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Alveolar Bone Morphotype in Orthodontic Patients

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ABSTRACT

Orthodontic treatments have been described as a risk factor for the development of gingival recessions. This descriptive and cross-sectional study was performed to evaluate the alveolar bone morphotype of the upper and lower anterior of 33 orthodontic treatment of candidate patients. The images were obtained from a high-resolution cone beam computerised tomography. Then, the thickness of the alveolar bone plate of teeth was measured in six levels, recording the presence of dehiscences and fenestrations. A total of 2,334 sites were evaluated. The average thickness of the maxillary alveolar bone at the buccal surface was 0.70, 0.62 and 1.43 mm at the cervical, middle and apical levels, respectively, while in the mandibular teeth it was 0.53, 0.50 and 2.96 mm. At the palatal and lingual surfaces, the bone was thicker than the buccal except at the apical level of the mandible. Most of the examined sites were measured less than 1 mm (n = 1,235, 52.9%), associated with high prevalence of bone dehiscences (57.6%) and fenestrations (33.3%), particularly in skeletal Class III patients. The observed bone morphotype involved a high vulnerability to bone resorption, and the subsequent gingival recession occurrence, face to orthodontic movements.

Keywords: *Alveolar bone; CBCT; dehiscence; fenestration; orthodontics*

INTRODUCTION

Orthodontic tooth movements are possible due to both bone resorption and apposition that resulting from the application of forces on the dental crown. A primordial factor for this movement is the presence of enough alveolar bone thickness surrounding the root of the tooth (Iwasaki *et al.*, 2000; Ren *et al.*, 2004). Uncontrolled forces may cause pulp necrosis, radicular reabsorption and/or loss of alveolar bone (Handelman, 1996). An alveolar bone loss that results in a defect without a bony lining is called dehiscence. However, if some bone remains in the most coronary part, the defect is defined as fenestration. Dehiscence and fenestration are more commonly found in anterior than posterior teeth where only the periodontal ligament and the mucosa protect the dental root (Lindhe & Lang, 2015). The loss of marginal bone, is a precondition for the apical migration of the gingival tissue from the cementoenamel junction (CEJ), or gingival recession (GR) (Cortellini & Bissada, 2018). This is one of the reasons why orthodontic treatment is suggested to be a predisposing factor for the occurrence or progression of GR, either during (Renkema *et al.*, 2013) or after orthodontic treatment (Morris *et al.*, 2017). However, there is contradictory information related to the latter statement (Bollen *et al.*, 2008; Joss-Vassalli *et al.*, 2010; Vasconcelos *et al.*, 2012).

The presence of a thin periodontal phenotype has been described as a predisposing factor for GR (Merijohn, 2016). The gingival phenotype – characterised by the gingival thickness and the keratinised tissue width and bone morphotype – characterised by the bone thickness and its morphology, are the main parameters used to categorise periodontal phenotype (Zweers *et al.*, 2014). Most of the studies investigating the effect of periodontal phenotype over the GR in orthodontic patients only examined the soft tissues (Yared *et al.*, 2006; Rasperini *et al.*, 2015). However, due to the vulnerability of thin alveolar bone (Araújo & Lindhe, 2005; Trombelli *et al.*, 2008), previous evaluation of orthodontic candidate patients may also include the analysis of hard tissues. Conventional radiology approaches allows just a 2D analysis of the interproximal bone resulting in an incomplete treatment planning with potential negative effects on the health of periodontal tissues (Sarikaya *et al.*, 2002). Nowadays, the gold standard for the 3D study of bone morphotype is the cone beam computed tomography (CBCT) (Januário *et al.*, 2008). The CBCT has proved to be precise when measuring the alveolar bone (Fu *et al.*, 2010), showing a high sensibility and specificity in the detection of dehiscence and fenestration (Leung *et al.*, 2010). Notwithstanding the precision of the CBCT, images are better if the size of the voxel is less than or equal to 0.2 mm. This high resolution-CBCT (HR-CBCT) facilitates the evaluation of thin anatomical structures (Wood *et al.*, 2013).

