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Original Article

Three-dimensional radiographic assessment of the mandibular interforaminal donor site in different vertical facial growth types

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ABSTRACT

Purpose: To assess volumetrically, the impact of vertical facial growth types (VFGT) on the mandibular interforaminal region as a potential bone donor site.
Material and methods: 60 cone beam computed tomography (CBCT) scans of adult individuals were classified in three groups according to their SN-GoGn angle: hypodivergent group (hG) ($N = 20$), normodivergent group (NG) ($N = 19$) and hyperdivergent group (HG) ($N = 21$). Total harvestable bone volume (TBV), cortico-cancellous bone volume (CBV-cBV), and cortical bone surface (CBS) were evaluated. ANOVA test followed by Tukey post hoc tests were used to compare the mean continuous outcomes according to their VFGT.
Results: The whole sample showed a mean TBV of 1376.32 ± 541.01 mm^3, CBV of 468.52 ± 121.54 mm^3 and cBV of 908.73 ± 474.71 mm^3. The mean CBS amounted to 782.58 ± 146.80 mm^2.

The comparison between the groups stated a significantly different mean TBV and cBV (-p-value < 0.001). The mean CBS was significantly different (-p-value = 0.015): the smallest for the NG, but not significantly different (-p-value < 0.001): the highest for the HG, intermediate for the NG and the smallest for the hG.
Conclusion: Hypodivergent individuals have the thickest cancellous bone suitable for an onlay bone graft, while hyperdivergent individuals have the thinnest bone ideal for a 3D grafting approach.

1. Introduction

Alveolar ridge dimensional changes following tooth extraction can cause a significant challenge in the replacement of missing teeth with dental implants [1]. Therefore, bone augmentation techniques might be required in most cases.

Autogenous bone blocks, due to their high osteogenic capabilities, have been considered as one of the most reliable and frequently used procedures [2]. Extra-oral bone harvesting, from sites such as the iliac crest and calvarium, has been rarely accepted by patients due to the fact that it usually is a long operative procedure and requires a general anaesthesia [3]. On the other side, intraoral donor sites such as the chin and the mandibular retromolar region, require a less invasive surgical procedure (local anaesthesia) [4]. Furthermore, intraoral bone harvesting can guarantee enough amount of bone for localized bone defects [5].

Bone quality and quantity vary depending on the donor site which may affect the graft remodelling. Hence, the findings regarding the parasymphyseal region are limited and may differ from an individual to another [6]. Due to its both cortical and cancellous components, the interforaminal area is considered an excellent source of growth factors and mesenchymal progenitor stem cells that can accelerate bone healing time and decelerate its resorption rate [6].

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Consequently, a pre-surgical analysis of bone quantity and quality is advisable to achieve a predictable result.

Otherwise, predicting symphyseal morphology was found to be associated with the mandibular growth pattern (MGP) [7]. A previous study showed that small depth, large height and large ratio of the symphysis was associated with a posterior growth direction of the mandible [7]. On the contrary, large depth, small height and small ratio of the symphysis was associated with an anterior growth direction of the mandible. Moshfeghi et al. [8] also studied three symphyseal parameters (depth, height, and ratio) on adolescents to assess it with different MGP and found a direct relationship between these parameters.

Nowadays, CBCT is the most used technique for pre-surgical bone volume assessment since it produces an accurate three-dimensional reconstruction with low radiation doses [9]. Additionally, the introduction of computer-aided design software improved the surgeon's ability to quantify the donor site's different parameters such as bone volume, surface, and cortico-cancellous bone proportions. Hence, Pre-operative surgical planning based on the reported information can be beneficial in avoiding per-operative complications and reducing surgery time.

The objective of the present study was to volumetrically assess the bone components (cortical and cancellous) of the mandibular interforaminal region according to different VFGT which can be a helpful pre-surgical diagnostic tool of the chin as a potential bone donor site.

