyze potential donor areas within the jaw and create virtual bone grafts

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Keywords Intraoral harvest site · Virtual analysis · Symphysis graft · Ascending ramus graft · Coronoid graft

Introduction

A sufficient volume of bone at the recipient site is necessary for the successful placement of endosseous implants in dentoalveolar surgery. However, bone volume is often lacking as a result of dental trauma, tooth loss, or infectious diseases such as advanced periodontal disease. In this case, bone augmentation is a possible method to eliminate these defects. Many different techniques have been developed to reconstruct segmental defects or an atrophic maxilla and mandible [1–4] including: distraction osteogenesis, onlay bone grafts, alveolar ridge preservation, bone splitting, and guided bone regeneration.

Different bone substitute materials are available nowadays, but autologous bone grafts represent the gold standard for oral reconstruction due to their osteoconductive, osteoinductive, and osteogenic properties [5]. Bone grafts from the iliac, tibia, ribs, and calvarium have been used in maxillofacial surgery. However, the use of intraorally harvested bone is considered superior for small and medium defects because of easy access, the proximity to the recipient region, and the possibility of simultaneous grafting. The grafting can be performed simultaneously [6–10]. Possible consequences include increased donor morbidity and complication probability. Preferred donor sites are the lateral aspect of the ramus, the anterior mandibular ramus, the buccal aspect of the third molar region, the mandibular lingual cortex, the zygoma, the maxillary tuberosity, the anterior spina nasalis, the coronoid process, and the mandibular symphysis [6–10].

In addition to the amount of bone required, bone quality determines the success of transplantation [11]. The intraoral grafts maintain their dense quality and exhibit minimal resorption upon incorporation [12]. It is of note that most studies have described the amount of available bone in relation to the surface area of the bone. Only a few studies have reported the available volume, with no distinction made between the dentate and edentulous jaws [13–17].

Three-dimensional computed tomography (CT) is used for preoperative planning in reconstructive surgery as it is able to provide information in relation to the availability and quality of the graft [18, 19]. However, only the study of Yavuz et al. [13] has evaluated the amount of harvestable bone graft in the mandibular symphysis using CT, and other types of donor sites were not considered.

The primary objectives of this study are to (1) estimate the width, thickness, height, volume, surface, and density of an autologous bone graft; and (2) identify the clinical differences between patients with a fully dentate mandible and those with an edentulous mandible.

Materials and methods

CT scans of mandibles taken between May 2013 and October 2013 were obtained through the radiology server of our department. A fully dentate or total endentulous mandible was a prerequisite for inclusion in the study. The patients were divided into two groups according to dentition. Group 1 consisted of 22 patients with a fully dentate mandible (8 females and 14 males; mean age of 51 years [range 25 to 72]). Group 2 consisted of 20 patients with an edentulous mandible (5 females and 15 males; mean age of 70 years [range 47 to 91]). The number of available CT scans obtained during the study period determined the sample size. The computed tomography (CT) scans were performed using a 128-row multi-slice CT scanner Somatom Definition Flash (Siemens, Erlangen, Germany). Slice thickness was 0.5 mm. The resulting CT data, in Digital Imaging and Communications in Medicine (DICOM) format, were read in Pro Plan 3.0 software (Materialise, Leuven, Belgium). Appropriate voxels were grouped based on Hounsfield units (HU) of between 250 and 3,000 to achieve a bone mask. This mask was processed by segmentation with the Pro Plan 3.0 software, and a virtual mandible was finally constructed.

