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Original Article

Digital evaluation of the zygomatic buttress intra-oral donor site dimensions in different vertical facial growth types

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Purpose: This study investigates the influence of vertical facial growth patterns on the morphology of the zygomatic buttress (ZB) donor site and its implications for preoperative planning in bone grafting.
Materials and methods: A total of 100 adult Cone beam computed tomography (CBCT) scans were analyzed and categorized into hypodivergent, normodivergent, and hyperdivergent groups based on SN-GoGn angles. Three-dimensional ZB models were created using semi-automatic segmentation, with key parameters—volume, surface area, thickness, and anteroposterior protrusion—measured using stable anatomical landmarks. Statistical analyses included descriptive statistics, one-way analysis of variance (ANOVA), Tukey's post-hoc tests, and Kruskal-Wallis H tests where necessary. A p-value < 0.05 was considered statistically significant.
Results: ZB morphology varied significantly across facial growth types. Hypodivergent faces exhibited the highest bone volume (533.25 ± 129.58 mm^3), surface area (560.70 ± 99.76 mm^2), total thickness (4.68 ± 1.91 mm), and bulge thickness (9.75 ± 2.51 mm). Normodivergent faces showed intermediate values for bone volume (394.39 ± 141.62 mm^3), surface area (504.27 ± 108.54 mm^2), and thickness (2.79 ± 1.05 mm total, 5.42 ± 2.45 mm bulge). Hyperdivergent faces had the lowest bone volume (259.00 ± 86.28 mm^3), surface area (422.64 ± 95.59 mm^2), total thickness (1.70 ± 0.49 mm), and bulge thickness (3.57 ± 1.66 mm). Anteroposterior protrusion also differed significantly, with hypodivergent faces showing the largest protrusion (21.56 ± 3.24 mm).
Conclusion: The ZB is a reliable donor site with morphology influenced by facial growth patterns. Preoperative radiographic assessment facilitates optimized surgical planning and tailored grafting strategies.

1. Introduction

Dental implant placement is a surgical procedure used for the replacement of a single or multiple missing teeth. Even though this surgical treatment can restore function and esthetics, it is subject to many challenges such as inadequate alveolar ridge shape and size in the implantation site [1]. Therefore, bone graft procedures are often required in order to rebuild an appropriate bone width and height prior to the implant placement [2].

Multiple bone grafting substitutes have been identified but the autogenous bone is considered as the most reliable and frequently used substitute for alveolar ridge regeneration [2]. Moreover, several extra-oral donor sites are available yet intra-oral bone harvesting from sites such as the mandible ramus or the symphysis remain more common due to the fact that the surgical procedure is less invasive, highly successful and can be done under local anesthesia [3–5].

More recently, the zygomatic buttress (ZB) has emerged as a potential autogenous bone donor site showing many promising results [6,7]. The ZB is a convex bony landmark situated in the posterior maxilla cranially to the first and second molar at the junction

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between the maxillary process of the zygomatic bone and the zygomatic process of the maxilla [8]. This region is made of cortical bone exclusively. Gellrich et al., have considered ZB as an ideal source for bone harvesting in order to restore small to medium-sized alveolar ridge defects showing many advantages such as good bone quantity and quality, convex morphology and easy access [8]. In addition, the surgical grafting procedure for the reconstruction of atrophic maxilla using ZB blocks can be less invasive and done using only one flap due to ZB proximity from the recipient site and reducing therefore the operative time [9].

The dimensions of the harvested ZB block can dictate the grafting technique, when thick enough, the ZB block can be used as an onlay graft where a full contact between grafted bone and recipient site is considered mandatory for a successful healing [7]. However, when facing a thin shell, The Containment and Contouring technique (CoCoon) should be used[10]. The latter technique introduced by Gellrich et al. came as a new alternative using a composite graft [10]. It relies on using the convex shape-giving outer bone graft to establish a free space that can be filled with scraped bone particles creating by that an inner three-dimensional matrix [10].

The inter-patient variability of the donor's site bone quantity and shape can complicate the intra-operative decision making of the surgeon and thus compromise the final outcome [11,12]. Therefore, a successful ZB blocks bone graft relies on an adequate pre-surgical analysis of the morphology of the donor site using the right diagnostic tools in order to achieve a predictable result.