2. Materials and methods

Sixty CBCT records were selected from the radiology department of Saint-Joseph University dental school. The present study was approved by the university institutional review board (USJ-2020-137) and all the involved patients have signed an informed consent allowing the use of their data in the study. The CBCTs were acquired in the same conditions using Newtom VGI CBCT machine 15×15 field of view and 0.3 mm voxel size (QR s.r.l via Silverstrini, 20-37135-Verona, Italy). Projection data were collected with a device rotating 360 degrees around patients over a total acquisition time of 18 s.

Patients who presented one of the following criteria were excluded from the study:

- Patients under 18 years old.
- CBCTs taken with an open bite.
- Patients who underwent orthognathic surgery.
- Distorting pathologies of the facial mass.
- Periodontal or endodontic diseases affecting the bone in the interforaminal region.
- Presence of metallic artefacts in the interforaminal region.

2.1. Image evaluation

Images were first evaluated in the NNT 5.6 software (QR s.r.l via Silverstrini, 20-37135-Verona, Italy). Axial images were re-oriented to the occlusal plane and exported as DICOM datasets.

2.2. VFGT determination

DICOM files were imported and loaded into the Blue Sky Plan® 4,5 (Blue Sky Bio, LLC, Grayslake, IL, USA) software and cephalometric mode was selected.

Modified Steiner measurement bundle was used in order to measure the SN-GoGn angle (Fig. 1). Patients were divided into three groups according to the obtained angle value; hG consisted of individuals with less than 27 degrees angle, NG contained individuals with a value lying between 27 and 37 degrees while the HG included individuals who recorded a greater value than 37 degrees. The sample consisted of 24 males and 36 females with a mean age 34.03 ± 7.615 years. The mean ages for males and females were 37.43 ± 5.514 and 30.42 ± 3.675 years respectively.

2.3. 3D volumetric measurements

For each patient, DICOM files were imported and loaded into ITK-snap software v 3,6 [10].

In order to perform volumetric measurements of the interforaminal harvestable zone, a custom region of interest

Fig. 1. SN-GoGn angle measurement on a CBCT based Cephalogram.

(ROI) was defined in 3D which presented a shape of a smaller rectangular box over a larger rectangular box. The margins were drawn as follow:

The larger rectangular box margins:

- Cranial: 5 mm caudally from the longest canine root.
- Distal: 5 mm medially from the mental foramina.
- Caudal: 5 mm cranially from the basal bone caudal border.
- Lingual: 2 mm bucally from the lingual cortex.
- Buccal: The apparent buccal surface of the interforaminal zone.

The smaller rectangular box margins:

- Cranial: 5 mm apically from the longest incisal root apex.
- Distal: 3 mm medially from the canine root.
- Lingual: 2 mm buccally from the lingual cortex.
- Buccal: The apparent buccal surface of the interforaminal zone.

A semi-automatic density based active contour segmentation was done for the ROI's cortical bone (green label) and then for the cancellous bone (yellow label) (Fig. 2). Each segmentation was rechecked manually on every single slice (0.3 mm interval) in order to add or remove any undesired voxel selection using the brush and the polygon tools [10].

The volume of the cortical and cancellous bone was then measured using the volumes and statistics tools in the software.

2.4. Cortical bone surface measurement

In order to calculate the CBS, the cortical bone segmentation was exported as STL file format and transferred to Autodesk Meshmixer® 3.5 software. The buccal cortical was selected (Fig. 3A), separated from 3D model (Fig. 3B) and the surface area was automatically calculated in the software using the Analysis/Stability tool (Fig. 3C).

2.5. Statistical analyses

The statistical package software for social sciences (SPSS for Windows, Chicago, IL, USA, version 25.0) was used for statistical analyses of the data. The type I error was set at 0.05.

Intra-operator reproducibility was evaluated using the intra class correlation coefficient (ICC) with 95% confidence interval; the ICC for all measurements were superior to 0.980 indicating an excellent reproducibility.

Kolmogorov–Smirnov tests were performed to assess the normality distribution of continuous variables. ANOVA followed by Tukey post hoc tests were executed to compare the mean continuous outcomes according to facial topology.