Unfortunately, despite the relevance of the 3D evaluation of the bone morphotype, the literature describing the anatomy of the alveolar bone of the anterior teeth, using a HR-CBCT, is yet limited. Our aim was to evaluate the thickness of the alveolar bone at the anterior teeth and identify the prevalence of dehiscence and fenestration in orthodontic treatment candidate patients. A secondary aim was to identify the prevalence of skeletal class and their association with the prevalence of bone defects.

MATERIALS AND METHODS

For the structure of this article, the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement were followed. The CBCT images used in this descriptive cross-sectional study were requested for patient evaluations and orthodontic treatment planning at a private practice in Santiago City, Chile. HR-CBCT and profile radiographies were obtained between August and November 2014. A radiologist, selecting the CBCT images meeting our inclusion criteria, consecutively examined the images. The absence of exclusion criteria was then confirmed from clinical files. Finally, selected patients were asked for signing an informed consent to be included in the sample. None of the CBCT was requested exclusively for the present study. The following inclusion criteria were defined: Patient aged between 12 and 25 years old, with upper and lower anterior teeth without any history of previous orthodontic treatment. Criteria for exclusion included the following: Patients with systemic diseases or the use of any prescription drugs that interfere with bone metabolism processes; patients with past or present active periodontal disease; a history of previous surgical treatments in the examined area such as apicectomy, orthognathic or mucogingival surgery, extensive restorations, cavities, fractures or dental calculus at the CEJ, the presence of apical lesions, internal or external root resorption, incomplete apical closure or non-fully erupted teeth.

The HR-CBCT images were taken by using a Planmeca ProMax 3D Max device (Planmeca, Helsinki, Finland), with 12 mA, 80 kV, a 130 mm × 90 mm field of view, 22 seconds of exposure and a 0.2 mm voxel size. The carried out examinations fully met the current radioprotection principles about justification, optimisation and dose limitation. All the patients were initially examined by an orthodontist, who decided the pertinence of the radiological examination, following the ALARA (as low as reasonably achievable) principles. The radiation dose achieved was 122 uSv, which is within the stipulations of the Sedentex guidelines regarding the effective dose that patients can receive from a CBCT (https://www.sedentexct.eu/). The evaluation of 389 anterior teeth, canine (C), lateral incisor (LI) and central incisor (CI), was performed by two previously calibrated examiners (FB and AB), who analysed the images using the Romexis Viewer software programme (Planmeca, Helsinki, Finland). Each image was positioned along the main axis of the tooth, passing the sagittal plane over root's longest buccal-lingual diameter. The thickness of the alveolar bone was measured in three levels: (1) Cervical level (CeL), at the level of a line perpendicular to the tooth's main axis, traced at 2 mm from the CEJ, (2) Apical level (ApL), at the level of a line perpendicular to the tooth's main axis, passing through the root apex, and (3) Middle level (MiL), at the level of a equidistant line between the previous two (see Fig. 1). The measurements of the bone thickness were rounded to the second decimal. Six measurements of alveolar bone thickness were taken on each tooth: three on the buccal and three palatal or lingual surfaces, registering a total of 2,334 measurements. Next, the examiners recorded the presence of dehiscence and fenestration. A dehiscence was identified when the distance from the CEJ to the start of the bony crest was more than 2 mm. Meanwhile, fenestration was identified when there was an absence of bone in the measurements made at the MiL and ApL, with no bone loss at the CeL. A total of 1,556 sites were analysed for these variables. To identify the skeletal classification of the patients, a profile (Steiner, 1953) radiography was captured using a Planmeca ProMax® (Planmeca, Helsinki, Finland).

Statistical Analyses

In order to calculate the size of the sample, a GRANMO 7 calculator (Programme of Research in Inflammatory and Cardiovascular Disorders, Institut Municipal d'Investigació Mèdica, Barcelona, Spain) was used. The maximum estimated prevalence of teeth with bony defects (dehiscences) used was 43% (Yagci *et al.*, 2012). Approximately, 377 selected teeth were necessary to reach the prevalence considering 95% of confidence, a 20% power and a precision of 5%. This 377-number divided by 12 teeth per patient (8 incisors and 4 canines) gave a patient-wise sample of 31 patients. However, 33 patients accepted to participate and had the inclusion criteria.