The aim of our study is to radiographically assess the bone quantity and morphology in the ZB site in addition to investigate a possible link between the varying morphology and the vertical facial growth types.

2. Materials and methods

2.1. Population selection

The CBCT scans acquiring method and used software were identical to the used ones in the authors previously published articles in the same field [11,12].

100 CBCT scans were selected from the Saint-Joseph University dental school radiology archive where all the patients have signed an informed consent allowing researchers to use their data in future studies. The present study was approved by the university institutional review board (USJ-2022-180).

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° 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.
- Patients who underwent orthognathic surgery or orthodontic treatment involving the maxilla.
- Distorting pathologies of the facial mass.
- Periodontal or endodontic diseases affecting the bone in the posterior maxilla
- Presence of metallic artefacts in the posterior maxilla region.
- Extracted molar or premolar in the region of interest.

2.2. 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.

2.3. Vertical facial typology classification

Each CBCT scan was imported to the imaging software (BlueSky Plan, BlueSky Bio, USA), a CBCT based lateral cephalometric image was then generated and orthodontic landmarks were placed by an orthodontist.Finally using the modified Steiner package, The SN-GoGn angle was measured and the population was divided in three groups according to Steiner et al. classification [13]:

- Hypodivergent group included individuals with angles less than 27 degrees.
- Normodivergent group comprised those with angles between 27 and 37 degrees.
- Hyperdivergent group consisted of individuals with angles greater than 37 degrees.

2.4. Three-dimensional segmentation and volumetric measurements

For each patient, DICOM files were imported and loaded into ITK-snap software v 4.2.2 (ITK-snap, USA). In order to perform volumetric measurements of the maxillary zygomatic buttress harvestable zone, a custom region of interest (ROI) was defined in 3D which presented a square shape. The borders were selected as follow:

Caudally: 3 mm from the highest apex of the posterior maxilla region.

- Cranially: 10 mm from the highest apex of the posterior maxilla region.
- Anteriorly: 5 mm from the middle of radiographic bulge of the buttress.
- Posteriorly: 5 mm from the middle of radiographic bulge of the buttress.

A semi-automatic density based active contour segmentation was done for the ROI's bony structure (Fig. 1).

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.

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

2.5. Shape differentiation

Following the segmentation, the whole sample was divided in 4 groups based on its appearance (Fig. 2):

- Thick pyramidal.
- Thin pyramidal.
- Thick rectangular.
- Thin rectangular.

2.6. Surface and bulge protrusion measurements

The bone segmentation was exported as STL file format and transferred to the Meshmixer software (Meshmixer v13.5; Autodesk research) where the bulge protrusion was automatically measured in millimeters. In order to measure the surface, the buccal cortical was selected, separated from 3D model and automatically calculated in the software using the Analysis/Stability tool.

As for the anterior bulge, the xyz orientation of the software was used, the protrusion was considered a horizontal variate therefore the x parameter was used.

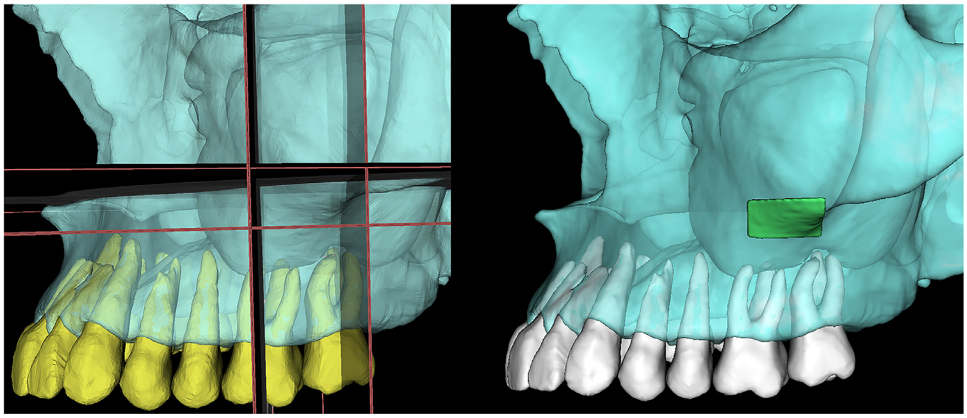

Fig. 1. A software based three-dimensional reconstruction of the region of interest at the zygomatic buttress zone.

