Special Article

Alveolar bone morphology under the perspective of the computed tomography: Defining the biological limits of tooth movement

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Abstract

Introduction: Computed tomography (CT) permits the visualization of the labial/buccal and lingual alveolar bone. **Objectives:** This study aimed at reporting and discussing the implications of alveolar bone morphology, visualized by means of CT, on the diagnosis and orthodontic treatment plan. **Methods:** Evidences of the interrelationship between dentofacial features and labial/buccal and lingual alveolar bone morphology, as well as the evidences of the effects of the orthodontic movement on the thickness and level of these periodontal structures were described. **Results:** Adult patients may present bone dehiscences previously to orthodontic treatment, mainly at the region of the mandibular incisors. Hyperdivergent patients seems to present a thinner thickness of the labial/buccal and lingual bone plates at the level of the root apex of permanent teeth, compared to hypodivergent patients. Buccolingual tooth movement might decentralize teeth from the alveolar bone causing bone dehiscences. **Conclusion:** The alveolar bone morphology constitutes a limiting factor for the orthodontic movement and should be individually considered in the orthodontic treatment planning.

Keywords: Computed tomography. Alveolar bone. Dehiscence. Orthodontics.

INTRODUCTION

Computed tomography (CT) permits the dental professional to visualize what the conventional radiographs never showed: the thickness and level of the labial/buccal and lingual alveolar bone. Previously to the introduction of CT, the visualization of labial/buccal and lingual bone plates was not possible due to image superimposition of conventional radiographs and due to gingival covering in clinical analysis.

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The thickness of the alveolar bone defines the boundaries of the orthodontic movement and challenging these limits may cause undesirable collateral effects for the periodontal tissues. The most critical orthodontic movement includes dental arch expansion and incisor buccal-lingual movements.[7] Such mechanics can decentralize teeth from the alveolar bone envelope, causing bone dehiscences and fenestrations and gingival recession, depending on the initial morphology of alveolar bone as well as on the amount of tooth movement.

Due to the high definition and sensitivity, helical and Cone-Beam CT images can show bone dehiscences and fenestrations.[8,9,17,18] Bone dehiscences can be defined as an increase in the distance between the cementoenamel junction (CEJ) and the buccal or lingual alveolar bone crest (Fig 1). Bone fenestrations are alveolar bone discontinuation on the buccal or lingual aspects which exposes a small root region (Fig 2). Before the introduction of CT, efforts to define tooth movement effects on the buccal and lingual bone plates were concentrated on animal experiments[24,29] and on studies with conventional radiographs.[21] Currently, CT studies on the alveolar bone morphology before orthodontic treatment[12,25,30], as well as on the consequences of tooth movement on the alveolar bone are numerous.[11,16,22,23] These evidences can change usual treatment plans, pointing the limits of the therapeutic choices in Orthodontics.

The classical Orthodontics considered the amount of dental crowding, the lower incisor position and the growth facial pattern as the tripod which defines diagnosis and treatment planning. Contemporary Orthodontics included the smile and facial esthetics to the list of importance. Future Orthodontics will add the patient initial periodontal morphology to the other four features. With time, Cone-Beam Computed Tomography (CBCT) will answer if it is sound to move tooth to an edentulous region of atrophic alveolar bone. CBCT will elucidate the individual acceptable amplitude of tooth movement during a malocclusion compensation or decompensation. Additionally, the buccal bone plate morphology will help the orthodontist to decide if expansion or extraction should be performed. The visualization of the anatomical details of our patients and the comprehension of tooth movement collateral effects permits to recognize our limits, practicing a more secure Orthodontics.

MORPHOLOGY OF THE ALVEOLAR BONE

CT axial sections show a general panorama of buccal and lingual bone plate thickness (Figs 3 and 4).

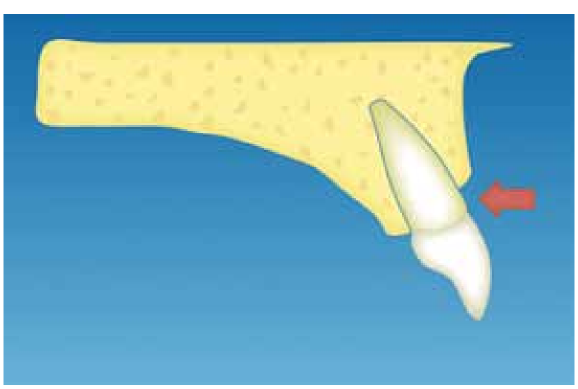


FIGURE 1 - Bone dehiscence.

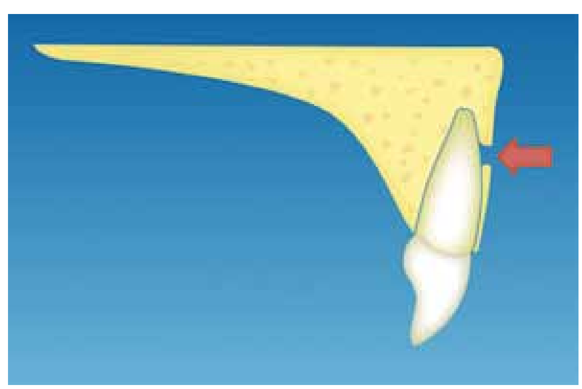


FIGURE 2 - Bone fenestration.

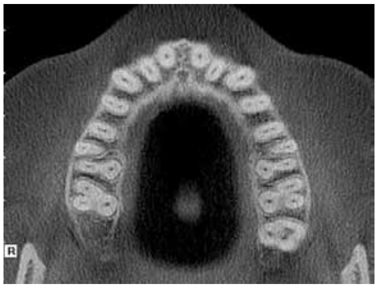


FIGURE 3 - Axial section of the maxilla at the middle third of the roots of maxillary teeth. Observe the thin labial/buccal bone plates of permanent teeth.