The Kappa factor between examiners was 0.91 for the cortical measurements (high). The averages and standard deviations (SD) of the thicknesses of the alveolar bone were determined per site (i.e., cervical, middle and apical), per tooth groups (i.e., canines, lateral and central incisors) and per surface (i.e., buccal and lingual) in both maxilla and mandible. The average comparison of the alveolar bone per site and surface was made between each arch using non-parametric tests with SPSS version 24 software (IBM, NY, US). Descriptive analysis was also computed regarding to the dehiscence and fenestration per site.

RESULTS

The HR-CBCT of 33 patients (21 women and 12 men), aging from 12 to 23 years old (15.8 average age) was analysed. The majority of the patients were skeletal Class II (n = 17, 52%) followed by skeletal Class I (n = 11, 33%). About 2,334 sites were measured from 389 upper and lower anterior (canines, lateral and central incisors).

Alveolar Bone Thickness

Thickness of the alveolar bone, according to maxilla, tooth type and surface is presented in Table 1. Alveolar bone showed two zones where the average thickness was smaller; the CeL and the MiL, both on the mandible buccal surface; the maxillary buccal MiL and the lingual CeL followed them. The smallest thickness of bone was registered at the MiL on the buccal surface of the lower LI, followed by the CeL on the buccal surface of the lower canines and central incisor. On the other hand, the average thickness of the alveolar bone increased towards the apical zone, on the palatal and lingual surfaces, in a proportion of 1:2:4, on the CeL, MiL and ApL, respectively. On the buccal surface, bone thickness only increased from the MiL to the ApL, registering a 3× increase on the maxilla and a 6× on the mandible. On the other hand, the comparison between bone thickness of the CeL and the MiL in buccal surface showed a thicker bone on the CeL at the maxilla, Furthermore, in spite of we observed small differences in the thickness of bone surrounding teeth on the same jaw, bone was slightly thicker on the MiL of the central incisor and on the ApL of the lateral incisor, at the maxillary buccal surface. Meanwhile, on the palatal surface, the bone was thicker in the canines and central incisor, on the MiL and ApL. On the mandible the lingual bone was thicker in the canines whereas on the buccal surface, this thickness was similar among all lower anterior teeth.

On the other hand, the maxilla had a significantly thicker palatal bone than the buccal one, especially towards the apical zone. In the mandible, the lingual bone was also significantly thicker than the buccal on the CeL and MiL, whereas, on the ApL, bone was significantly thicker on buccal surface. The comparison between the thickness of the upper and lower alveolar bone revealed significant differences in the average thickness on the palatal surface, which was greater than the lingual on the three examined levels. On the buccal surface, the average bone thickness was also greater in the upper maxilla, on the CeL and MiL. On the contrary, in the ApL, the bone was significantly thicker in the mandible. Finally, most of examined sites measured less than 1 mm (n = 1,235, 52.9%) with the highest proportion found at the CeL, buccal and palatal/lingual (29.3% and 25.8%, respectively) followed by buccal MiL (29.1%) (see Table 2).

Dehiscence

Of the 33 patients included in this study, 19 had this defect in at least one site (57.6%), only one of those patients having 10 defects (see Table 3). Eight patients (24.2%) had dehiscences in the maxilla and 16 in mandible (49.5%). Of the 389 examined teeth, 44 presented these defects in one or more examined sites (11.3%). The prevalence in the 1,556 examined sites was 4.3% (n = 67). Regarding to the distribution of these sites, the largest number of dehiscences was founded in the mandible (n = 57, 85.1%), particularly on the buccal CeL (n = 29, 43.3%), 10 (14.9%) reaching the MiL (see Table 4). None of the dehiscences had reached the ApL.