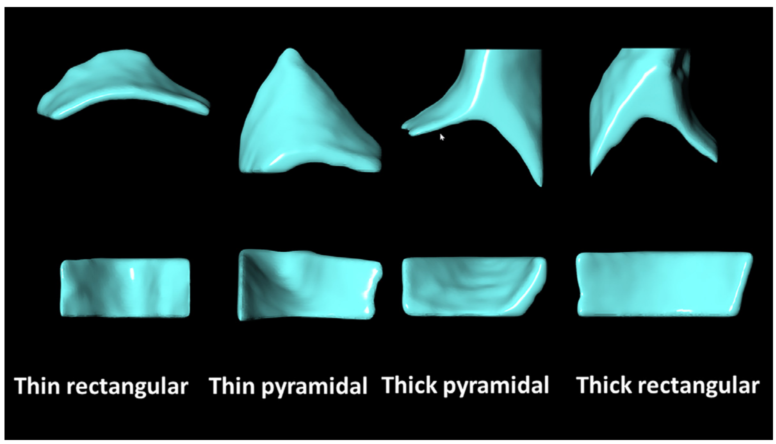

Fig. 2. A software based three-dimensional reconstruction of different harvestable bone graft shapes.

2.7. Thickness measurements

The inner and outer surfaces of the shell were selected and separated using the Meshmixer software, then they were exported separately in STL format and imported to a mesh-to-mesh measurement software (Cloudcompare, EDF R&D Energy research and development, France). The STL files were transformed to meshes and the distance between them was automatically calculated using the mesh to mesh compare option. The value was given in millimeter.

2.8. Statistical analysis

A descriptive statistical analysis was first carried out to describe the sample using the following characteristics: age (quantitative continuous), sex (dichotomous) as well as the bone pattern (qualitative nominal variable with four modalities: pyramidal thin, thick pyramidal, thin rectangular and thick rectangular). Quantitative variables are presented as means and standard deviations; and the qualitative variables are presented by their frequencies and their percentages.

Table 1
General population metrics.

	Minimum	Maximum	Mean	SD
Volume (mm^3)	142.50	712.80	402.41	165.41
Surface (mm^2)	300.14	867.85	496.37	117.64
Anteroposterior Protrusion (mm)	10.30	28.13	18.76	4.24
Total mean thickness (mm)	1.02	8.75	3.13	1.81
Bulge mean thickness (mm)	1.71	14.91	6.40	3.45

Bivariate analysis was performed to assess potential statistically significant relationships between the outcome variable (bone pattern) and the various independent variables, including bone volume, area, anteroposterior protrusion, mean total thickness, and bulge mean thickness. To do this, a one-way analysis of variance (ANOVA) test was used along with Tukey's post-hoc test; and Kruskal-Wallis' H-test when ANOVA assumptions were violated. A P value of <0.05 was considered statistically significant. Statistical analysis was performed with IBM SPSS Statistics 25.

3. Results

3.1. Descriptive statistics

One hundred (n = 100) participants were included in the study. The sample consisted of 52 women and 48 men; and the mean age of participants was 27.81 (SD = 6.53). Regarding bone patterns: 45 % of participants had thin rectangular bone, 21 % thick rectangular, 15 % thin pyramidal, and 19 % thick pyramidal. The characteristics of the different bone patterns in our sample are presented in Table 1 (Table 1).

3.2. Bone metrics based on the shape

3.2.1. Bone volume

- The bone volume varies significantly (p < 0.001) between the different bone patterns except between the thin pyramidal and the

Table 2
Bone metrics based on graft shape.

