Journal of Digital Imaging (2023) 36:2249–2258
https://doi.org/10.1007/s10278-023-00877-y

Virtual Three-Dimensional Model Analysis in the Assessment of the Maxillary and Mandibular Donor Sites on Cone-Beam Computed Tomography Images

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Received: 22 April 2023 / Revised: 23 June 2023 / Accepted: 23 June 2023 / Published online: 10 July 2023

Abstract

Using the Mimics software to assess the maxillary and mandibular donor sites on cone-beam computed tomography (CBCT) images. This cross-sectional study was conducted on 80 CBCT scans. Data in DICOM format were transferred to the Mimics software version 21, and a maxillary and a mandibular mask according to cortical and cancellous bones were virtually created for each patient based on Hounsfield units (HUs). Three-dimensional models were reconstructed, and boundaries of donor sites, including mandibular symphysis, ramus, coronoid process, zygomatic buttress, and maxillary tuberosity, were defined. Virtual osteotomy was conducted on the 3D models to harvest bone. The volume, thickness, width, and length of harvestable bone from each site were quantified by the software. Data were analyzed by independent *t*-test, one-way ANOVA, and Tukey's test (alpha = 0.05). The greatest harvestable bone volume and length differences were observed between ramus and tuberosity ($P < 0.001$). The maximum and minimum harvestable bone volumes were found in symphysis (1753.54 mm^3) and tuberosity (84.99 mm^3). The greatest difference in width and thickness was noted between the coronoid process and tuberosity ($P < 0.001$) and symphysis and buttress ($P < 0.001$), respectively. Harvestable bone volume from tuberosity, length, width, volume from symphysis, and volume and thickness from the coronoid process was significantly greater in males ($P < 0.05$). The harvestable bone volume was the highest in symphysis, followed by ramus, coronoid, buttress, and tuberosity. The harvestable bone length and width were the highest in the symphysis and coronoid process, respectively. Maximum harvestable bone thickness was found in symphysis.

Keywords Cone-beam computed tomography · Alveolar bone grafting · Imaging · Three-dimensional

Introduction

Considering the increasing use of dental implants and the significance of adequate alveolar bone support, finding reliable donor sites for autogenous bone harvesting is significant. Long-term edentulism, aging, trauma, and systemic diseases can trigger or aggravate the existing alveolar bone resorption [1]. Surgical bone grafting is performed to regain the lost space, preserve the bone contour, enhance the soft tissue, and regenerate and augment bone. Autogenous bone remains the gold standard for bone grafting [1].

Bone is the most commonly transplanted tissue in the human body, which can be used for the reconstruction of bone defects caused by atrophy, trauma, congenital anomalies, or neoplasms. To date, autogenous bone has been the only source of osteogenic cells and is therefore considered the gold standard for oral reconstructions. Bone grafts harvested from the ileum, ribs, calvaria, and intraoral donor

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sites are commonly used in reconstructive oral and maxillofacial surgical procedures [2]. The main advantage of using a local donor site is easy surgical access, decreasing anesthesia and operation time. The lateral and anterior parts of the mandibular ramus, the area buccal to the third molars, mandibular lingual cortex, zygomatic bone, maxillary tuberosity, hard palate, coronoid process, and mandibular symphysis are all donor sites used for oral and maxillofacial bone grafting [2].

The selection of bone grafting technique and material depends on several factors, such as the severity of atrophy, morphology of bone defect, and the number of existing bony walls. The growth of blood vessels from the surrounding bone into the defect site provides a path for bone progenitor cells and subsequent new bone formation. In cases with fewer bony walls and more significant alveolar bone atrophy, techniques and materials with higher potential for biological activity and greater regenerative capacity are required [3].

Intramembranous autogenous bone grafts are superior to other graft types for the maxillofacial region due to minimal resorption, preservation of high volume of bone, minimal antigenicity, and higher concentration of bone morphogenetic proteins [2]. Autogenous bone grafts may be harvested from intraoral or extraoral donor sites. Intraoral donor sites often bring about more favorable results than extraoral donor sites. Intraoral donor sites include the mandibular symphysis, ramus, internal and external oblique ridges, and maxillary tuberosity. Mandibular ramus is a better option for bone graft harvesting due to fewer postoperative complications.

On the other hand, mandibular symphysis, compared with ramus, is more easily accessible in patients with mouth-opening limitations or temporomandibular disorders. Moreover, the mandibular symphysis has a higher volume of cancellous bone than the ramus [2]. Despite the advantages of mandibular symphysis for bone harvesting, the amount of available bone for harvesting and the critical anatomical structures in this region should be precisely assessed preoperatively due to the risk of complications such as perioperative bleeding, mental nerve injury, and pulp necrosis of mandibular anterior teeth [2].

Maxillary tuberosity or buttress can also serve as suitable sites for bone graft harvesting for sinus floor augmentation due to approximation to the surgical site and easy access in this surgical procedure. Each donor site has its advantages and shortcomings, depending on several factors, such as the adjacent anatomical structures, quality and quantity of available bone for harvesting, and easy access, which should be taken into account by the surgeon before and during the harvesting procedure. Selection of a suitable donor site and availability of the required volume and dimensions of bone for harvesting are among the main challenges encountered by surgeons in this procedure.