Fenestration

Of the 33 patients included in this study, 11 had this defect (33.3%). Eight patients had them on the maxilla (24.2%) and five on the mandible (15.2%). A high percentage of patients only had one fenestration (45.6%), one patient having five defects (9.1%) (see Table 3). Of the 389 examined teeth, 24 had a fenestration in one site, showing a prevalence of 6.2% at tooth-level. The

Table 1 Thickness of the alveolar bone, according to maxilla, tooth type and surface

	Location	Teeth												Surface			
		Canines				Lateral incisors				Central incisors							
		B		P/L		B		P/L		B		P/L		B		P/L	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Maxilla	Cervical	0.69	0.3	0.83	0.3	0.70	0.3	0.75	0.2	0.71	0.2	0.82	0.2	0.70^{a*}	0.2	0.80^{d*}	0.2
	Middle	0.60	0.2	2.21	0.9	0.57	0.3	1.56	0.8	0.70	0.2	2.40	0.9	0.62^{b**}	0.3	2.05^{e**}	0.9
	Apical	1.39	0.8	5.93	2.2	1.57	0.8	3.99	1.5	1.34	0.8	5.33	1.9	1.43^{c**}	0.8	5.06^{f**}	2.0
Mandible	Cervical	0.49	0.3	0.77	0.3	0.59	0.3	0.59	0.2	0.50	0.3	0.52	0.3	0.53^{a*}	0.3	0.63^{d*}	0.3
	Middle	0.52	0.3	1.54	0.8	0.47	0.3	0.92	0.5	0.53	0.3	0.90	0.6	0.50^{b**}	0.3	1.12^{e**}	0.7
	Apical	3.27	1.2	2.77	1.2	2.92	1.3	2.36	1.0	2.68	1.1	2.56	1.0	2.96^{c*}	1.2	2.57^{f*}	1.1

Notes: B = Buccal surface, P/L = Palatal or lingual surface.
Identical superscript letters indicate statistically significant differences between the two groups Mann-Whitney U test $p < 0.001$;
*p value < 0.05 between buccal and palatal surfaces for the same site and maxilla using the Mann-Whitney U test.
**p value < 0.001 between buccal and palatal surfaces for the same site and maxilla using the Mann-Whitney U test.

Table 2 Distribution of sites according to thickness (> or < 1 mm)

Surface	Site	> 1 mm *N* (%)	< 1 mm *N* (%)
B	CeL	27 (2.5)	362 (29.3)
	MiL	29 (2.6)	360 (29.1)
	ApL	328 (29.8)	61 (4.9)
P/L	CeL	70 (6.4)	319 (25.8)
	MiL	269 (24.5)	120 (9.7)
	ApL	376 (34.2)	13 (1.1)
Total		1,099 (47.1)	1,235 (52.9)

B = Buccal surface, P/L = Palatal or lingual surface, CeL = Cervical level, MiL = Middle-level, ApL = Apical level

Table 3 Distribution of dehiscences and fenestrations per patient

Dehiscences		Fenestrations	
Patients *N* (%) = 19 (100)	Number of dehiscences	Patients *N* (%) = 11 (100)	Number of fenestrations
7 (36.8)	1	5 (45.6)	1
3 (15.8)	2	2 (18.2)	2
2 (10.5)	3	2 (18.2)	3
1 (5.3)	4	1 (9.1)	4
2 (10.5)	5	1 (9.1)	5
1 (5.3)	7		
2 (10.5)	8		
1 (5.3)	10		

Table 4 Distribution of dehiscences and fenestrations per affected site

	Dehiscences					Fenestrations				
	Alveolar Bone Surface *N* (%)				Total *N* (%)	Alveolar Bone Surface *N* (%)				Total *N* (%)
	B		P/L			B		P/L		
	MiL	CeL	MiL	CeL		MiL	ApL	MiL	ApL	
Maxilla	0	10 (14.9)	0	0	10	8 (33.3)	8 (33.3)	0	1 (4.2)	17 (70.8)
Mandible	10 (14.9)	29 (43.3)	3 (4.5)	15 (22.4)	57 (85.1)	7 (29.2)	0	0	0	7 (29.2)
Total	10 (14.9)	39 (58.2)	3 (4.5)	15 (22.4)	67 (100)	15 (62.5)	8 (33.3)	0	1 (4.2)	24 (100)

Notes: B = Buccal surface, P/L = Palatal or lingual surface, CeL = Cervical level, MiL = Middle-level, ApL = Apical level

prevalence in 1,556 sites examined was 1.5% (n = 24). The distribution of these affected sites shows a higher presence of fenestration in the maxilla (n = 17, 70.8%) particularly the buccal surface, both MiL and ApL (n = 8, 33.3% each) (see Table 4).