3. Results

3.1. General population parameters

The mean, minimum, maximum and standard deviation values of cortical, cancellous and total bone volume in addition to the

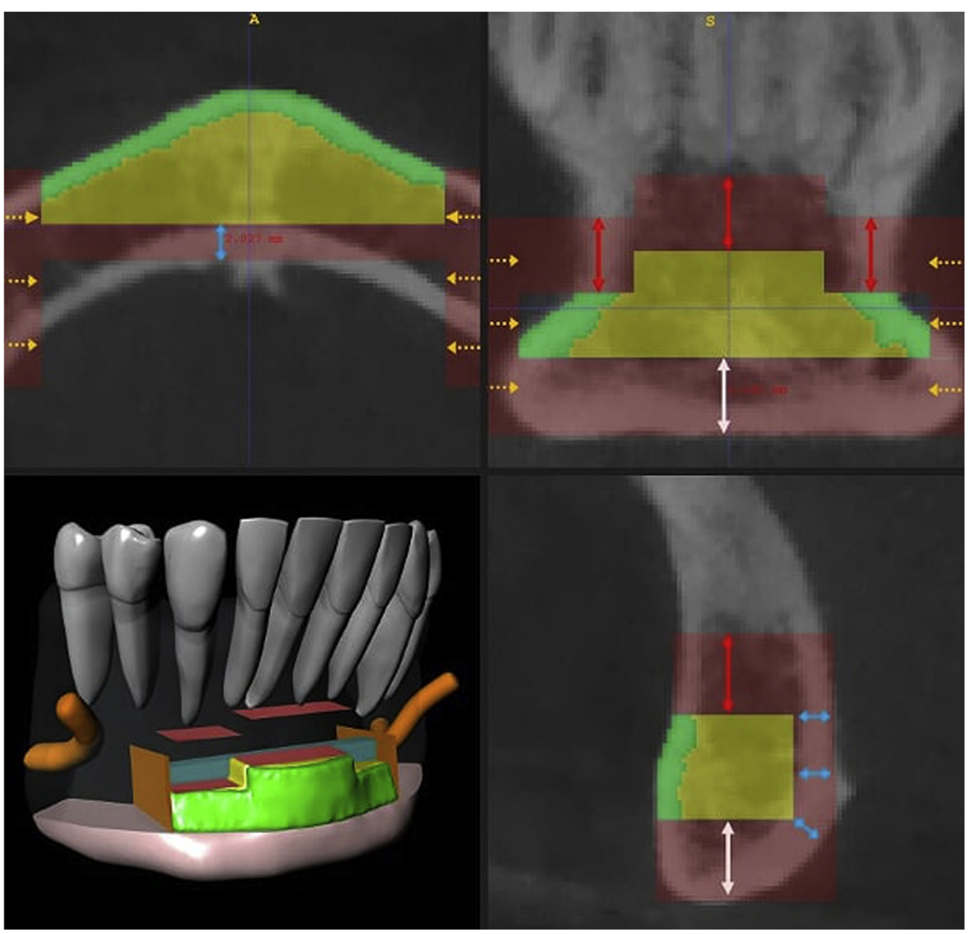

Fig. 2. Bone graft safety margins in different views (A: Axial, B, Coronal, C, Sagittal, D, 3D). Total safety margins highlighted in red in the 2D views; Red arrows and planes: 5 mm safety from root apices; Blue: 2 mm from lingual cortical; Pink: 5 mm from basal bone caudal border; Orange: 5 mm medial projection from the mental foramina; Green: cortical bone label; Yellow: Cancellous bone label.