Precise planning is imperative for graft harvesting to obtain favorable results like any other surgical procedure. Three-dimensional (3D) analysis by cone-beam computed tomography (CBCT) can be of great help in these cases. CBCT is a diagnostic imaging modality, especially for the assessment of the maxillofacial complex [3]. It enables the reconstruction of oral and maxillofacial skeletal structures without distortion and with a lower radiation dose than computed tomography [4]. Several studies have confirmed the reliability of CBCT for precise volumetric and dimensional measurements, assessment of bone quality at the donor site, and identification of the position of anatomical structures [2, 5–7]. Mimics software was used for the evaluation of the donor site of the mandibular symphysis in several studies [1, 8]. These studies focus only on assessing the symphysis as a donor site by the Mimics software, but in the present study, we used this software to evaluate the different donor sites of the maxilla and mandible and compare them quantitatively to offer the proper donor sites.

Considering all the above, this study aimed to quantitatively and three-dimensionally assess the maxillary and mandibular donor sites for bone harvesting on CBCT images using the Mimics software.

Materials and Methods

This cross-sectional study was conducted on CBCT scans of adults (over 18 years) retrieved from the Oral and Maxillofacial Radiology Department of the School of Dentistry, Guilan University of Medical Sciences, from 2016 to 2021. The protocol of this study was approved by the ethics committee of the University of Medical Sciences (IR.GUMS.REC.1401.141). The CBCT scans had been requested for different reasons unrelated to this study, such as third molar surgical extraction and dental implant surgery. Informed consent was obtained from all individual participants included in the study.

The sample size was calculated to be 78 according to a study by Ataman-Duruel et al., assuming the standard deviation of ramus length to be 4.29 mm, alpha = 0.05, the accuracy of 1 mm, and 10% possible dropouts.

Eligibility Criteria

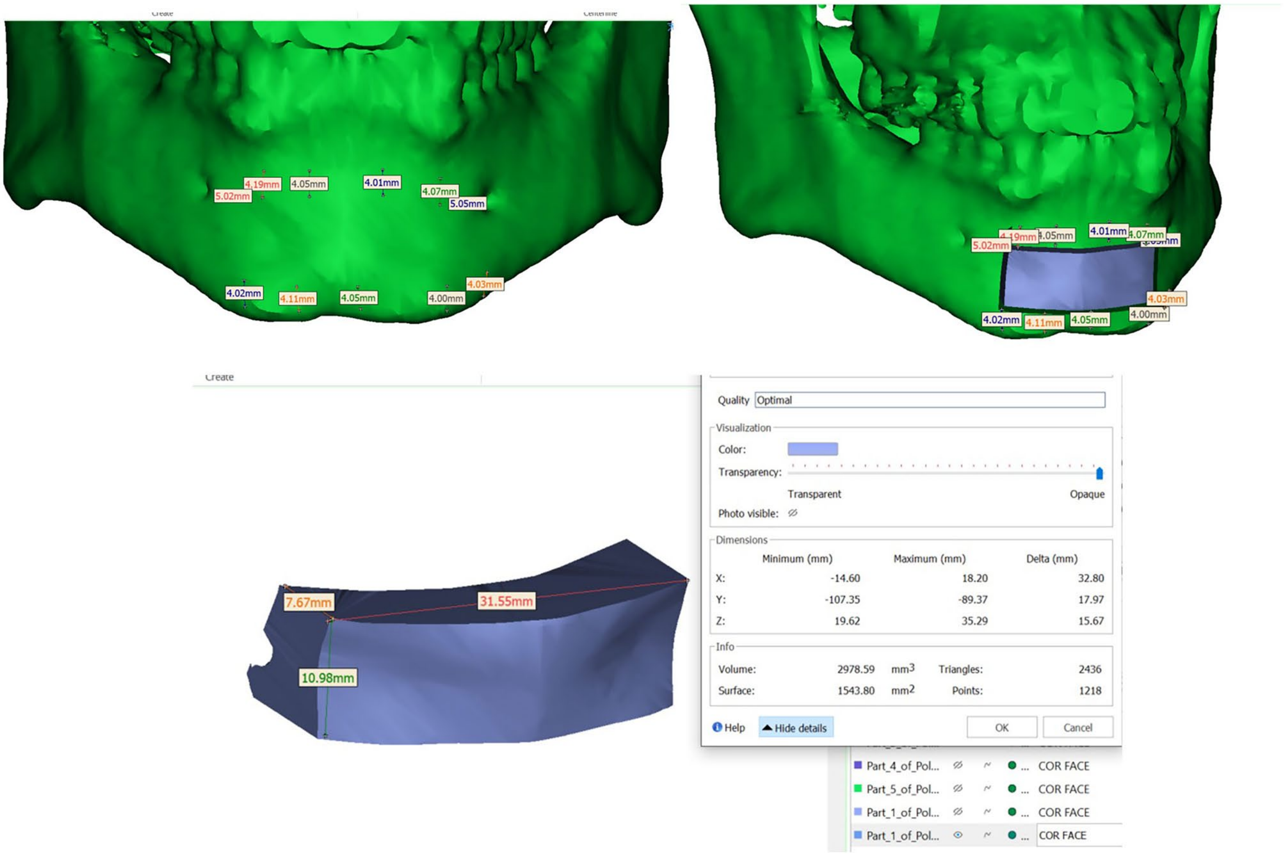
The inclusion criteria were high-quality CBCT images without motion artifact, high metal artifact, or blueness (DICOM format) of the maxilla, mandible, or both of Iranian adults over 18 years old with completed skeletal growth and development. The CBCT scans were taken with Pax-I 3D CBCT scanner (VATECH, Korea) with exposure settings of 95 kV, 5.5 mA, and 0.25 mm voxel size. Other exposure parameters, such as field of view, were adjusted case-by-case depending on the size of the region of interest and the reason for CBCT. The size of the field of view was 90 × 120 mm in the maxilla and 150 × 150 mm for both the maxilla and mandible.