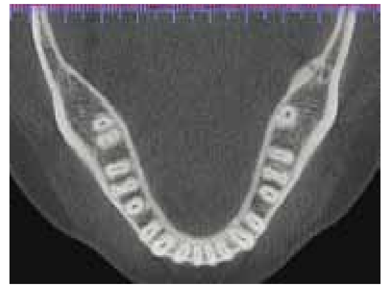


FIGURE 4 - Axial section of the mandible at the middle third of the roots of mandibular teeth.

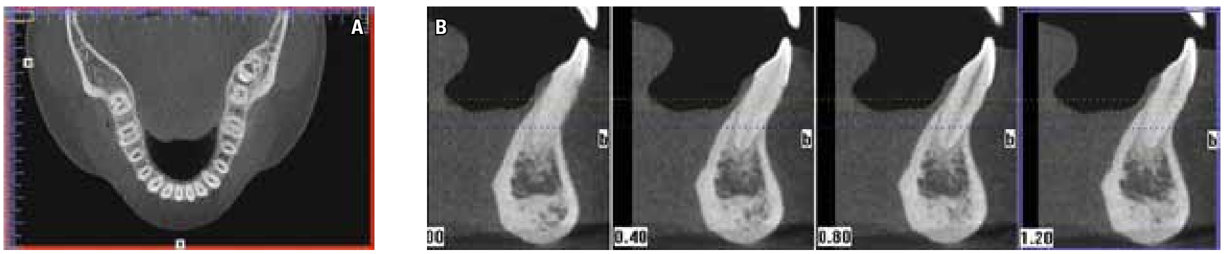


FIGURE 5 - Facial bone dehiscences in the lower incisors in a 21-year-old patient, previously to orthodontic treatment (i-CAT CBCT, voxel size of 0.2 mm). **A**) Axial sections reveal a disproportion between buccal-lingual dimensions of the alveolar ridge and the volume of mandibular incisor roots. **B**) Cross sections of central incisors show an increased distance between the alveolar bone crest and the cementoenamel junction.

Analyzing an axial section of the maxilla at the level of the middle third of the roots, it becomes clear that the labial/buccal bone plate is very thin both in the anterior and posterior regions (Figs 3 and 4). The permanent canines, due their greater volume, and the mesiobuccal root of the first molars, present a buccal bone plate even thinner compared to the other maxillary teeth. The maxillary lingual bone plate thickness is thicker than the buccal bone plate, and in general, the maxillary incisors have the thicker lingual bone plate (Fig 3).

In the mandible, the labial/buccal bone plate also is very thin, with the exception of the second and third permanent molars which are covered for a very thick buccal bone plate (Fig 4). Equally to the maxilla, the lingual bone plate of mandibular teeth is thicker compared to the buccal bone plate, with the exception of the lower incisor regions which show a very thin bone plate both in the labial and lingual aspects. In the mandible, the thickness of the alveolar ridge remarkably decreases from the posterior to the anterior region.[25] In the region of mandibular symphysis, visualizing bone dehiscences previously to orthodontic treatment is not rare, mainly in adult patients[7] (Fig 5). The explanation is the disproportion between the buccolingual diameter of the incisor roots and the buccal-lingual diameter of the alveolar ridge which may not have enough thickness to contain all the root volume[7] (Fig 6).

A recent study measured the labial/buccal and lingual bone plate thickness of maxillary and mandibular permanent teeth, previously to orthodontic treatment[5]. For the maxilla, CT axial sections passing 3 and 6 mm apically to CEJ of maxillary teeth were analyzed (Fig 7). For the mandible, the measurements were performed on the axial sections passing 4 and 8 mm apically to CEJ of the lower teeth (Fig 8). The reference values for the labial/buccal and lingual bone plate thickness in adolescent and young adults is shown in Figures 7 and 8.[5] Lee et al[15] showed similar results for the thickness of the buccal bone plate in Korean adults with normal occlusion.

FIGURE 6 - Sagittal section passing through the mandibular central incisor region. Observe the presence of bone dehiscences. The disproportion between buccal-lingual root diameter and faciolingual dimension of mandibular symphysis is notable (Source: Moraes[20]).

Teeth with eccentric positions in the alveolar ridge, as crowded incisors and canines, constitute risk factors for bone dehiscences and fenestrations[7] (Figs 9 and 10).

The growth facial pattern has an influence on the morphology of labial/buccal and lingual bone plates. Hypodivergent patients present a thicker alveolar ridge, compared to normodivergent or hyperdivergent patients.[12,26] Hyperdivergent patients present a thinner mandibular symphysis and a thinner alveolar ridge in the anterior region of the mandible, compared to the other facial patterns[4,13] (Fig 11). Regarding the thickness of the buccal and lingual bone plates, the difference between hypodivergent and hyperdivergent patients seems to be restricted to the level of the root apex. The thickness of the bone plates at the level of cervical and middle thirds of the root is very similar in different facial patterns.[5] However, the distance from the root apex to the external surface of buccal and lingual cortical bone is greater in hypodivergent patients compared to hyperdivergent patients[26] (Fig 12). Under this perspective, in hypodivergent patients, the orthodontic treatment planning presents less restriction for

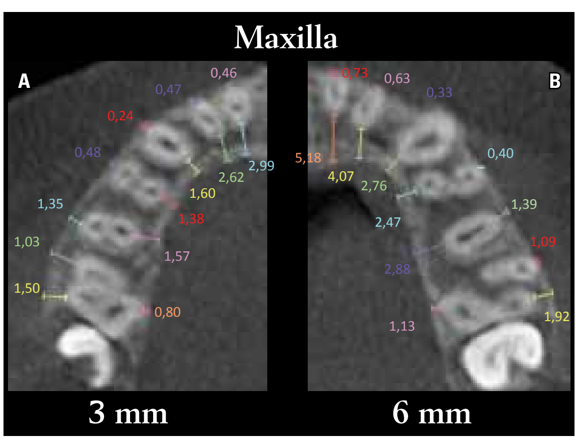


FIGURE 7 - Mean thickness of buccal and lingual bone plates of maxillary teeth, previously to orthodontic treatment, in adolescents and young adults. **A**) Mean thickness 3 mm apically to CEJ; **B**) Mean thickness 6 mm apically to CEJ (Source: Ferreira[5]).