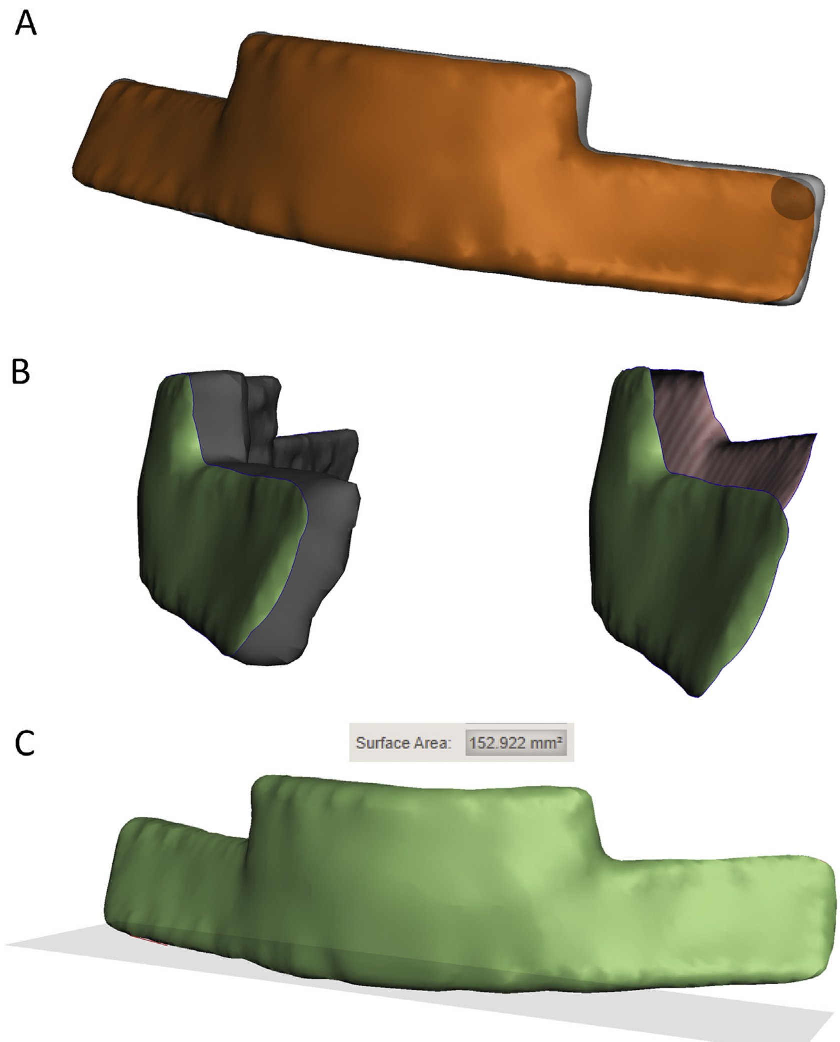

Fig. 3. Surface area assessment of the graft using Autodesk Meshmixer®. A: Cortical part of the graft imported to Autodesk Meshmixer and the surface of the graft was selected (in orange), B: Lateral view showing the selection and isolation of the surface, C: Calculation of graft surface area in mm^2.

cortical bone surface of the population ($N = 60$) are displayed in the Table 1

3.2. Comparison of TBV, CBV, Cbv and CBS according to VFGT

The mean, standard deviation, minimum and maximum values of total, cortical and cancellous bone volume in addition to the cortical bone surface for each group are displayed in the Table 2. The mean CBV was not significantly different among the groups (-p-value = 0.161).

The mean cBV was significantly different (-p-value < 0.001): The HG had the smallest value; the hG had the greatest one and the NG was in between. The mean TBV was also significantly different among the groups (-p-value < 0.001); it was the smallest in the HG, intermediate in the NG and the highest in the hG (Table 2). As for the CBS, The mean surface was significantly different among groups (-p-value = 0.015); it was smaller for NG, and the difference was not significant between hG and HG (p-value = 0.976).

4. Discussion

The perpetual need to find a sustainable bone source for bone augmentation, lead the authors to investigate intra-orally what is considered today as the most predictable autogenous source for pre-prosthetic oral rehabilitation.

Table 1
Different measured parameters of the general population.

	N	Mean value	Std. deviation	Minimum	Maximum
Cortical bone volume ($mm^{3)}$)	60	468.52	121.54	156.00	773.40
Cancellous bone volume (mm^3)	60	908.73	474.71	908.73	1851.10
Total bone volume(mm^3)	60	1376.32	541.01	462.50	2451.20
Percentage of cancellous bone volume (%)	60	63	12	34	88
Cortical bone surface (mm^2)	60	782.58	146.80	424	1193

Table 2
Mean bone components volumes and surface for different groups.