The exclusion criteria were edentulous patients, history of bone grafting surgery, history of jaw fracture, intraoral exostosis, and pathologies such as maxillary or mandibular cysts and tumors.

Methodology

The zygomatic buttress and tuberosity were evaluated on images of the maxilla, while mandibular symphysis, ramus, and coronoid process were evaluated on complete images of both jaws. In other words, on each scan, the measurable data regarding each of the donor sites that were retrievable were collected. After data extraction from CBCT images, data in DICOM format were transferred to the Mimics software (Mimics Medical 21.0, Materialise, Belgium). DICOM format files were used to create a mask for the maxilla and mandible of each patient according to Hounsfield units (HUs) in the software environment based on cortical and cancellous bones. The 3D models were then reconstructed (Fig. 1). The boundaries of harvestable bone at each donor site, including mandibular symphysis, mandibular ramus, coronoid process, zygomatic buttress, and maxillary tuberosity, were marked on 3D models of the maxilla and mandible, and virtual osteotomy was performed on the 3D model to harvest the marked areas as a bone graft. After the isolation of the bone graft from the surrounding osseous parts, its volume and dimensions (width, length, and thickness) were three-dimensionally measured using the Mimics software. The boundaries of graft donor sites were as follows, which were determined by taking into account the areas and critical anatomical structures, nerves, vasculature, and teeth adjacent to osteotomy lines, preserving the harmony of the bone contour in the maxilla and mandible according to the literature [9–12] and the expert opinions of oral and maxillofacial surgery faculty members of the Department of Oral and Maxillofacial Surgery of Guilan School of Dentistry.

Two observers, a postgraduate student of maxillofacial surgery (SMD) and an expert maxillofacial radiologist (ZDK), who are familiar with and trained to use the Mimics software, did all the measurements at the same time, and the mean of their measurements was considered as



Quality: Optimal

Photo visible: ∅

Dimensions

	Minimum (mm)	Maximum (mm)	Delta (mm)
X:	-14.60	18.20	32.80
Y:	-107.35	-89.37	17.97
Z:	19.62	35.29	15.67

Info

Volume:	2978.59	mm3	Triangles:	2436
Surface:	1543.80	mm2	Points:	1218

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Part_5_of_Pol...	...	COR FACE
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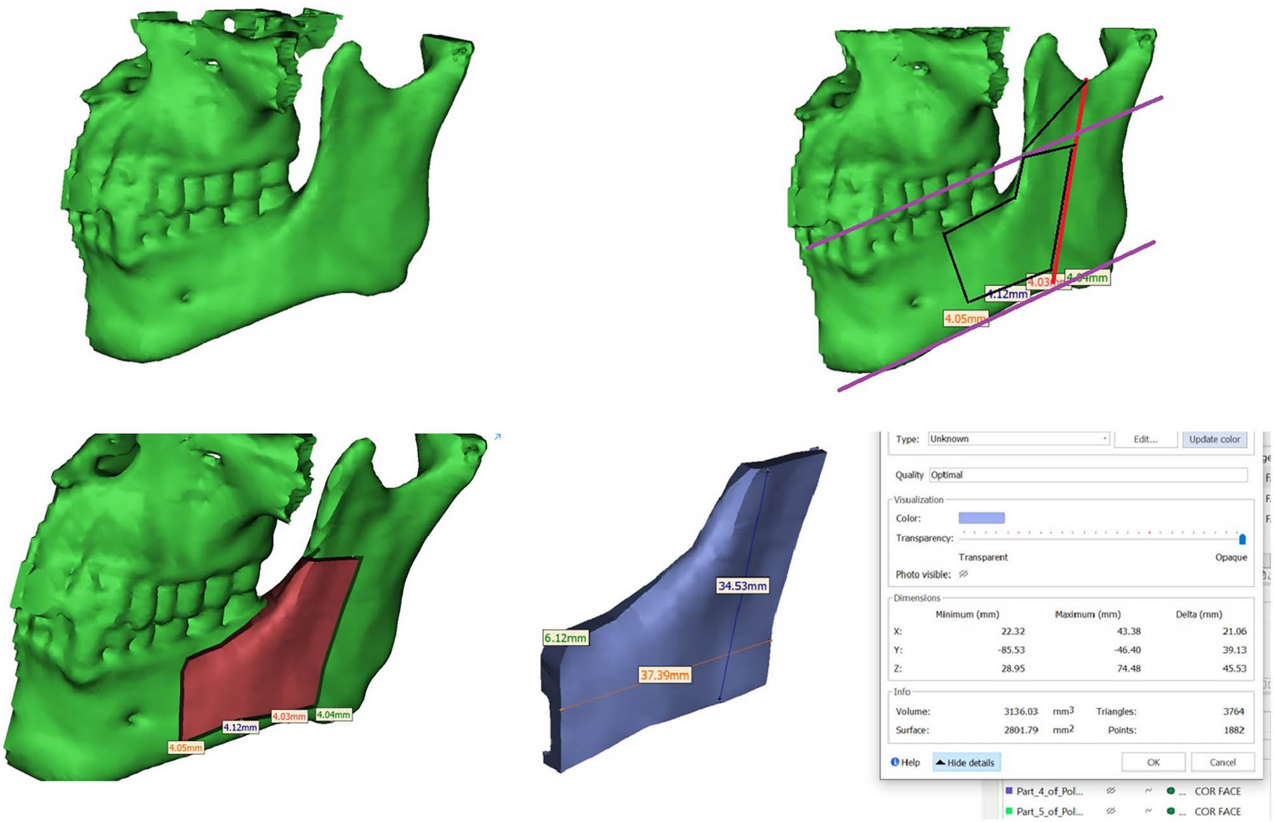
Fig. 1 Mimics software environment indicating the boundaries of mandibular symphysis donor site