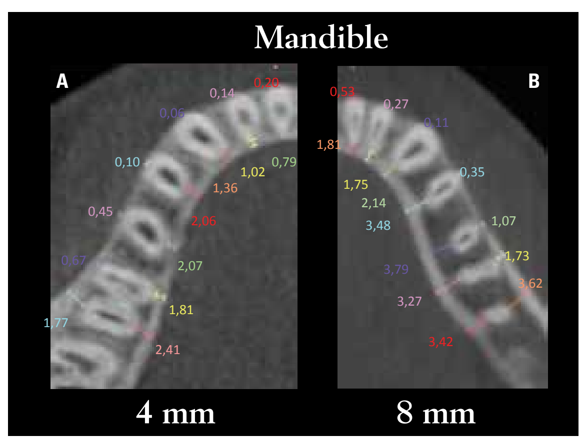


FIGURE 8 - Mean thickness of buccal and lingual bone plates of mandibular teeth, previously to orthodontic treatment, in adolescents and young adults. **A**) Mean thickness 4 mm apically to CEJ; **B**) Mean thickness 8 mm apically to CEJ (Source: Ferreira[5]).

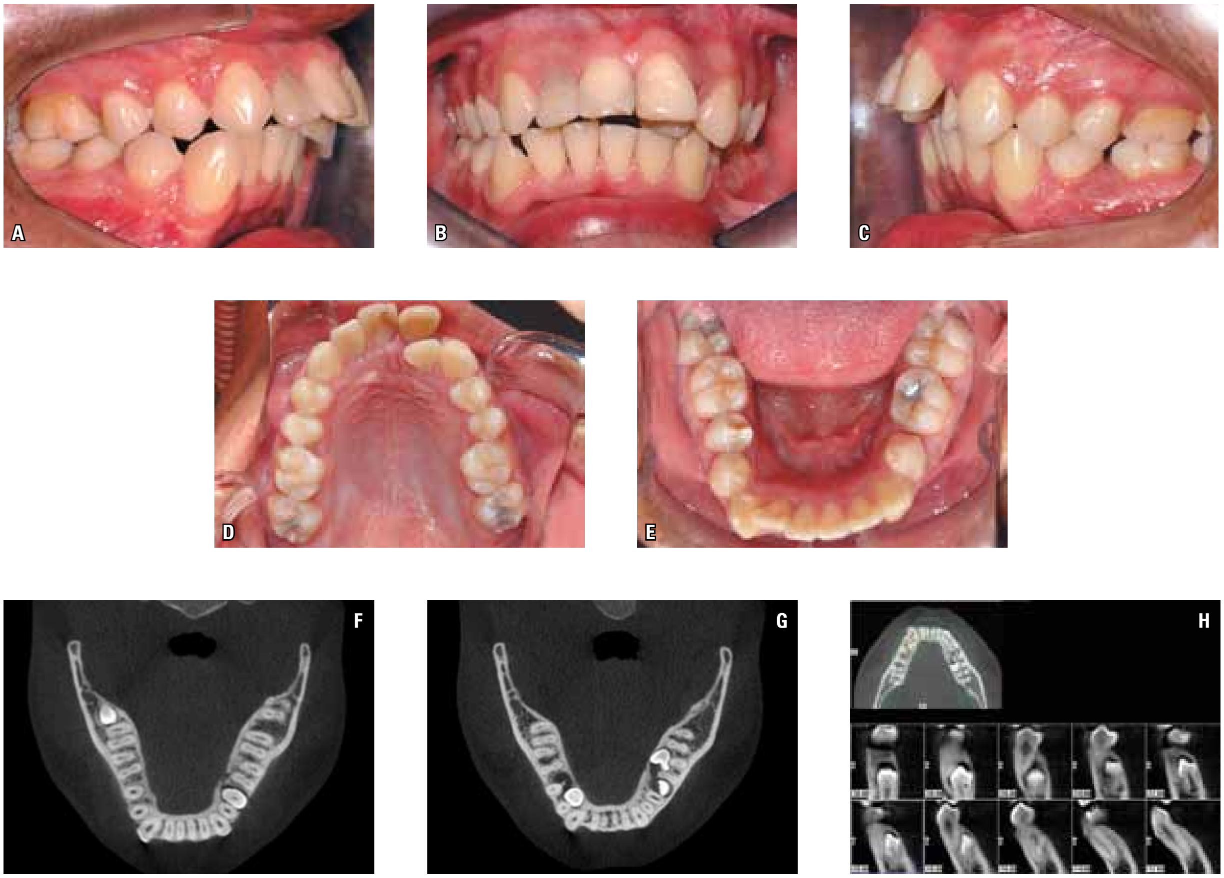


FIGURE 9 - **A-E**) This case illustrates a Class II malocclusion with maxillary and mandibular anterior crowding. Observe that the right mandibular canine is dislocated toward buccal. **F, G**) Axial sections at the level of CEJ and at the level of the cervical third of the root of the right canine, respectively. In figure **G**) observe the absence of alveolar bone in the buccal aspect of the right canine. **H**) Cross sections of the right mandibular canine. The most lower and right image shows the presence of buccal bone dehiscence.