		N	Mean Value	Std. Deviation	Minimum	Maximum	*p*
Cortical bone volume (mm^3)	Hypodivergent	20	508.96	142.37	156.00	773.40	0.161
	Normodivergent	19	436.59	112.45	234.40	640.99	
	Hyperdivergent	21	458.89	101.17	256.00	600.80	
Cancellous bone volume (mm^3)	Hypodivergent	20	1473.13^c	260.06	1000.00	1851.10	<0.001
	Normodivergent	19	832.97^b	189.83	478.80	1173.40	
	Hyperdivergent	21	439.76^a	114.81	206.50	644.40	
Total bone volume (mm^3)	Hypodivergent	20	1982.08^c	370.88	1256.00	2451.20	<0.001
	Normodivergent	19	1269.03^b	287.24	713.20	1806.00	
	Hyperdivergent	21	896.48^a	197.14	462.50	1199.00	
Percentage of cancellous bone volume (%)	Hypodivergent	20	74.66%^{c}	4.483%	65%	88%	<0.001
	Normodivergent	19	65.68%^{b}	3.655%	58%	71%	
	Hyperdivergent	21	48.82%^{a}	5.532%	34%	58%	
Cortical bone surface (mm^2)	Hypodivergent	20	823.931	98.929	537.61	954.00	0.015
	Normodivergent	19	703.316	133.279	424.00	958.00	
	Hyperdivergent	21	814.905	171.802	451.00	1193.00	

a,b,c: different letters indicate the presence of significant difference with Tukey post hoc tests.

The mandibular interforaminal area is considered as an intriguing site due to its dual cortico-cancellous origin [6].

However, inter-individual anatomical variations alike different facial growth patterns seem to have a direct impact on the bone quantity and quality in the symphyseal region [7].

Hence, the evolution in dento-maxillofacial radiology had a direct impact on the practitioner decision-making: At first, the surgeon had to adapt the grafting technique to the available bone volume per-operatively based on limited 2D informative resources. Nowadays, the introduction of computed tomography and more recently the computer aided design software, has allowed the quantification of bone volume and its cortico-cancellous proportions [10], thus preventing unexpected per-operative complications.

4.1. General population values

According to the results of the present study, the whole population sample ($N = 60$) showed an important standard deviation of the TBV (1376.32 ± 541.01 mm^3) and the cBV (908.73 ± 474.71 mm^3) values. Such fluctuations, coupled with the sophisticated quantification techniques, can make the oral surgeon reluctant in considering the interforaminal area as a choice for bone grafting.

Correspondingly, and according to Swasty et al. [7] who attributed the symphyseal diverse body shapes to the VFGT, the general population was divided into three groups according to their VFGT.