Type: Unknown

Quality Optimal

Visualization

Color: 🟦

Transparency: Transparent — Opaque

Photo visible:

Dimensions

	Minimum (mm)	Maximum (mm)	Delta (mm)
X:	22.32	43.38	21.06
Y:	-85.53	-46.40	39.13
Z:	28.95	74.48	45.53

Info

Volume:	3136.03	mm3	Triangles:	3764
Surface:	2801.79	mm2	Points:	1882

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Fig. 2 Mimics software environment indicating the boundaries of mandibular ramus donor site

the final measurements. The same observers re-evaluated twenty CBCT images at the same time 2 weeks later for intra-observer agreement.

The chosen limits or borders of the donor sites are described one by one in the following sentences*:*

(a) Mandibular symphysis (Fig. 1):

- Upper limit: 5 mm below the anterior tooth apices
- Lower limit: 4 mm above the inferior border of the mandible
- Lateral limit: 5 mm anterior to mental foramen

(b) Mandibular ramus (Fig. 2):

Visualization

Color: 🟦

Transparency: Transparent — Opaque

Photo visible:

Dimensions

	Minimum (mm)	Maximum (mm)	Delta (mm)
X:	36.51	46.84	10.33
Y:	-68.15	-41.99	26.16
Z:	76.84	104.69	27.85

Info

Volume:	1350.48	mm3	Triangles:	1602
Surface:	959.07	mm2	Points:	803

Green 1 COR FACE

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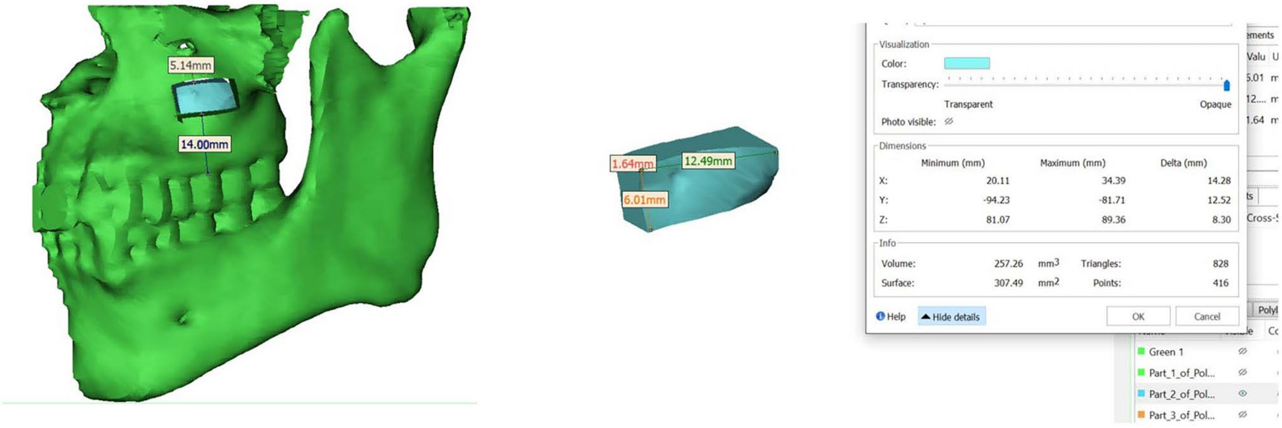
Fig. 3 Mimics software environment indicating the boundaries of coronoid process donor site



Visualization

Color:

Transparency: Transparent — Opaque

Photo visible:

Dimensions

	Minimum (mm)	Maximum (mm)	Delta (mm)
X:	20.11	34.39	14.28
Y:	-94.23	-81.71	12.52
Z:	81.07	89.36	8.30

Info

Volume:	257.26	mm3	Triangles:	828
Surface:	307.49	mm2	Points:	416

Fig. 4 Mimics software environment indicating the boundaries of zygomatic buttress donor site