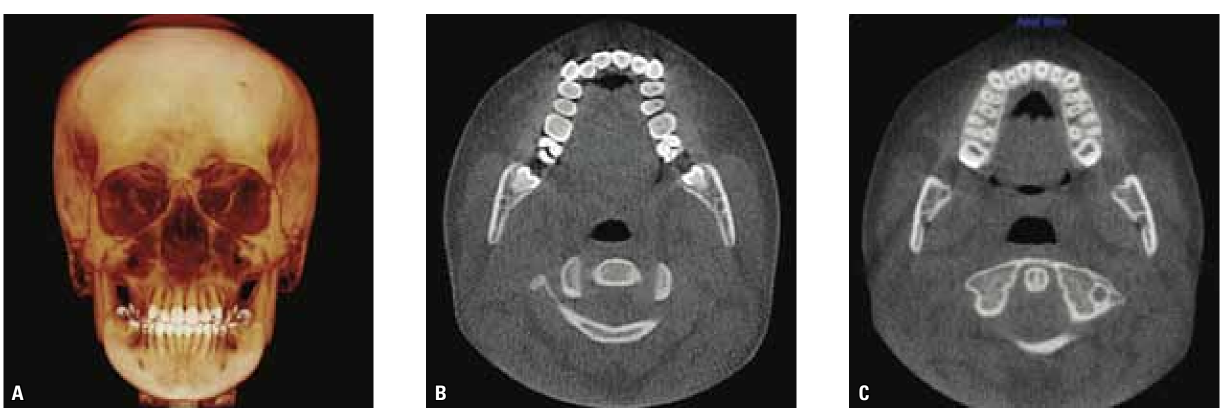


FIGURE 10 - Buccal bone dehiscences at the canine region. **A**) 3D reconstructions; **B, C**) axial sections at the level of the crown and at the cervical third of the root of the maxillary canines. Observe the absence of buccal bone plate in figure **C**.

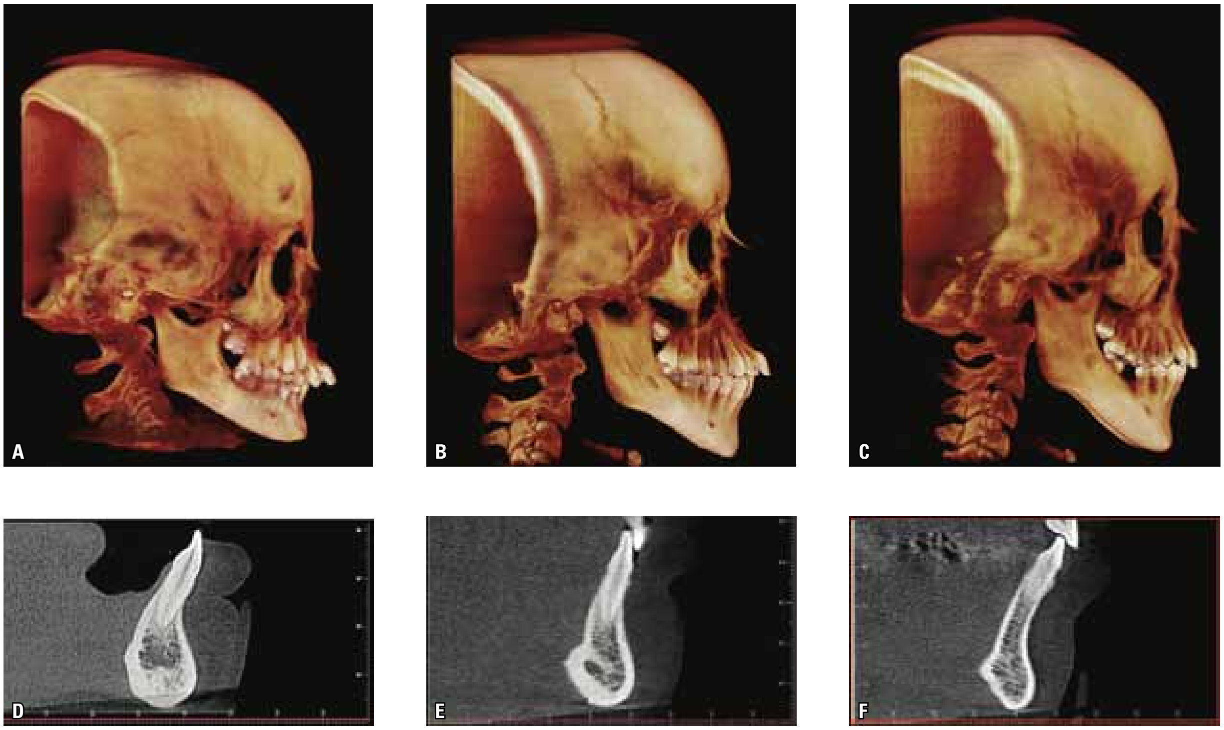


FIGURE 11 - Morphology of mandibular symphysis in different facial types: **A** and **D**) Hypodivergent patient; **B** and **E**) Normodivergent patient; **C** and **F**) Hyperdivergent patient.