	Pyramidal		Rectangular		P-value
	Thick	Thin	Thick	Thin	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	< 0.001
Volume (mm^3)	616.63 ± 83.67^{abc}	476.38 ± 112.53^{ad}	440.08 ± 96.69^{be}	269.72 ± 100.27^{cde}	< 0.001
Surface (mm^2)	568.81 ± 66.05^{a}	563.50 ± 93.77^{b}	560.15 ± 124.99^{c}	422.64 ± 95.59^{abc}	< 0.001
Anteroposterior Protrusion (mm)	24.15 ± 1.81^{abc}	22.27 ± 1.67^{ade}	18.93 ± 1.52^{bdf}	15.24 ± 2.77^{cef}	< 0.001
Total mean thickness (mm)	6.00 ± 1.58^{abc}	3.49 ± 0.96^{ad}	3.19 ± 0.76^{be}	1.77 ± 0.53^{cde}	< 0.001
Bulge mean thickness (mm)	11.71 ± 1.22^{abc}	7.64 ± 1.52^{ad}	7.50 ± 1.54^{be}	3.24 ± 0.93^{cde}	< 0.001

*Same lowercase letters indicate significant differences between pairs bone patterns ($p < 0.05$).

thick rectangular whose respective bone volumes do not show statistically significant differences ($p > 0.05$) (Table 2).

- Thick pyramidal bone was found to have the highest mean volume (with a mean of 616.6 3mm^3 and a SD of 8 3.67mm^3) among the different bone patterns, and that is significantly different from all other mean bone pattern volumes ($p < 0.001$) (Table 2).
- Thin rectangular bone was found to have the lowest mean volume (with a mean of 269.72mm^3 and a SD of 100.27mm^3) among the different bone patterns, and that is significantly different from all other mean bone pattern volumes ($p < 0.001$) (Table 2).

3.2.2. Bone surface

- Statistically significant differences were observed between thin rectangular bone mean surface and the other bone patterns surfaces ($p < 0.001$), with thin rectangular bones presenting the lowest bone surface mean (with a mean of 422.64mm^2 and a SD of 95.59mm^2) (Table 2).
- No statistically significant differences were found between the thick pyramidal, thin pyramidal and thick rectangular bone surfaces' means ($p > 0.05$) (Table 2).

3.2.3. Anteroposterior protrusion

- The anteroposterior protrusion differs significantly between the different bone patterns ($p < 0.001$), with thick pyramidal bones having the highest anteroposterior protrusion (with a mean of 24.15 mm and a SD of 1.81 mm), followed by thin pyramidal bones (with a mean of 22.27 mm and a SD of 1.67 mm), thick rectangular bones (with a mean of 18.93 mm and a SD of 1.52 mm) and thin rectangular bones (with a mean of 15.24 mm and a SD of 2.77 mm) (Table 2).

3.2.4. Total mean thickness and bulge mean thickness

- Total mean thickness and bulge mean thickness vary significantly between the different bone patterns except for the thin pyramidal and thick rectangular bones that present no statistically significant differences in terms of total mean thickness and bulge mean thickness ($p > 0.05$) (Table 2).
- Pyramidal thick bones were found to have the highest total mean thickness (with a mean of 6.00 mm and a SD of 1.58 mm) and bulge mean thickness (with a mean of 11.71 mm and a SD of 1.22 mm) and that are is statistically different than total and bulge mean thicknesses of other bone patterns ($p < 0.001$) (Table 2).
- Thin rectangular bones were found to have the lowest total mean thickness (with a mean of 1.77 mm and a SD of 0.53 mm) and bulge mean thickness (with a mean of 3.24 mm and a SD of 0.93 mm), and that are statistically different than total and bulge mean thicknesses of other bone patterns ($p < 0.001$) (Table 2).

3.3. Bone metrics based on face typology

3.3.1. Bone volume

- The bone volume significantly differs between the three face typologies ($p < 0.001$), with hypodivergent typology having the highest mean volume (with a mean of 53 3.25mm^3 and a SD of 129.58mm^3), followed by normal (with a mean of 394. 39mm^3 and a SD of 141.62mm^3) and hyperdivergent typologies (with a mean of 259.00mm^3 and a SD of 86.28mm^3), respectively (Table 3).

3.3.2. Bone surface

- The bone surface significantly differs between the hypodivergent typology and the two other typologies ($p < 0.001$), with the

Table 3
Bone metrics based on face typology.