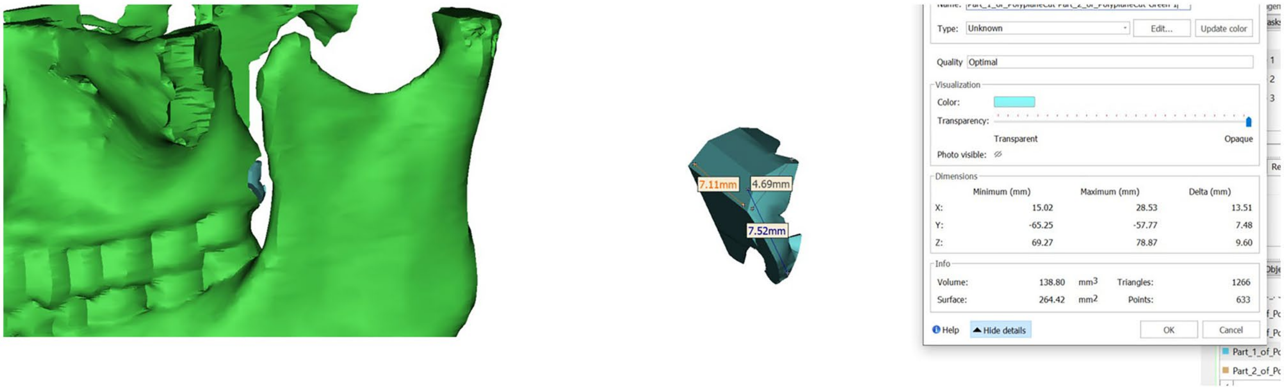
- Upper limit: an osteotomy line was drawn along the anterior border of the ramus from the distal of the first molar to a hypothetical line drawn from the mandibular canal parallel to the inferior border of the mandible and extending to the anterior border of the ramus.
- Lower limit: 4 mm superior to the inferior border of the mandible
- Anterior limit: a vertical line at the distal half of the first molar
- Posterior limit: a hypothetical line from the deepest point of the sigmoid notch to the antegonial notch
- Medial limit: only at a depth of the lateral mandibular cortex; in case of the absence of second and third molars, it could extend to the alveolar ridge of the missing teeth.

(c) Coronoid process (Fig. 3): an Osteotomy line is drawn from the deepest point of the sigmoid notch to the anterior border of the ramus at the site of a hypothetical line drawn from the mandibular canal parallel to the inferior border of the mandible and extending to the anterior border of the ramus

(d) Zygomatic buttress (Fig. 4):

- Upper limit: 5 mm below the infraorbital foramen
- Lower limit: 14 mm above the cementoenamel junction of teeth; in edentulous patients, from the interface of alveolar bone and zygomaticomaxillary buttress
- Posterior limit: distal of the second molar; in edentulous patients, 1 cm posterior to the region with maximum prominence of the zygomaticomaxillary buttress
- Medial limit: maxillary sinus

(e) Maxillary tuberosity (Fig. 5):



Type: Unknown

Quality Optimal

Visualization

Color:

Transparency: Transparent — Opaque

Photo visible:

Dimensions

	Minimum (mm)	Maximum (mm)	Delta (mm)
X:	15.02	28.53	13.51
Y:	-65.25	-57.77	7.48
Z:	69.27	78.87	9.60

Info

Volume:	138.80	mm3	Triangles:	1266
Surface:	264.42	mm2	Points:	633

Fig. 5 Mimics software environment indicating the boundaries of maxillary tuberosity donor site

- Upper limit: 2 mm from the maxillary sinus
- Anterior limit: 2 mm distal to the second and third molars; in case of missing second and third molars, it could extend to the distal of the second molar.

Data Collection

The demographic information of the patients was collected in a designed checklist. Linear and volumetric measurements of bone graft donor sites in the maxilla and mandible were made on CBCT scans (including volume, thickness, width, and length of harvestable bone graft).

Statistical Analysis

The normal distribution of data was evaluated by the Kolmogorov–Smirnov test, while Levene's test analyzed the homogeneity of variances. Considering the normal distribution of data and homogeneity of variances ($P > 0.05$), a *t*-test was used for pairwise comparisons of the mean values between males and females. Multiple comparisons were carried out by one-way ANOVA (analysis of variance). In case of the presence of a significant difference, pairwise comparisons of the sites were conducted by Tukey's test. All statistical analyses were performed using SPSS version 24 (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Armonk, NY, USA) at 0.05 level of significance.

Results

CBCT scans of 37 males (46.3%) and 43 females (53.8%) were evaluated. The mean age of patients was < 30 years in 22.5% ($n = 18$), between 30 and 40 years in 26.3% ($n = 21$), between 40 and 50 years in 32.5% ($n = 26$), and over 50 years in 18.8% ($n = 15$). The statistics showed that the intra-observer agreement was 92% and 89% for the observers by Cohen's kappa.

Table 1 presents the mean length, width, thickness, and volume of harvestable bone from the donor sites in the maxilla (including zygomatic buttress and tuberosity) and mandible (including symphysis, ramus, and coronoid process).

(a) Zygomatic buttress: independent *t*-test showed no significant difference in length, width, thickness, and volume of harvestable bone in total or separately on the right and left sides between males and females ($P > 0.05$).

(b) Maxillary tuberosity: independent *t*-test showed no significant difference in length, width, and thickness of harvestable bone in total or separately on the right and left sides between males and females ($P > 0.05$). The volume was not significantly different between males and females on the right or left sides ($P > 0.05$). However, in total, the volume of harvestable bone from this donor site was significantly greater in males than females ($P = 0.02$).

Table 1 Mean length, width, thickness, and volume of harvestable bone from the donor sites in the maxilla (including zygomatic buttress and tuberosity) and mandible (including symphysis, ramus, and coronoid) in males and females as measured on CBCT scans by the Mimics software