Finally, there was a tendency demonstrating that patients diagnosed as Class I presented less defects (47% dehiscence and 27% fenestration) compared with Class II (59% dehiscence and 35% fenestration) and Class III (80% dehiscence and 40% fenestration) (see Fig. 2). However, this tendency was not statistically significant ($p > 0.05$).

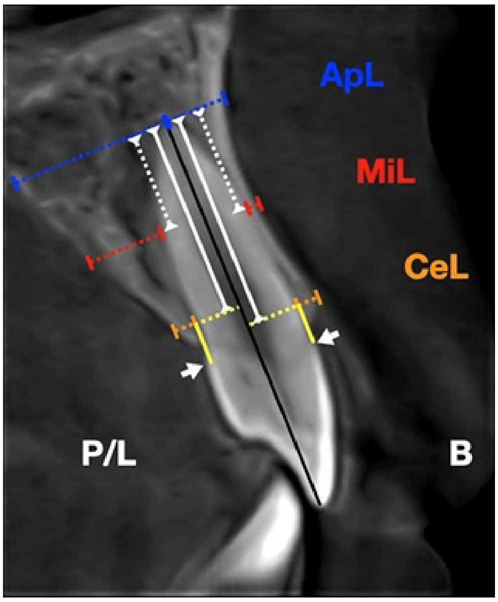

Fig. 1 Measurement of buccal and palatal, lingual, alveolar bone. B = Buccal surface, P/L = Palatal or lingual surface. CeL = Cervical level, MiL = Middle level, ApL = Apical level. † White arrows = CEJ; ‡‡ Black line = tooth long axis; Yellow lines = 2 mm distance from CEJ. Orange dotted line = CeL of bone measurements; Blue dotted line = ApL of bone measurements; Continuous white line = CeL-ApL distance; White dotted line = (CeL-ApL distance)/2; Red dotted line = MiL of the bone measurements.

DISCUSSION

For years, orthodontics used cephalometric norms as guides to plan and project tooth positioning after treatment (Hasund & Ulstein, 1970). However, in these norms there is no reference to the 3D aspect of the cortical plates of the alveolar bone, which now can be precisely approached through the analysis of the 3D image reconstruction, obtained by the CBCT (Misch *et al.* 2006). According to our results, a high percentage of teeth from orthodontic candidates' patients had a thin alveolar bone with patients expressing a high prevalence of dehiscences and fenestrations.

Regarding the thickness of the alveolar bone, our results are in line with previous publications, showing: (1) Similar measurements of maxillary bone thickness (Cook *et al.*, 2011); (2) A homogeneous bone thickness, between the teeth of the same jaw (Shao *et al.*, 2018); (3) A greater thickness of the palatal/lingual surface (Fu *et al.*, 2010); (4) An increase in thickness of the alveolar bone from cervical towards the apex in palatal/lingual (La Rocca *et al.*,