The mandibular symphysis, coronoid process, and ascending ramus were analyzed as regions for potential bone harvest using virtual images of bone grafts that resulted after performing virtual osteotomies (Figs. 1 and 2). Each grafting of the reconstructed mandible was performed by one person. The thickness of the osteotomy was 0.1 mm, and the resulting boundaries were controlled on the respective axial, coronal, and sagittal CT slices. There were no occurrences of nerve damage. The linear dimensions (width, thickness, and height, in mm), surface (mm^2), volume (mm^3), and density (HU) of the virtual grafts were then measured using Pro Plan 3.0 software. To compare our results, the osteotomies were performed based on the studies by Yates et al. [14]:

Description of osteotomy

Symphysis graft

- Superior dimension: dentate—5 mm below from the apexes
  total edentulous—5 mm below superior border of the mandible
- Inferior dimension: 4 mm superior from inferior border of the mandible
- Lateral dimension: 5 mm anterior to the mental foramen
- Posterior dimension: lingual cortex of the mandible

Ascending ramus graft

- Superior dimension: the superior osteotomy is made along the anterior boarder of the ramus, approximately 4 to 6 mm from the lateral surface and between the distal half of the first molar area to the coronoid base
- Inferior dimension: 4 mm superior from inferior border of the mandible
- Anterior dimension: vertical cut in the area of the distal half of the first molar
- Posterior dimension: osteotomy from the sigmoid notch to the antegonial notch

Coronoid graft

- Inferior dimension: horizontal cut from the sigmoid notch to the ascending ramus, which runs parallel to the inferior border of the mandible

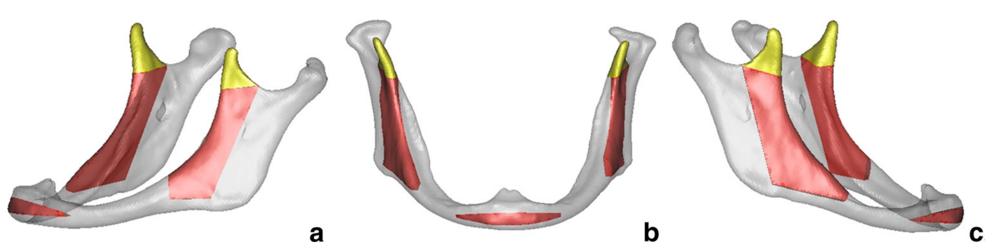

Fig. 1 **a**–**c** 3D Model of the total edentulous mandible with the symphysis, coronoid process, and ascending ramus as harvest regions

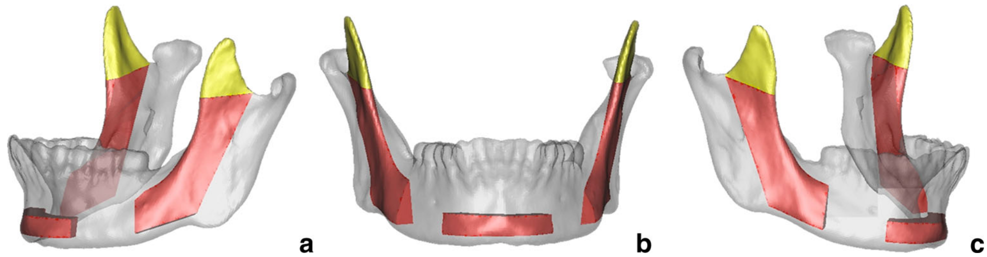

Fig. 2 **a**–**c** 3D Model of the dentate mandible with the symphysis, coronoid process, and ascending ramus as harvest regions

Statistical analysis

Continuous data of the width, thickness, height, volume, surface, and density were described using means and corresponding standard deviations (SDs). A two-level generalized linear model (first level: status, i.e., dentate/edentulous; second level: donor side, i.e., symphysis, coronoid, or ramus) with a random intercept, and a variance component covariance structure was fitted to the width, thickness, height, volume, surface, and density of the outcome parameters. Comparisons of patients with a fully dentate mandible and those with an edentulous mandible within each graft side (symphysis, coronoid, or ramus) were made using linear contrasts, and *p* values less than or equal to 0.05 were regarded as statistically significant. Because of the explorative nature of the study, no adjustment to the significance level was made. All statistical analyses were performed using SAS V9.3 software (SAS Institute Inc., Cary, NC, USA).