	Face typology						P-value
	Hypodivergent		Normal		Hyperdivergent		
	Mean	SD	Mean	SD	Mean	SD	
Volume (mm^3)	533.25^{ab}	129.58	394.39^{ac}	141.62	259.00^{bc}	86.28	<0.001
Surface (mm^2)	560.70^{ab}	99.76	489.65^{a}	122.13	428.79^{b}	91.71	<0.001
Anteroposterior Protrusion (mm)	21.56^{ab}	3.24	18.66^{ac}	3.56	15.62^{bc}	3.72	<0.001
Total mean thickness (mm)	4.68^{ab}	1.91	2.79^{ac}	1.05	1.70^{bc}	0.49	<0.001
Bulge mean thickness (mm)	9.75^{ab}	2.51	5.42^{ac}	2.45	3.57^{bc}	1.66	<0.001

*Same lowercase letters indicate significant differences between pairs bone patterns ($p < 0.05$).

hypodivergent typology having the highest mean surface (with a mean of 560.70mm^2 and a SD of 99.76mm^2) (Table 3).

- No significant differences were observed between bone mean surfaces of normal and hyperdivergent typologies.

3.3.3. *Anteroposterior protrusion*

- The anteroposterior protrusion significantly differs between the three face typologies (p < 0.001), with hypodivergent typology having the highest mean volume (with a mean of 21.56 mm and a SD of 3.24 mm), followed by normal (with a mean of 18.66 mm and a SD of 3.56 mm) and hyperdivergent typologies (with a mean of 15.62 mm and a SD of 3.72 mm), repectively (Table 3).

3.3.4. *Total mean thickness and bulge mean thickness*

- Total mean thickness and bulge mean thickness vary significantly between the different face typologies (p < 0.001) (Table 3).
- Hypodivergent faces were found to have the highest total mean thickness (with a mean of 4.68 mm and a SD of 1.91 mm) and bulge mean thickness (with a mean of 9.75 mm and a SD of 2.51 mm) and that are statistically different than total, and bulge mean thicknesses of other face typologies (p < 0.001) (Table 3).
- Hypodivergent faces are followed by those presenting a normal typology with a total mean thickness of 2.79 mm and a SD of 1.05 mm and bulge mean thickness of 5.42 mm and a SD of 2.45 mm (Table 3).
- Hyperdivergent faces were found to have the lowest total mean thickness (with a mean of 1.70 mm and a SD of 0.49 mm) and bulge mean thickness (with a mean of 3.57 mm and a SD of 1.66 mm), and that are statistically different than total, and bulge mean thicknesses of other face typologies (p < 0.001) (Table 3).

3.3.5. *Bone shape*

A statistically significant relationship was identified between the face typology and bone pattern (p < 0.001). For instance:

- Hypodivergent faces present only thick bone patterns that were distributed as follows: 52.8 % thick pyramidal (only observed in hypodivergent faces) and 47.2 % thick rectangular (Table 4).
- The majority (90.9 %) of bones in faces with a normal typology are thin (39.4 % being thin pyramidal and 51.5 % thin rectangular) and only 9.1 % are thick. None of the faces with a normal typology had a thick pyramidal bone (Table 4).
- The majority (90.3 %) of faces with a hyper divergence were found to have a thin rectangular bone, only one case of thick rectangular was observed in this category, two cases of thin pyramidal bones and none had a thick pyramidal bone (Table 4).

Table 4
Bone graft shape based on facial typology.

	Face typology			P-value
	Hypodivergent N (%)	Normal N (%)	Hyperdivergent N (%)	
Bone pattern				<0.001
Thin pyramidal	0 (0)	13 (39.4)	2 (6.5)	
Thick pyramidal	19 (52.8)	0 (0)	0 (0)	
Thin rectangular	0 (0)	17 (51.5)	28 (90.3)	
Thick rectangular	17 (47.2)	3 (9.1)	1 (3.2)	

4. Discussion

The zygomatic buttress site is widely regarded as an easily accessible area with low postoperative morbidity [8]. However, one of the primary difficulties faced by surgeons in this region is the considerable variation in graft dimensions. These variations can profoundly affect the choice of bone grafting technique. According to previous studies, the vertical growth patterns of the maxillofacial complex are a key factor contributing to these variations [11,12,14].

Consequently, the aim of this article was to quantify and classify the maximum harvestable bone from the ZB site based on different vertical growth patterns. This was achieved using a fixed anatomical landmark and evaluating both the visual shape and numerical dimensional values.