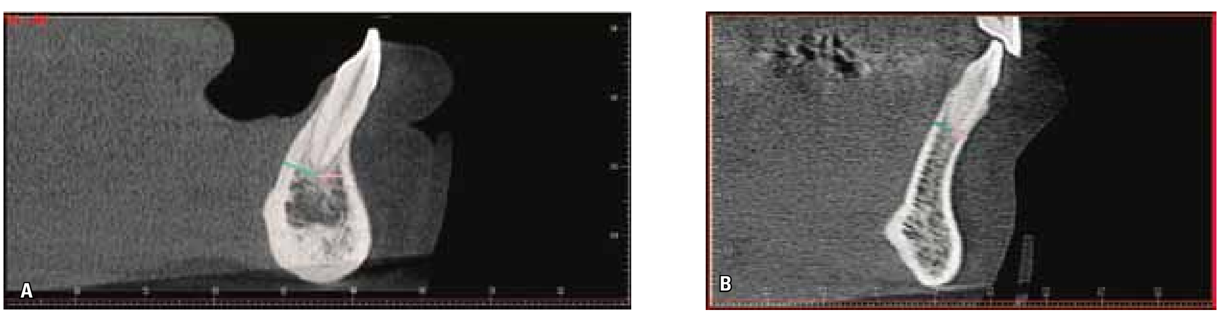


FIGURE 12 - The main difference between hypodivergent and hyperdivergent patients, regarding the morphology of the alveolar bone, is the thickness of the labial/buccal and lingual bone plates at the level of root apexes. In hypodivergent patients (**A**), there is a thicker alveolar rigde, as well as a thicker facial and lingual bone plate thickness in the apical third of the roots, compared to hyperdivergent patients (**B**). On the other hand, the thickness of buccal and lingual bone plates at the level of cervical and middle thirds of the roots is very similar for both facial growth patterns.

moving the lower incisors in the labial-lingual direction. Conversely, hyperdivergent patients present more restrictions for moving the lower incisors in the labial-lingual direction, mainly at the level of the root apex. In this way, in face of the need of labial-lingual movement of the mandibular incisors, tooth tipping should be preferred instead of bodily tooth movement in hyperdivergent patients. Tooth translation would move, besides the tooth crown, also the root apex, with the possibility to move tooth throughout the limits of the alveolar bone. On the other hand, tooth tipping with a rotation center at the level of the root apex could change tooth crown position, while the root apex would be maintained inside the alveolar bone limits. Round arch wires, or rectangular arch wires with reduced size compared to the bracket slot size, could be used for accomplishing tipping movements in these patients. Additionally, when the maintenance of the position of root apex is intended, the classic procedure of resistant wire torque should not be performed during anteroposterior tooth movement.

The labial-lingual movement of the mandibular incisors should be carefully planned in hyperdivergent patients with bimaxillary protrusion, in Class III camouflage treatments, in dental Class II compensation or in Class III malocclusions treated surgically. In long face patients with an extreme vertical growth pattern, the ideal position of the mandibular incisors should be the initial, and therefore natural, incisor position.

Comparing hyperdivergent patients with different sagittal maxilomandibular relationships, it was verified that Class III patients present a mandibular symphysis even thinner than Class I and Class II patients.[14,30] Considering these evidences, the Orthodontist should be careful when planning labial-lingual movements of the mandibular incisors, both for compensatory and surgical treatment planning. Again, tipping movement of mandibular incisors should be preferred instead of bodily tooth movements in hyperdivergent Class III patients.

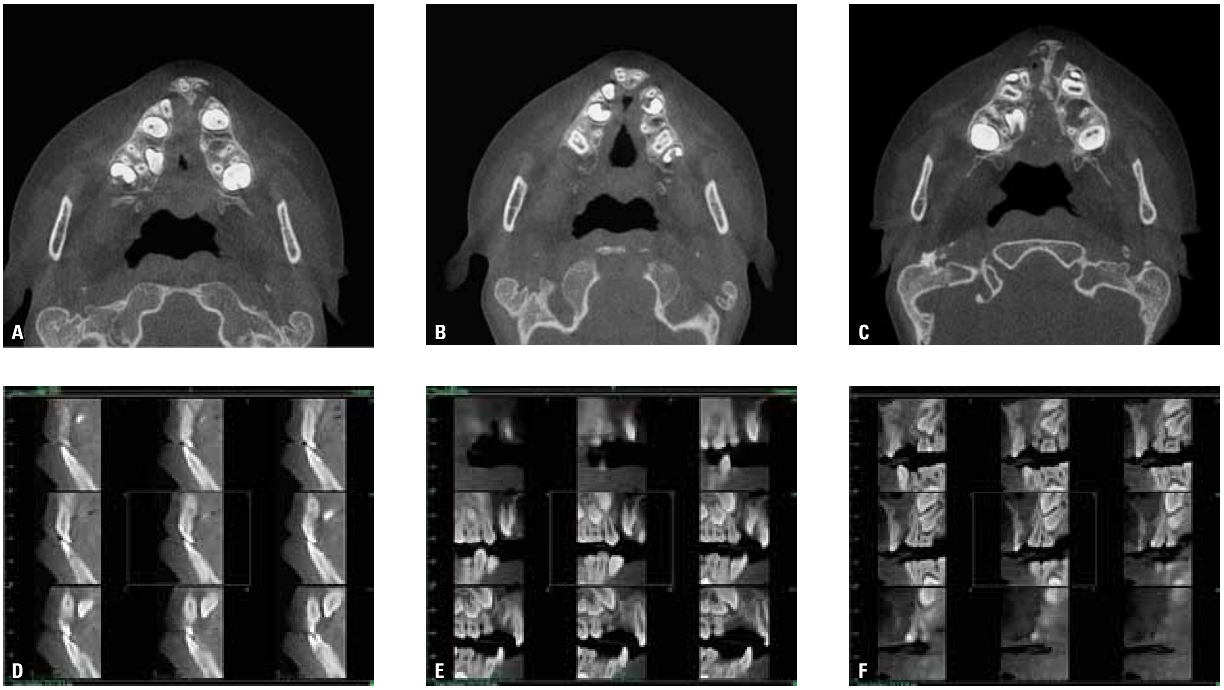
Besides the mandibular symphysis region, other area which is critical regarding the thickness of bone plates is the anterior region of the maxilla in cleft patients (Fig 13). In children with bilateral cleft lip and palate, although the thin thickness of alveolar bone plates surrounding the cleft neighboring teeth (Table 1), the alveolar crests show a normal level, without the presence of bone dehiscences. The thin periodontal bone surrounding the teeth next to the alveolar cleft constitutes a limitation for tooth movement previously to the alveolar bone graft procedure in these patients.