Results

Outcomes (dimension, surface, volume, and density) of the different bone grafts (symphysis, ascending ramus, and coronoid process) are shown in Table 1. A comparison of the average value among the three graft sites, dependent on the dentition is presented in Table 2. Table 3 shows comparisons of the average values for dentate vs. edentulous, depending on donor site. For both dentate and edentulous mandibles, the symphysis provided the horizontally widest transplant and the mandibular ramus the vertically-highest and thickest transplant. The coronoid grafts had a substantially lower surface area, volume, and thickness. Significant differences in the average bone volume were found between dentate and edentulous ramus ($p<0.0001$), and edentulous ramus and symphysis ($p<0.0001$). The average bone volume was approximately 3,616.76 (SD 1,072.45) mm^3 for the dentate ramus; 2,360.93 mm^3 (SD 917.10) for the edentulous ramus; and 3,661.31 mm^3 (SD 1,720.19) for the edentulous symphysis; and the surface parameters were similar between these grafts. The differences in the graft surface area were significant between the dentate and edentulous ramus grafts ($p<0.0001$) and also between the dentate ramus and symphysis ($p<0.0001$). The average surface area was approximately 2,523.81 mm^3 (SD 534.62) for dentate ramus grafts; 2,022.32 mm^3 (SD 469.66) for edentulous ramus grafts; and 357.34 mm^3 (SD 1,313.95) for dentate symphysis grafts. An investigation of bone density found no significant variations between dentate and edentulous jaws, but significant differences were found within each group between the three graft areas.

Discussion

Even though allogenic and alloplastic materials are available, autogenous bone grafts are used because of their osteoinductive and osteoconductive potential, and in particular intraoral bone grafts are used for jaw reconstruction [20]. Commonly, the literature reported only about one to two oral

Table 1 Measurements of width, thickness, height, volume, surface, and density

			Width (mm)		Thickness (mm)		Height (mm)		Volume (mm^3)		Surface (mm^2)		Density (HU)	
Graft side	Status	Number of patients	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Coronoid	Dentate	22	19.83	2.73	9.45	2.16	17.66	6.87	693.20	321.28	556.43	146.62	1,173.66	212.97
	Edentulous	20	18.97	3.00	8.76	2.01	16.45	4.22	534.58	236.24	482.68	154.85	1,082.26	220.44
Ramus	Dentate	22	31.49	7.19	17.78	4.16	57.75	5.11	3616.76	1,072.45	2,523.81	534.62	1,263.37	172.24
	Edentulous	20	27.66	5.71	14.86	3.28	52.13	7.51	2,360.93	917.10	2,022.32	469.66	1,205.71	139.92
Symphyis	Dentate	22	41.51	2.72	17.84	1.61	16.86	3.10	4,026.25	1,292.64	1,828.38	357.34	1,007.93	133.78
	Edentulous	20	40.53	3.56	17.12	2.00	17.58	5.10	3,661.31	1720.19	1,865.51	537.84	932.39	80.59

SD standard deviation

Table 2 *p* values of comparisons between donor sites depending on dentition

Dentiton	Donor side	Width (mm)	Thickness (mm)	Height (mm)	Volume (mm^3)	Surface (mm^2)	Density (HU)
Dentate	Coronoid vs. ramus	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005
	Coronoid vs. symphyis	<0.0001	<0.0001	0.5951	<0.0001	<0.0001	0.0003
	Ramus vs. symphyis	<0.0001	0.9268	<0.0001	0.1088	<0.0001	<0.0001
Endentulous	Coronoid vs. ramus	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Coronoid vs. symphyis	<0.0001	<0.0001	0.4708	<0.0001	<0.0001	0.0019
	Ramus vs. symphyis	<0.0001	0.0039	<0.0001	<0.0001	0.1442	<0.0001