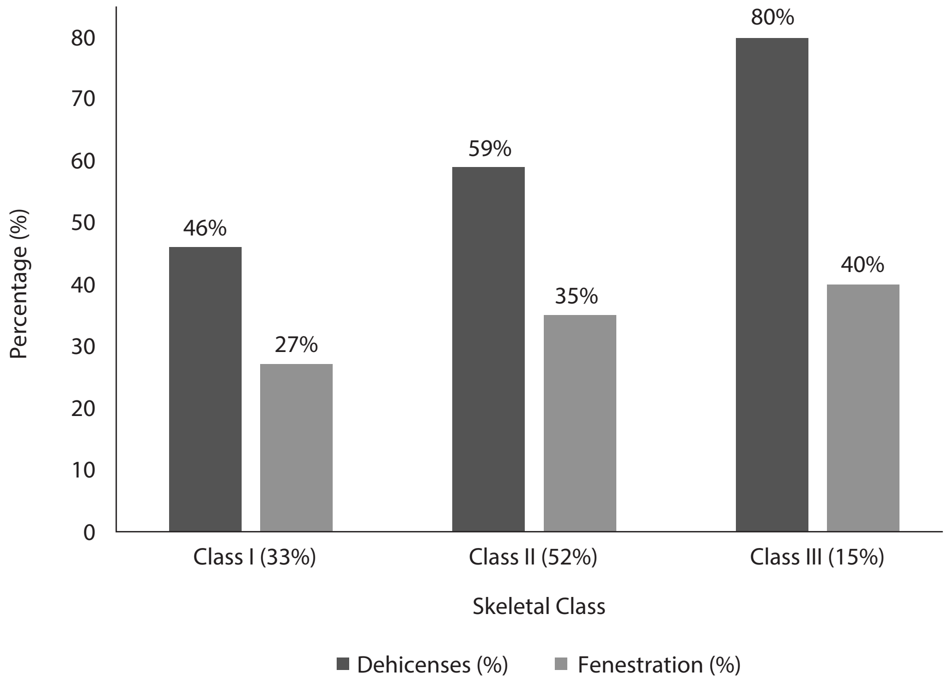

Fig. 2 Distribution of patients' skeletal class and the prevalence of dehiscences and fenestrations.

2012), and; (5) A thicker buccal alveolar bone at the MiL of the upper maxilla compared to the same zone in the mandible, while on the ApL this thickness is greater in the mandible (Pascual *et al.*, 2017). In addition, a high proportion of examined sites measured was less than 1 mm: on the CeL and MiL of the buccal side of all teeth, on the CeL of palatal and lingual sides of all teeth, and on the MiL of lower incisors. This is relevant because 1 mm is the dimension proposed as the threshold bone reabsorption susceptibility (Tomasi *et al.*, 2010). This thickness decreases with age (Choe *et al.*, 2007) and may promote the previously described correlation between thin alveolar bone and bone defects development – as dehiscence and fenestration – (Khoury *et al.*, 2016), both considered as predisposing factors for GR (Zuhr & Hürzeler, 2012; Jati *et al.*, 2016).

On other hand, our study showed at patient level, a high prevalence of dehiscence and fenestration, similar to ones informed previously (Fuhrmann, 1996; Rupprecht *et al.*, 2001; Evangelista *et al.*, 2010; Enhos *et al.*, 2012). Fenestration were more frequent in the maxilla and dehiscence were more frequent in the mandible, the last can be related to a larger presence of dental crowding (Yagci *et al.*, 2012), in a zone typically characterised by presenting a thin periodontal phenotype (Kolte *et al.*, 2014; Agarwal *et al.*, 2017). Fortunately, only a reduced percentage of these defects extend towards the MiL of the alveolar bone plate limiting the extension of an eventual GR. On the contrary, fenestrations were more frequent in the maxilla, on the buccal surface, affecting in a similar way the mild and apical levels.

The wide diversity in the bone measurement methods and the characteristics of the studied population seems to be relevant in the variety of the observed alveolar bone thicknesses as well as in the prevalence and distribution of dehiscence and fenestration. Class I patients with dento-alveolar protrusion showed a very similar pattern of bone thickness compared to our sample; however, they had more homogenous thicknesses of the buccal bone of maxillary incisors (Chanmanee & Charoemratrote, 2019), as well as a higher prevalence of fenestrations in the mandible (Nahm *et al.*, 2012). Our studied sample consisted of candidate patients to routine orthodontic treatment, with a wide range of pretreatment skeletal classes. This heterogeneous sample provide us a wide perspective of bone morphology of young patients and it should be considered clinically relevant. Our results showed that Class III patients should be considered at risk for GR and bone defects development during orthodontics treatment, as there is a tendency demonstrating that these patients have a higher number of dehiscence and fenestration; although, not statistically significant. This fact could be related with the limited number of participants. Nevertheless, according to previous works, Class III patients may frequently have dehiscence and fenestration in mandible, showing a limited bone thickness in presence of a high mandibular plane angle (Oh *et al.*, 2020). Finally, buccal bone in mandible of Class III patients have been described as thicker than lingual bone, not only at the ApL (Lee *et al.*, 2018), as described in our results, but also at the CeL (Park *et al.*, 2018).