4.1. *General population values*

In the present study, thick pyramidal bones recorded the highest mean values concerning bone volume, anteroposterior, total mean and bulge mean thickness compared to thin rectangular bones which had the lowest values of the aforementioned parameters. This significant difference can be attributed to the anatomy and shape of the bone. In fact, the pyramidal shape of the caudal ZB zone confers its superiority to the rectangular shape and explains the difference in surface. Also, the thickness of the pyramidal bone, versus the rectangular one which is thin, plays a role in the total volume of the bone. Thus, it is purely anatomical and has to do with the shape of the bone in question. On the other hand, no significant difference was shown in bone metrics between thin pyramidal bone and thick rectangular bone.

4.2. *The relation between facial typology and bone metrics*

One key finding of this study is the significant influence of vertical facial growth patterns on ZB morphology. Hypodivergent individuals demonstrated the most favorable characteristics, with greater bone volume, surface area, and thickness compared to normodivergent and hyperdivergent individuals. These results are consistent with previous studies that have shown hypodivergent facial types to have thicker and more robust craniofacial structures, which are advantageous for grafting procedures [11,12]. The greater bone volume in hypodivergent faces makes the ZB a particularly promising donor site for these patients, allowing for the use of onlay grafts with direct contact between the graft and recipient site [15]. In contrast, hyperdivergent individuals exhibited thinner and less voluminous ZB morphology, which may limit the applicability of traditional grafting techniques. For such cases, the Containment and Contouring (CoCoon) technique, which utilizes a composite graft to create a three-dimensional matrix, is a viable alternative [10]. This technique has been shown to compensate for the reduced cortical thickness in hyperdivergent patients, ensuring stable outcomes even with limited bone availability.

These results suggest that different facial growth patterns appear to have an influence on bone quantity and quality. Actually, in hyperdivergent faces, the maxilla grows caudally whereas the mandibular ramus increases in height due to the mandibular clockwise rotation. As a result, the anterior dento-alveolar complex undergoes changes to compensate, leading in an elongated ZB in the vertical dimension and a decrease in depth when compared to other face typologies [14,16]. This explains why hypodivergent faces have thick bone patterns and normodivergent and hypodivergent have mostly thin bone patterns.

4.3. *Comparison with other studies and sites*

To the authors knowledge, no radiographic study assessing the bone metrics of the ZB in general or according to different vertical facial typologies. However cadaveric and clinical studies mentioned a mean thickness of 2.1 mm and a surface of 167.67 mm^2 which is close to our observed results bearing in mind the clinical harvesting techniques and the used instruments [3,17]. Compared to other sites influenced by the facial typology, the ZB zone can be an easier alternative of the mandibular interforaminal and ramal zones [11,12] for hyperdivergent patients due to the difficulty of harvest and considerable surgical complications. Nevertheless, if the recipient site is mandibular and the patient is hypodivergent or normodivergent, the ZB zone is not recommended due to the need of opening two surgical sites and the sole cortical nature of this graft, which may be subject to resorption if compared to the interforaminal donor site where a fair amount of cancellous bone is present [11]. It is worth noting that the study also confirmed the need for detailed preoperative imaging and planning. The use of advanced three-dimensional imaging, as demonstrated in this study, allows for precise evaluation of donor site dimensions and facilitates the selection of the most appropriate surgical approach.

In conclusion, the ZB remains a valuable donor site, particularly for hypodivergent patients with optimal ZB morphology. By incorporating preoperative radiographic assessment and tailoring surgical approaches to individual anatomical variations, clinicians can maximize the success of grafting procedures while minimizing intraoperative challenges.

4.4. Study limitations

In order to be more conclusive concerning the ZB region variations, future studies should investigate other growth patterns and root lengths, additionally, a larger population with equal subgroups could lead to a more decisive result.

Declaration of competing interest

The authors report no conflicts of interest related to the technical note. The manuscript was not presented as part at a conference/convention/meeting.

CRediT authorship contribution statement

Ronald Younes: Data curation, Conceptualization. **Bachar Husseini:** Conceptualization. **Joseph Ryan Younes:** Visualization. **Nabil Ghosn:** Methodology. **Joe Najjar:** Investigation. **Pia EL Sayegh:** Writing – original draft. **Paul Fawaz:** Writing – review & editing. **Joseph Bouserhal:** Project administration, Writing – review & editing.

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