bone grafts in relation to the harvest area and the amount of bone supply [15–17, 21–25]. The largest study was based on 59 cadavers, and was published by Yates et al. [14]. This was the first investigation to quantify and compare the amount of bone that it was possible to harvest from the mandibular symphysis, ascending ramus/body, coronoid process, and the zygomatic-maxillary buttress, using a within-subject study design. For the symphysis, the results showed an average thickness of 7.82 mm, a surface area of 358.99 mm^2, and a volume of 1.15 ml. For the ascending ramus, the authors described a thickness of 5.12 mm, a surface area of 855.51 mm^2, and a bone volume of 2.02 ml; and for the coronoid process a thickness of 3.08 mm, a surface area of 155.88 mm^2, and a volume of 0.17 ml. The zygoma graft was reported as requiring a thickness of 2.10 mm, a surface area of 167.67 mm^2, and an average volume of bone of 0.11 ml. The study was also the first to quantitatively describe grafts from the coronoid process and the zygomatic-maxillary complex. In light of results from literature, only a direct comparison with the investigations of Güngörmüş et al. and Montazem et al. is possible in relation to the symphysis and ascending ramus [15–17]. For the ramus, Güngörmüş et al. [16] presented an average surface area of 495.13±79.20 mm^2 and a possible graft volume of 2.36±0.76 ml, whereas Montazem et al. [15] examined the mandibular symphysis of 16 cadavers and found an average bone volume of 9.55 ml (range of 3.25 to 6.50 ml), and an average size of the harvested corticocancellous block from the ascending ramus measuring about 20.9×9.9×6.9 mm. Therefore, a comparison of the results of Yates et al. [14] with the results of Güngörmüş et al. [16] and Montazem et al. [15] shows that Yates et al. present significantly lower values, although they concluded that the ramus provided the greatest volume of bone, as well as the largest amount of cortical bone. In addition, the ramus was associated with significantly lower donor morbidity compared with the symphysis, (the next largest bone graft with a larger amount of cancellous bone).

Significant differences were noted in the literature compared to our results when making a direct comparison of the amount of intraoral harvestable bone. Our investigations show more available bone, or larger dimensions for every graft, than in the study of Yates et al. [14]; and particularly in relation to the ramus, depending on the status (dentate/edentulous). For the graft of the ascending ramus, Yates et al. [14] found a volume of 2.02 ml, which is similar to our results for the edentulous mandible, with an average volume of 2,360.93± 917.1 mm^3 (2.36 ml). However, for the edentulous mandible, the amount of available bone in this study was about 3,616.76 ±1,072.45 mm^3 (3.62 ml). In relation to the amount of bone grafts, our results show a difference between the harvested sites within each group, and a variation in relation to dentition (Table 2). In each group, the most available bone was located in the symphysis. However, this difference was not significant between the ascending ramus and the symphysis in the edentulous mandible. Nevertheless, it should be noted that the ramus and the coronoid process were available twice in a mandible, and thus more bone was expected in these donor areas. However, a comparison of the results with those reported in the literature is difficult because in this study, we use different analytical methods for the volumetric investigations, where the calculation of volume is described as the sum of the width, height, and thickness, or by a measurement of the displaced liquid.

It is therefore necessary to discuss the possible influence in relation to the method of examination used. At the beginning of analysis of the mandible as a donor site for bone grafts, a calliper was used to estimate the bone volume. Meanwhile, the CT technique was used to evaluate bone, because it allows

Table 3 *p* values of comparisons between dentitions (dentate vs. edentulous) depending on donor site

Graft side	Width (mm)	Thickness (mm)	Height (mm)	Volume (mm^2)	Surface (mm^2)	Density (HU)
Coronoid	0.4010	0.2666	0.3347	0.4563	0.3884	0.0172
Ramus	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	0.1309
Symphyis	0.3062	0.4056	0.6848	0.2263	0.7586	0.1614

highly accurate volumetric measurements in three dimensions [26, 27]. Yavuz et al. [13] were the first to evaluate the volume and density of mandibular symphysis bone grafts using three-dimensional CT. They used 15 CT scans to calculate an average bone volume of 3,491.08±772.12 mm^3 and the average size of the autograft block (38.75×11.05×7.80 mm. In our results, similar dimensions were shown. It can therefore be concluded that this method is also suitable for an analysis of the ascending ramus and the coronoid process.