Despite the high prevalence of bone defects, the vast majority of our patients had an extremely limited number of affected sites. According to certain authors, this would be explained by the presence, in our sample, of a bone dimension associated with a “thick periodontal biotype” (Frost *et al.*, 2015) and therefore less susceptible to bone reabsorption. However according others reports the observed bone thickness could correspond to a thin gingival phenotype (Frumkin *et al.*, 2017), which is, in turn, more susceptible to develop a GR. These apparent contradictions only reflect, once again, the heterogeneous definition of the periodontal phenotype found in the literature. However, the identification of a given gingival thickness seems to be relevant in the success and longtime stability of dental procedures. Surprisingly, classically cited papers failed to show consistent evidence of a correlation between gingival thicknesses and alveolar bone thick (Fu *et al.*, 2010; Cook *et al.*, 2011). Nowadays, clinical studies suggest a positive correlation between gingival thickness and bone thickness (Frost *et al.*, 2015; Khoury *et al.*, 2016; Frumkin *et al.*, 2017; Silva *et al.*, 2017; Shao *et al.*, 2018), which would allow us to predict the bone dimensions following a gingival clinical examination.

The use of a HR-CBCT, allowed us to obtain an improvement in the specificity of the diagnosis of dehiscence and fenestration (Wood *et al.*, 2013) and to distinguish between bone, periodontal ligament and tooth (Sun *et al.*, 2011). HR-CBCT, prior to orthodontic treatment, may be useful to identify "high-risk sites/patients", particularly in sextant two and five, improving the planning of usual camouflage movements. In this way, dental displacements towards sites with an unfavourable bone morphotype should be avoided (Jäger *et al.*, 2017), particularly in the cervical or middle levels of teeth (Sarikaya *et al.*, 2002). Moreover, the use of HR-CBCT could help to: (1) Identify and plan cases of malocclusions that must be resolved with the expansion of the dental arches, instead of performing excessive incisive pro-inclination movements, such as Class III malocclusions at the mandible; (2) To detect cases in which we dental extractions should be performed at the beginning of the treatment (Gebistorf *et al.*, 2018; Domingo-Clérigues *et al.*, 2019); or (3) To recognise sites where negative torque movements should be avoided, as in the maxillary anterior zone. Finally, HR-CBCT in addition to soft-CBCT, may be useful in the evaluation of the effectiveness of surgical procedures, such as gingival increase (Grover *et al.*, 2011) or corticotomy with bone graft (Wilcko *et al.*, 2009), promising alternatives in preventing the occurrence of mucogingival issues, but still has little scientific evidence supporting them (Kim & Neiva, 2015; Wang *et al.*, 2020; Kao *et al.*, 2020).

The present study did not evaluate the gingival phenotype and their correlation with the bone morphotype or the effect of teeth inclination over the bone thickness; a future research should address these topics more deeply. Moreover, it is necessary to study the influence of different orthodontic appliances, prescriptions, or treatment mechanics, on bony changes during orthodontic treatment as well as the influence of accelerated tooth movement techniques, or periodontal phenotype modifications, on soft and bony tissue responses.

CONCLUSION

The alveolar bone of the sextants two and five frequently present a thin thickness – smaller than 1 mm – associated with the frequent presence of bone dehiscence in mandible and fenestrations in maxilla, particularly in patients with skeletal Class III. Careful orthodontic treatment planning must include assessment of the status of the bone housing of the teeth, avoiding tooth movement towards the zones thinner than 1 mm. This analysis should be performed using a HR-CBCT, following the existing guidelines for their use (American Academy of Oral and Maxillofacial Radiology, 2013), particularly in patients with a skeletal Class III, having a thin periodontal phenotype and with indication of movements that will compromise the alveolar bone at the buccal side or the CeL.

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