PERIODONTAL CONSEQUENCES OF BUCCAL-LINGUAL TOOTH MOVEMENT

Tooth movements which may decentralize teeth from the alveolar ridge represent the most critical movement for developing bone dehiscences.[7] Therefore, buccal-lingual movements present more risk for breaking the limits of the alveolar bone, causing buccal and lingual bone plate resorption.

There is a clear correlation between buccal-lingual tooth movement and the occurrence of buccal bone dehiscences. Study in animals showed that the labial movement of the incisors, even using light forces, produces an increase in the distance between buccal alveolar crest and CEJ.[24,29] Interesting studies conducted in human maxillary bones extracted during autopsy presented similar conclusions[27,28] (Fig 14). Decreasing changes in the thickness and level of labial/buccal bone plates when teeth are moved toward this direction indicate the absence of equivalent compensatory bone apposition under the buccal periosteum. The occurrence of bone dehiscences after incisor sagittal movements also have been suggested in studies conducted with conventional radiographs and laminography[21] and in clinical studies which reported the development of gingival recession in teeth moved naturally or orthodontically toward the vestibulum.[1,2,3]

Bone dehiscence caused by tooth movement cannot be seen clinically. The gingival clinical features do not change after the apical migration of the bone crest level, at least in the short term. Gingival recession has not been observed immediately after the development of bone dehiscences. The junctional ephitelia migration and the loss of attachment have not followed the apical migration of the labial/buccal bone crest,[24,29] mainly in the absence of gingival inflammation.[29] In reality, the occurrence of bone dehiscences is followed by the establishment of a long conjunctive attachment, and then, the gingival sulcus does not become deeper.[29]



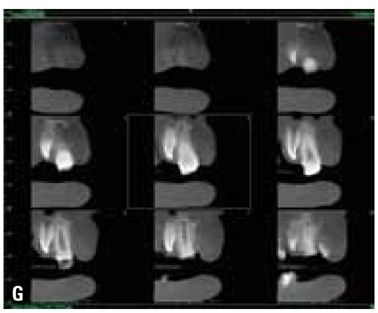


FIGURE 13 - Patient with a complete bilateral cleft lip and palate. **A, B, C**) Axial sections. Observe the interruption of the alveolar ridge in the anterior region, on both sides. **D**) Cross sections of the anterior region reveal a thin buccal bone plate. **E, F**) Coronal sections of the alveolar cleft region. Observe the thin mesial bone plate of the canines neighboring to the cleft area. **G**) Coronal sections of the premaxilla show the presence of a thin bone plate distally to the central incisors.

TABLE 1 - Mean and standard deviation for alveolar bone thickness of teeth adjacent to palatal cleft (transforamen bilateral fissure), in mixed dentition children with mean age of 9 years.

LEVEL (in relation to the CEJ)	ALVEOLAR BONE THICKNESS											
	Teeth Mesial to the cleft (n=20)						Teeth distal to the cleft (n=20)					
	Buccal		**Lingual**		**Distal**		**Buccal**		**Lingual**		**Mesial**	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
3 mm	0.62	0.42	1.44	0.67	1.55	0.79	0.75	0.58	2.07	1.07	1.59	1.10
6 mm	0.95	0.37	2.78	2.05	1.60	0.66	1.05	0.40	2.42	1.93	1.61	1.08
Root Apex	1.49	0.51	2.33	1.34	2.72	4.69	1.67	0.48	3.59	2.43	1.16	0.94

FIGURE 14 - Mandible extracted during autopsy in a young patient who passed away in an accident while the comprehensive orthodontic treatment was been performed. Remarkable bone dehiscences in the mandibular symphysis were related to incisor lingual movement during anterior retraction, as well as to rotational movements of the incisor in a thin symphysis (Source: Wehrbein, Bauer and Diedrich[27]).

Computed tomography widened even more our vision regarding the repercussion of tooth movement on the buccal and lingual alveolar bone. CT has revealed that arch expansion, incisor protrusion or retraction represent the movements which have the greater risk of causing bone dehiscences[7]. The orthodontic retraction of maxillary and mandibular incisors cause a decrease in the thickness of the lingual bone plate in the coronal and middle third of the roots, as well as lingual bone dehiscences.[23] The thickness of the labial bone plate has not been changed during incisor retraction, with the exception of the coronal third of the facial bone plate in the mandibular incisor region which may present a reduction.[23]

The pre-surgical orthodontic treatment for decompensating hyperdivergent Class III patients can determine notable bone dehiscences in the area of mandibular symphysis.[14] In the permanent dentition, both the maxillary rapid expansion[11,12] and the slow maxillary expansion,[7] might cause buccal bone dehiscences in the posterior teeth, mainly in patients with an initial thin buccal bone plate (Fig 15). Maxillary first premolars showed more critical bone dehiscences than the first molars during RME, due to the anatomical characteristics of the maxilla[11] (Fig 16). The maxillary first premolars are located in an area which becomes narrower upwards (Fig 16, A). In this area, when there is a bodily buccal movement, the root may perforate the alveolar bone much more easily.[11] The first molars are located in a maxillary region that widens upwards (Fig 16, B). Hyrax expanders caused more extensive dehiscences than Haas type expanders.[11]