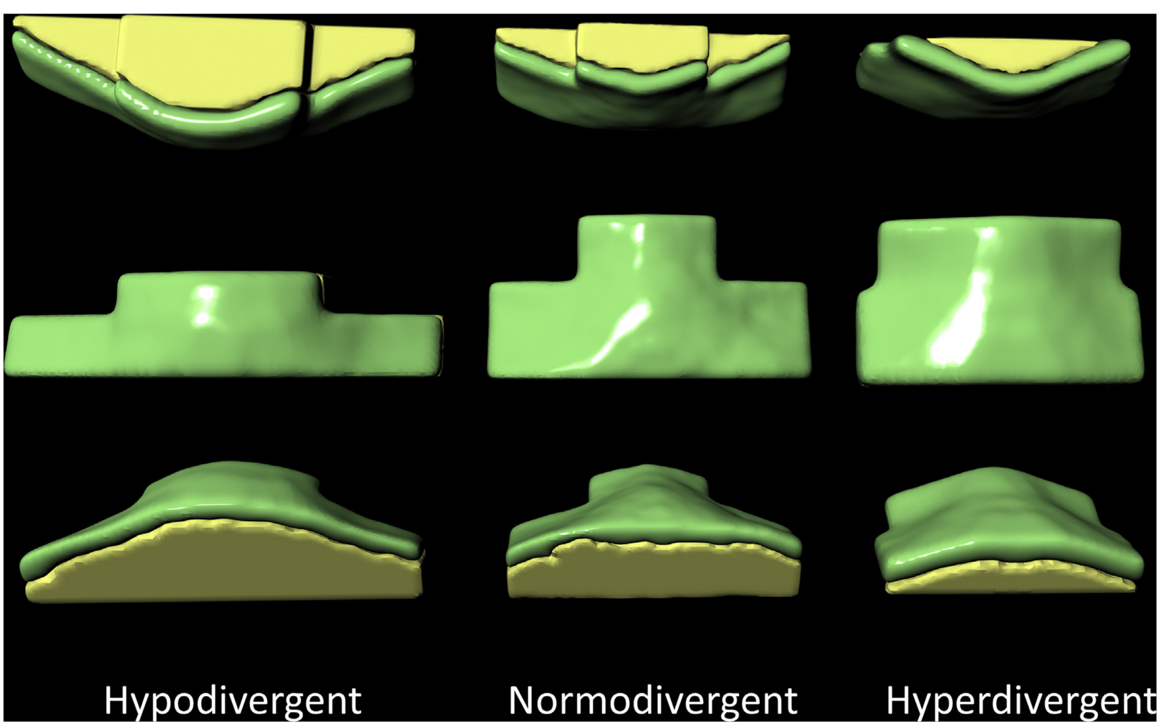

Fig. 4. The harvestable bone graft according to the vertical facial growth types. Harvestable grafts in hypodivergent type tend to have a wider width and shorter surface height compared to the other types (middle frontal view), and thicker/higher proportion of cancellous bone (upper and lower views).

4.2. Comparison of bone characteristics in different VFGT

The patients included in the HG group showed the lowest mean TBV (896.48 ± 197.14 mm^3) and the lowest mean percentage of cBV (48.82% ± 5.53%) among the others. However, the CBS mean value in this group was similar to the hG but higher than the NG.

It is important to note that in HG cases, the maxillary growth advances caudally while the mandibular vertical ramus height is increased. The mandible main reaction is to insure the intracuspal contacts which leads to an augmentation of the molar region vertical position. Due to these changes and to the mandibular clockwise rotation, the anterior gap between teeth may increase causing the anterior dento-alveolar complex to grow cranially in an attempt to fill this gap. The result is a stretched symphysis where the vertical dimension is increased, and the depth is less pronounced in comparison with the other facial types.

Elsewhere, the individuals in the hG showed the highest harvestable BV (1982, 08 ± 370, 88 mm^3) and the highest mean percentage of cBV (74, 66% ± 4483%) among the three facial types. As for the CBS, the mean value was higher than the NG group but similar to the HG group. It can be explained by the thick crest which allows the bone graft margins to be extended horizontally thus giving it a bigger surface value (Fig. 4). Consequently, the clinician is able to extend the osteotomy borders to the premolar area thus allowing him to reconstruct a larger defect.

Finally, the subjects included in the NG group recorded a mean TBV (1269.03 ± 287.24 mm^3) that stand in between the two other groups values. The same applies for cBV mean percentage (65.68% ± 3.655%). This indicates that the harvestable bone thickness is acceptable for this group. Interestingly, they recorded the lowest CBS mean value (703.316 ± 133.279 mm^2). This can be explained by an intermediate bone crest height and thickness usually found in individuals with a NG typology.

Nevertheless, there was no statistical difference between the CBV of the three investigated groups. A previous study reported similar results [7]. This might be explained by the fact that both bone height and thickness can have a direct effect: an increased bone height in the HG group is counterbalanced by an elevated bone thickness in the hG (Fig. 4).

4.3. Comparison with other studies

Whereas previous computed volumetric studies investigated the available bone volume in the interforaminal area, they have not considered the vertical growth patterns that may affect the pre-operative individual assessment.

There was a large variation in the selection of the region of interest amid different studies. In most of them, the margins of the limits used were impractical and neither safe nor adapted to the clinical practice. A single study done by Verdugo et al. [6], followed a logical path, taking into consideration a realistic surgical osteotomy design.