Donor site	Variable	Mean			*P* value
		Males	Females	Total	
Zygomatic buttress	Length (mm)	9.64	9.51	9.57	0.57
	Width (mm)	4.21	4.44	4.32	0.25
	Thickness (mm)	1.21	1.27	1.24	0.11
	Volume (mm^3)	93.71	91.43	92.57	0.66
Maxillary tuberosity	Length (mm)	7.51	7.26	7.38	0.47
	Width (mm)	3.90	3.87	3.88	0.86
	Thickness (mm)	2.02	2.06	2.04	0.81
	Volume (mm^3)	92.82	78.11	84.99	0.02
Mandibular symphysis	Length (mm)	33.31	30.40	31.77	0.004
	Width (mm)	8.69	6.87	7.71	0.001
	Thickness (mm)	5.99	5.58	5.77	0.30
	Volume (mm^3)	2014.47	1525.74	1753.54	0.001
Mandibular ramus	Length (mm)	25.12	23.98	24.53	0.11
	Width (mm)	10.03	9.53	9.80	0.19
	Thickness (mm)	3.45	3.21	3.32	0.03
	Volume (mm^3)	1968.47	1447.50	1690.15	0.15
Coronoid process	Length (mm)	19.03	17.66	18.31	0.36
	Width (mm)	13.48	13.85	13.69	0.25
	Thickness (mm)	4.06	3.81	3.92	0.01
	Volume (mm^3)	1001.81	738.79	861.30	0.001

(c) Mandibular symphysis: the mean length ($P = 0.004$), width ($P = 0.001$), and volume ($P = 0.001$) of harvestable bone from mandibular symphysis in males were significantly higher than those in females. However, the difference in thickness was not significant between males and females ($P = 0.30$).

(d) Mandibular ramus: no significant difference existed between males and females in length, width, thickness, and volume of harvestable bone from the mandibular ramus on the right and left sides, as shown by an independent *t*-test ($P > 0.05$). In total, the difference in length, width, and volume was not significant between males and females ($P > 0.05$). However, in total, the thickness of harvestable bone from the mandibular ramus was significantly greater in males than in females ($P = 0.03$).

(e) Coronoid process: independent *t*-test showed significantly higher length ($P = 0.002$) and volume ($P = 0.001$) of the harvestable bone from the coronoid process on the right side, significantly higher volume on the left side ($P = 0.001$), and thickness ($P = 0.01$) and volume ($P = 0.001$) in total in males compared with females. No other significant difference was found between males and females ($P > 0.05$).

Comparison of the Volume of Harvestable Bone from Different Donor Sites

Since the assumption of homogeneity of variances was met ($P = 0.82$), one-way ANOVA was applied for comparisons of the mean volume of harvestable bone from different donor sites in the maxilla and mandible, which revealed a significant difference ($P = 0.001$). Pairwise comparisons by Tukey's test (Table 2) showed significant differences between all groups ($P = 0.001$ for all) except for the difference between symphysis and ramus ($P = 0.980$) and buttress and tuberosity ($P = 0.999$). The maximum difference in volume was found between ramus and tuberosity, and the minimum mean difference existed between buttress and tuberosity. Maximum bone volume was recorded in symphysis, followed by ramus, coronoid process, and buttress. Tuberosity had the lowest volume of harvestable bone.

Comparison of the Width of Harvestable Bone from Different Donor Sites

One-way ANOVA revealed a significant difference in the width of harvestable bone from different donor sites ($P = 0.001$). Pairwise comparisons by Tukey's test (Table 2) showed significant differences between all groups ($P = 0.001$ for all) except for the difference between buttress and tuberosity ($P = 0.063$). The maximum difference in the mean width existed between the coronoid process and tuberosity such that the mean width of harvestable bone from the coronoid process was significantly higher than the tuberosity. The minimum difference existed between the buttress and tuberosity. The coronoid process noted the maximum width, followed by ramus, symphysis, buttress, and tuberosity.

Comparison of Length of Harvestable Bone from Different Donor Sites

One-way ANOVA revealed a significant difference in the length of harvestable bone from different donor sites ($P = 0.001$). Pairwise comparisons by Tukey's test (Table 2) showed significant differences between all groups ($P = 0.001$

Table 2 Pairwise comparisons of the volume, length, width, and thickness of harvestable bone from different donor sites in the maxilla (including zygomatic buttress and tuberosity) and mandible (including symphysis, ramus, and coronoid process) in males and females as measured on CBCT scans by the Mimics software

Thickness	Site	*P* value	Width	Site	*P* value	Length	Site	*P* value	Volume	Site	*P* value
Symphysis	Ramus	0.001*	Symphysis	Ramus	0.001*	Symphysis	Ramus	0.001*	Symphysis	Ramus	NS0.980
	Coronoid	0.001*		Coronoid	0.001*		Coronoid	0.001*		Coronoid	0.001*
	Buttress	0.001*		Buttress	0.001*		Buttress	0.001*		Buttress	0.001*
	Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*
Ramus	Coronoid	0.001*	Ramus	Coronoid	0.001*	Ramus	Coronoid	0.001*	Ramus	Coronoid	0.001*
	Buttress	0.001*		Buttress	0.001*		Buttress	0.001*		Buttress	0.001*
	Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*
Coronoid	Buttress	0.001*	Coronoid	Buttress	0.001*	Coronoid	Buttress	0.001*	Coronoid	Buttress	0.001*
	Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*		Tuberosity	0.001*
Buttress	Tuberosity	0.001*	Buttress	Tuberosity	NS0.063	Buttress	Tuberosity	0.001*	Buttress	Tuberosity	NS0.999

NS non-significant

*Significant at 0.0.5

for all). The maximum mean difference in length was noted between symphysis and tuberosity, such that the mean length of harvestable bone from symphysis was significantly higher than the tuberosity. The minimum mean difference was found between the buttress and tuberosity. The highest length of harvestable bone was recorded in symphysis, followed by ramus, coronoid process, buttress, and tuberosity.