All these evidences are important to guide the Orthodontists to prevent future gingival recessions. Predisposing and precipitant factors of gingival recession should be prevented in patients submitted to maxillary expansion. Initially, the professional should recommend the gingival graft in regions with a poor amount of keratinized mucosa as well as to motivate oral hygiene in order to avoid traumatic brushing or gingival inflammation. Additionally, the periodontal consequences of rapid maxillary expansion in the permanent dentition highlight the importance of early intervention. During the deciduous and mixed dentition RME produces a larger orthopedic effect and transfers the anchorage to deciduous molars and canines. Although there is no evidence that RME cause buccal bone dehiscences in the deciduous

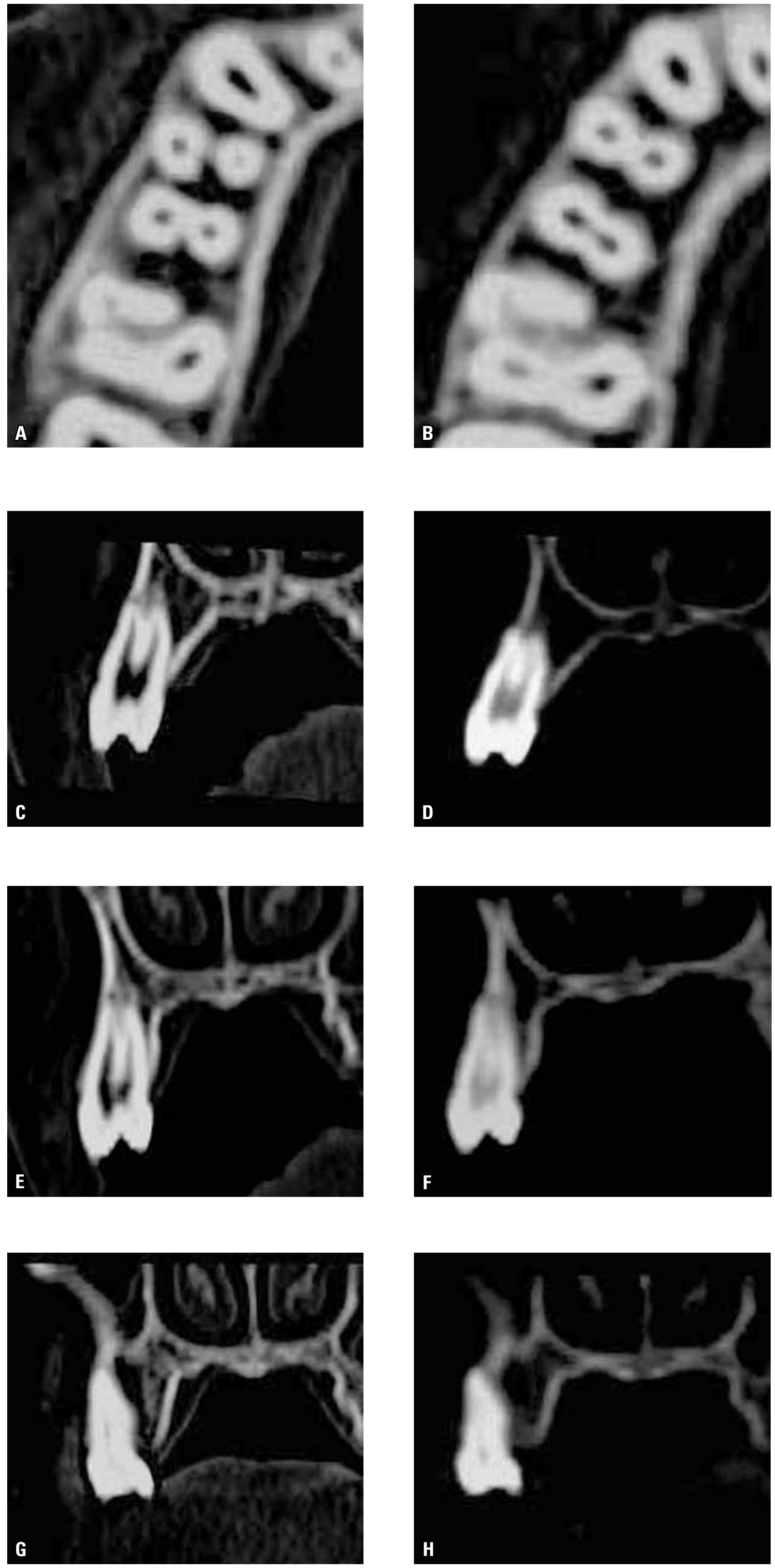


FIGURE 15 - Periodontal effects of RME. **A, B**) Maxillary axial sections before and after RME, respectively. Observe that the orthodontic effect of maxillary expansion produced a decrease in the thickness of the buccal bone plate of posterior teeth. **C, D**) Cross sections of a maxillary first premolar before and after RME, respectively. Observe the development of buccal bone dehiscences after expansion, in a region which originally had a very thin bone plate. **E, F**) The same example in the opposite side of the dental arch. **G, H**) Cross sections of the maxillary first molar before and after RME, respectively, showing that tooth movement has occurred through the alveolar bone and not together with the alveolar bone.

FIGURE 16 - Maxillary external contour on CT coronal reconstruction: **A**) First premolar area. **B**) First molar area. First premolars are located in a maxillary region which becomes narrower upwards (**A**). In this area, when there is a bodily buccal movement, the root may easily perforate the alveolar bone.

and mixed dentitions, despite the possibility of some degree of periodontal involvement, the future eruption of the succeeding permanent teeth will be followed by new alveolar bone reestablishing the periodontal integrity.

Computed tomography studies also have demonstrated that, during the retention phase, some partial regeneration of bone dehiscences caused by tooth movements may take place.[7] However, we are just at the beginning. With the introduction of CBCT, the future seems promising in providing additional evidences on the longitudinal effect of several orthodontic mechanics on the alveolar bone.