The limiting factor in this study was the type of CT technique used. To obtain axial slices of 0.5-mm thickness for adequate contrast resolution, conventional CT was needed. Cone beam computed tomography (CBCT), which is routine in clinical practice, allows an assessment of high-contrast structures in the oral region with a significantly reduced radiation dose [28]. However, this results in a reduced contrast resolution of CBCT images, and impairs the detectability of tissue structures [29], and such related artifacts can complicate evaluations. Therefore, only conventional CT data were used.

Some authors have described bone quality by use of the density shown in three-dimensional computed tomography (3D CT) images [30, 31]. According to Lekholm and Zarb [32, 33], trabecular bone density can be classified into different groups based on HU. However, in other literature, the specifications vary in the relationship between bone quality and radiological density. Misch [6] classified bone into five categories: D1, >1,250 HU; D2, 850–1,250 HU; D3, 350–850 HU; D4, 150–350 HU; and D5, <150 HU. However, Norton and Gamble [34] proposed the following categories: quality 1, >850 HU; quality 2 and 3, 500–850 HU; quality 4, 0–500 HU; and a failure zone, <0 HU. The study of de Oliveira et al. [31] provided bone type 1, >400 HU, type 2 and 3, 400–200 HU, and type 4, >200 HU. Yavuz et al. [13] achieved an average density for symphysis bone grafts of about 958.95±98.11 HU and classified this according to the Misch categories as D2. This value is close to our results of 932.39±80.59 HU in the edentulous mandible and of 1,007.93±133.78 HU in the dentate mandible. However, Hohlweg-Majert et al. showed a wide range of characterizing HU values for bone structure, based on DICOM datasets and concluded that there was no specific correlation between the HU for bone density and the anatomical region of interest. In their opinion, the finite element analysis is the only method for use in considering the microarchitecture, bone mass, and mechanical properties [35], and Shapurian et al. are in agreement with this opinion [36]. Therefore, our HU values need a critical interpretation.

The results for the bone density by Yavuz et al. [13] were close to our data for the additional bone graft, and are thus comparable. This implies a bone quality of D2 for almost all of our achieved densities, apart from the dentate ramus, which is D1 (Table 1). Considering the density of the other possible categories, the radiological bone quality for all of our harvested sites resulted in D1. However, although this was not our clinical experience of the drill feeling during implant site preparation, the high outcome of bone density in our measurements is explained by the fact that all grafts were corticocancellous in nature [15, 17]. In consequence, the mandible grafts allowed rigid fixation by onlay augmentation.

A few studies in the literature are related to the intraoral bone supply for jaw augmentation, and this study is therefore the first investigation to compare three different virtual autogenous donor sites in the mandible depending on dentition. We found no relationship between the amount of bone and dentition for the coronoid process and symphysis, and the possible reasons for this are that for the coronoid process there is probably a permanent load by the function of the musculus temporalis and in the area of the symphysis a limitation in relation to the roots of the front teeth. It is presumed that a reduction of the quantitative parameters for the ramus is related to the atrophy process, which means that with an increasing demand for augmentation at the same time, the available volume for the bone graft is missing. Such a result is a noticeable limitation of intraoral bone grafts, and in these cases, jaw reconstruction must be made with bone substitute materials, or with bone from extraoral donor sites. Nevertheless, the donor sites of the lower jaw are suitable for reconstruction in a large number of cases, due to its bone quality and quantity, and it can be demonstrated that even with increasing atrophy, the bone quality remains the same.

In accordance with Yavuz et al.[13], we consider that the use of CT in combination with suitable software is a good method for determining the dimensions, surface, and Hounsfield units (HU) of possible bone grafts. Furthermore, this is a more accurate method than that used by previous studies that involved the use of calipers or measured displaced saline for evaluation of the graft size. In clinical practice, three-dimensional computer-aided software is used for implant treatment, and it is therefore suitable to include in the planning of augmentation procedures. We have shown that it is possible to perform planning of the implant position at the same time as making an analysis of the jaw for potential donor areas, by using a corresponding software program. For cases that do not use three-dimensional imaging, the standard values presented here could be employed. However, it is considered that further studies are required to verify whether the virtual osteotomies can be transferred to real-time surgery using surgical guides.

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