Altug et al. [11] investigated the available bone volume in the mandibular interforaminal safe zone area. The bone block harvesting was done without considering the strict safety margins and the practical osteotomy linear limits. Consequently, they recorded a mean bone volume of 2616.45 mm^3 which is almost double the value of the present study (1376.2 ± 541.01 mm).

Elsewhere, Zeltner et al. [5], used CBCT records to study the volumetric amount of available bone in the symphysal and the ramal areas of the mandible. They stated a mean volume of 3500 ± 1300 cm^3 [5]. Nevertheless, the used safety margins limits were exaggerated (2 mm from the lingual surface of the mandible and 2 mm from the inferior border of the mandible) since they may lead to uneventful surgical complications such as mandible fracture and sublingual haematoma. In the same manner, block mobilization will become more difficult since the safety margin limits may reach the lingual cortex.

Di Bari et al. [12], divided the quantified bone into cortical and cancellous bone. The safety margins limits (the 5's rules) were identical to those used in Yavuz and Altug's study. They reported respectively a mean cortical and cancellous volumes of 710 ± 23 mm^3 and 2160 ± 76 mm^3. Whereas, the mean volumes registered in the present study were respectively 468.52 ± 121.54 mm^3 and 908.73 ± 474.71 mm^3. Having a nearly similar values of cortical bone and different values of cancellous bone, might be related to the different osteotomy cut angles; more precisely, at the lower third of the mandible where they marked all the cancellous bone without taking in consideration the surgical limitations.

Interestingly, Verdugo et al. [6] showed the closest results to the present study. They compared the pre-operative computer assisted measurements to the values of the clinically harvested blocks during the surgery. They measured a mean harvestable bone of 1400 mm^3. There was a statistically significant divergence in the volume values in their results which they correlated with the bucco-lingual thickness of the graft. Such divergence seems appropriate, since the used methodology was based on a realistic application of the 5's rule safety margins, such as straight osteotomy lines. However, the noticed divergence in their results, can be related to the strong influence of the facial typology as demonstrated in the current study.

Finally, the present volumetric investigation clearly demonstrated a variability among the three vertical facial growth types. Subsequently, the oral surgeon should assess pre-operatively the donor site in order to retrieve a sufficient bone volume in accordance with the desired bone augmentation technique.

4.4. Comparison with other donor sites

Although accurate comparison between different sites might not be possible due to the variability in the applied methodology and safety margins, the interforaminal site offers a limited amount of bone that can only rehabilitate a limited defect (2 to 6 teeth) [13]. The ascending ramus showed in a dry skull study almost twice (2360 mm^3) the harvestable bone volume when compared to interforaminal zone [14].

Recently, a computed tomography study comparing the harvestable bone volumes between calvarial, ramal and interforaminal zone of the same patient confirmed the superiority of the calvaria [13].

As for the post-operative complications, the interforaminal site might not be the ideal bone donor site due to the post-operative complications such as labial and teeth-neuro-sensitive deficiencies, lower face deformities and wound dehiscence [3].

4.5. Clinical implications

Within the limitations of the present study, it can be concluded that:

- Surgeons should take into consideration the patients VFGT when planning the surgical bone grafting technique.
- Patients with a hypodivergent facial typology, tend to have thick harvestable cortico-cancellous bone in the symphyseal area thus suitable for an onlay bone graft approach. Additionally, a large bone surface, extended horizontally allows the surgeon to treat large-segment defects.
- Patients with a hyperdivergent facial typology tend to have thin harvestable bone combined to a large surface, extended vertically, thus ideal for a 3D grafting approach.

- Patients with normodivergent facial typology, tend to have intermediate size harvestable bone blocks suitable for moderate bone defects.
- Consequently, harvestable interforaminal bone enable the surgeon to deal with reasonable bone defects; larger defects require either extra-oral or more invasive intra-oral donor sites.

4.6. Study limitations

Many parameters should be addressed in future studies such as other growth patterns, teeth positions, comparison of different donor sites to elucidate the exact volumes, surface and factors affecting its fluctuation.

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Declaration of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jormas.2021.02.003.

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