Comparison of the Thickness of Harvestable Bone from Different Donor Sites

One-way ANOVA revealed a significant difference in the thickness of harvestable bone from different donor sites ($P = 0.001$). Pairwise comparisons by Tukey's test (Table 2) showed significant differences between all groups ($P = 0.001$ for all). The maximum mean difference in thickness was noted between symphysis and buttress, such that the mean thickness of harvestable bone from symphysis was significantly greater than buttress. The minimum mean difference existed between the ramus and coronoid processes. The maximum thickness was noted in symphysis, followed by the coronoid process, ramus, tuberosity, and buttress.

Discussion

This study quantitatively and three-dimensionally assessed the maxillary and mandibular donor sites for bone harvesting on CBCT images using the Mimics software. It was among the first to determine the properties of different intraoral donor sites in terms of volume, thickness, length, and width in both males and females in an Iranian population. The results revealed significant differences between different donor sites in almost all parameters. Pairwise comparisons of the donor sites revealed significant differences in harvestable bone volume among all locations, except between symphysis and ramus and between buttress and tuberosity. The maximum harvestable bone volume was recorded in symphysis, followed by ramus, coronoid process, and buttress. Tuberosity had the lowest volume of harvestable bone.

Möhlhenrich et al. [13] compared dentate and edentulous patients regarding length, height, thickness (linear measurements), surface area, volume, and density (HUs) of donor sites. They reported the maximum harvestable bone volume at the symphysis, ramus, and coronoid processes in dentate patients, which agreed with the present findings. Although the anatomical boundaries were defined similarly in their study and the current investigation, they used computed tomography. In contrast, we used CBCT images, indicating that irrespective of the type of imaging modality, similar results may be obtained if the defined boundaries are the same. Ataman et al. [9] compared four intraoral donor sites and reported maximum harvestable bone volume from symphysis followed by ramus, hard palate, and tuberosity, which was almost in line with the present results. However, the harvestable bone volume from ramus was 900 mm^3 in their study versus 1690.15 mm^3 in the present study, which highlights significant differences in anatomical borders of the donor site. They defined the border of the ramus such that it did not pass through the interface of the mandibular canal, and its upper limit was at the level of dental occlusion. Also, they used a different software program (SIMPLANT Pro 17.01; Dentsply Implants, USA). Yates et al. [10] evaluated 59 cadavers and showed that the harvestable bone volume from the mandibular ramus was more significant than the symphysis and coronoid process, which was different from the present findings. This difference may be attributed to different study populations in terms of genetics and also differences in the definition of borders and measurement methods. Also, the harvestable volume of bone from ramus was 2.02 mL in a study by Yates et al. [10] and 2.13 mL in a study by Güngörmüş et al. [14]. In both of these studies, the defined borders for harvestable bone from ramus were different from those in the present study.

Standardized studies regarding the definition of borders are required to prevent such controversies, and borders commonly used by surgeons in the clinical setting should preferably be selected in such studies. Zeltner et al. [12] analyzed 60 CBCT scans of patients in three groups without mandibular second and third molars, lack of mandibular third molars, and complete mandibular dentition. They reported the mean volume of harvestable bone from the symphysis to be 3400 to 3600 mm^3 in the three groups, which was averagely higher than the value obtained in the present study (1770.1 mm^3). They also assessed the harvestable bone from ramus by only considering the retromolar area, which was significantly different among the three groups and depended on the presence of teeth (ranging from 1005 to 2580 mm^3). This value was an average of 1707 mm^3 in the present study. Kilinc et al. [15] evaluated the adequacy of harvestable bone from the symphysis for reconstructing unilateral and bilateral alveolar clefts using CBCT. They reported that the mean amount of harvestable bone was 2164.89 mm^3 which was averagely higher than the value obtained in the present study (1753.54 mm^3). Their methodology and applied software were similar to the current study. Thus, this difference may be attributed to their smaller sample size and the fact that they evaluated alveolar cleft patients. They reported that the amount of harvestable bone from the symphysis in adults with unilateral cleft palate was sufficient for cases requiring a mean volume of 1001.21 mm^3 of bone for alveolar reconstruction. However, they added that standardization of this scale is difficult due to wide variations in the bone volume of symphysis in different patients.

In the present study, pairwise comparisons of donor sites regarding the thickness of harvestable bone revealed significant differences between all locations, and the maximum thickness was noted in symphysis, followed by the coronoid process, ramus, tuberosity, and buttress. Möhlhenrich et al. [13] evaluated dentate patients and found no significant difference in the thickness of harvestable bone from the ramus (17.78 mm) and symphysis (17.84 mm). However, this difference was significant in the present study, and the thickness of harvestable bone from the symphysis was significantly greater than that from the ramus (5.77 mm versus 3.32 mm). The thickness of harvestable bone from the symphysis was more significant than that from the coronoid process in their study, which agreed with the present results. However, the mean thickness of harvestable bone from the coronoid process was less than that from the ramus in their study, which was different from the present findings and may be attributed to differences in definitions of anatomical boundaries. Due to this difference, the virtually harvested block in their study was a bi-cortical bone block, unlike the present study, which yielded different thickness (and subsequently volume) results. Yates et al. [10] found a significant difference in the thickness of harvested bone from the buttress and coronoid process, which agreed with the present results. Their study reported the maximum thickness of harvestable bone in the coronoid process, followed by ramus, symphysis, and zygomatic buttress. In graft harvesting from the ramus, the position of the mandibular canal should be taken into account. The harvestable bone thickness from the ramus in the present study was an average of 3.32 mm, which may not be generalizable to the clinical setting. This value was 5.12 mm in the study by Yates et al. [10], which may be due to the fact that they measured the blocks harvested from cadavers, while the present study conducted a radiographic assessment on CBCT scans.

Pairwise comparisons of donor sites regarding the length of harvestable bone revealed significant differences, such that the highest length of harvestable bone was recorded in symphysis, followed by ramus, coronoid process, buttress, and tuberosity. Pairwise comparisons of donor sites regarding the width of harvestable bone revealed significant differences between all locations except for the width of harvestable bone from the buttress and tuberosity. The coronoid process noted the maximum width, followed by ramus, symphysis, buttress, and tuberosity. According to the results, it may be stated that in case of requiring a bone graft with high length, the symphysis should be the preferred site, followed by ramus and then the coronoid process. Ataman-Duruel et al. [9] evaluated bone harvesting from the ramus and reported that the surface area (without considering thickness) of the bone block was $10.46 \pm 3.70 \times 9.94 \pm 4.29$ mm; this value was an average of 9.80×24.53 mm in the present study. The dimensions of harvestable bone from symphysis were $13.36 \pm 3.71 \times 29.76 \pm 7.17$ mm in their study versus 7.71×31.77 mm in the present study. The dimensions of the harvestable bone block (by considering thickness) from the tuberosity were $7.23 \pm 4.09 \times 7.92 \pm 4.10 \times 7.80 \pm 3.87$ mm in their study versus $2.04 \times 3.88 \times 7.38$ mm in the present study. In the study by Möhlhenrich et al. [13] on dentate patients, the largest linear dimension of harvestable bone (equal to the length in the present study) was found in the ramus, followed by symphysis and coronoid process, which was different from the order of harvestable bone length values in the present study. However, their results regarding the width of harvestable bone agreed with the current results. It should be noted that in the assessment of the length and width of bone blocks, the geometric form of harvestable block is also important. For instance, in the assessment of harvestable bone from the symphysis, Yates et al. [10] divided each bone block into two rectangular-shaped blocks, calculated the surface area of each block by a simple formula, and calculated the surface area of the entire harvested bone as such. Their methodology was different from the present study since we considered the harvestable bone from the symphysis as one single block.

In the present study, a harvestable bone from different donor sites was also compared between males and females, which revealed no significant difference in zygomatic buttress. In maxillary tuberosity, bone volume in males was 14.71 mm^3 greater than that in females, which was significant; no other significant difference was found between males and females at this site. In mandibular symphysis, the length, width, and volume of harvestable bone were significantly greater in males, but thickness was not significantly different. In the mandibular ramus, the thickness was significantly greater in males, but the width, length, and volume of harvestable bone were not significantly different between males and females. In the coronoid process, the thickness and volume of harvestable bone in males were significantly greater than in females, but width and length were not significantly different. Thus, in bone harvesting from the ramus and coronoid process, the thickness difference in males and females should be taken into account. Also, the difference in harvestable bone volume between males and females should be considered in bone harvesting from the tuberosity, symphysis, and coronoid processes. Studies on the role of gender in the dimensions of harvestable bone are highly limited. Yates et al. [10] reported that surface area, volume, and thickness of harvestable bone from the symphysis, ramus, coronoid process, and buttress were significantly affected by age and gender; however, they did not perform separate pairwise comparisons. Kadkhodazadeh et al. [16] evaluated the quality and quantity of harvestable bone from ramus using CBCT. They found no significant correlation between gender and bone volume, bone height, bone density, or ratio of cortical to cancellous bone, which was different from the present results since the thickness of harvestable bone from ramus was significantly greater in males in the present study. Safi et al. [2] evaluated the quality and quantity of harvestable bone from symphysis using CBCT. They reported that all parameters, including vertical and horizontal dimensions and cortical thickness of harvestable bone from the inter-foraminal region of the mandible, were significantly greater in males. In the present study, the length, width, and volume of harvestable bone from symphysis were significantly greater in males, which was in agreement with their findings despite methodological differences. Thus, it may be stated that linear dimensions of harvestable bone from the symphysis are influenced by gender.

This study had some limitations. The CBCT scans present in the archives of the Radiology Department of the School of Dentistry, Guilan University of Medical Sciences were used in this study. A limited number of CBCT scans had the inclusion criteria, so the effect of influential factors such as skeletal class of occlusion and facial growth pattern of patients on the harvestable bone dimensions from each site could not be taken into account. Future studies with a larger sample size are required to address the effect of such variables. Also, clinical studies are recommended to assess the success rate of graft surgeries conducted based on radiographic predictions regarding the dimensions of harvestable bone to find the best site for bone harvesting clinically.

Conclusion

The intraoral sites with maximum harvestable bone volume were found to be symphysis, ramus, and coronoid processes, and those with minimum harvestable bone volume included the buttress and maxillary tuberosity. Symphysis and zygomatic buttress yielded the highest and the lowest thickness of harvestable bone. Symphysis and coronoid process provided the highest, and tuberosity provided the lowest width and length of the harvestable bone.

Acknowledgements We would like to thank Dr. Ghafari for his help in the statistical analysis of the data.

Author Contribution "All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Seyed Moein Diarjani, Zahra Dalili Kajan, and Safa Motevasseli. The first draft of the manuscript was written by Seyed Moein Diarjani and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript."

Declarations

Ethics Approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Guilan University of Medical Sciences (IR.GUMS.REC.1401.141).

Conflict of Interest The authors declare no competing interests.

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