PERIODONTAL CONSEQUENCES OF MESIODISTAL TOOTH MOVEMENT

Another clinical situation which demands certain concern with the integrity of buccal and lingual bone plates is the mesiodistal movement of posterior teeth toward regions with atrophic alveolar bone. In patients with tooth agenesis or loss of permanent first molars, closing the arch space by means of mesial movement of posterior teeth is mechanically possible, mainly with the aid of skeletal anchorage devices. However, edentulous alveolar ridge usually presents a reduced buccolingual dimension. When moving posterior teeth toward atrophic alveolar bone regions, what can happen with the alveolar bone surrounding these teeth? Does the buccal and lingual alveolar bone follow the tooth movement, or does this type of movement cause bone dehiscences?

An interesting study was conducted on the extracted jaws of a 19-year-old patient who passed away in an accident while she was under comprehensive orthodontic treatment.[28] The patient presented agenesis of the maxillary second premolars and the right maxillary lateral incisor. The orthodontic treatment was conducted closing the spaces of tooth agenesis. The histological analyzes showed the presence

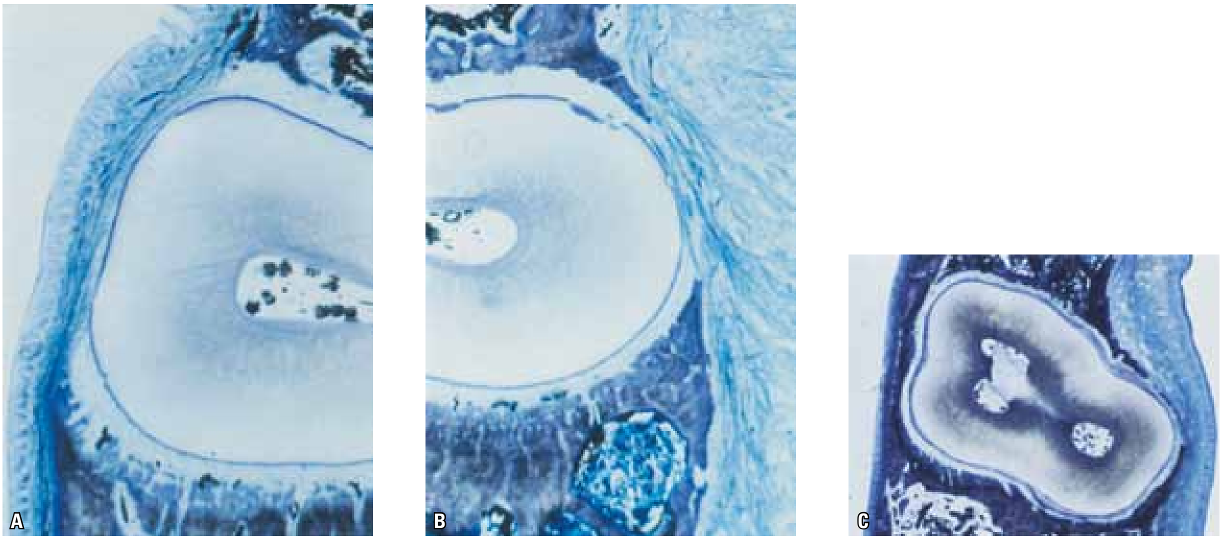


FIGURE 17 - Histological axial sections of a human maxilla extracted during autopsy. Observe bone dehiscences caused after tooth movement toward regions of atrophic alveolar bone (due to tooth agenesis). **A**) Buccal regions of the maxillary right first premolar; **B**) Lingual region of the same tooth; **C**) Lingual regions of the maxillary right first molar (Source: Wehrbein, Fuhrmann and Diedrich[28]).

of bone dehiscences in the teeth moved to the regions of atrophic alveolar bone[28] (Fig 17). Additionally, the authors observed that the alveolar bone may follow tooth body movement, causing compensatory bone neoformation in the buccal and lingual periosteum, when the tooth movement was very slow.[28] Cone-Beam Computed Tomography has much value for permitting the clinician to follow these clinical cases and for showing the pattern of bone remodelation in the region of atrophic alveolar bone.

Other critical movement for the development of bone fenestrations and dehiscences is the mesiodistal movement of maxillary molars toward areas with maxillary sinuses extensions[28] as well as rotational tooth movements.[27] During orthodontic alignment, the rotation correction can cause resorption of the facial and lingual bone plates when the tooth has a root with the buccal-lingual dimension greater than the mesiodistal diameter.[27]

CT SCANS REQUIREMENTS FOR VISUALIZING ALVEOLAR BONE PLATES

In 1995, helical CT was validated for the identification of labial/buccal and lingual alveolar bone.[10] Only alveolar bone plates with the thickness smaller than 0.2 mm could not be apparent in medical CT images.[10] Moreover, a study in human cadavers showed that artificial horizontal bone defects made in the buccal and lingual alveolar plates were identified in helical CT images while could not be visualized in periapical radiographs[9]. In 1996, an experimental study which performed artificial bone dehiscences in the maxillary bone of human cadavers has concluded that CT was the only mean of diagnosis which permits a quantitative evaluation of buccal-lingual thickness of both the alveolar ridge and the buccal and lingual bone plates.[6] In 2008, a high accuracy of CBCT for quantitative analyses of the level of buccal and lingual bone plates was demonstrated.[17,18]

The sensitivity and specificity for the identifications of bone dehiscences and fenestrations were evaluated in tridimensional reconstructions of CBCT images taken with voxel size of 0.38 mm and 2 mA.[16] Tridimensional reconstructions of dry skulls showed good sensitivity and specificity (0.8) for the identifications of bone fenestrations[16]. On the other hand, the identifications of bone dehiscences presented high specificity (0.95) but low sensitivity (0.40).[16] This means that CBCT 3D reconstructions show a small frequency of false-positive results and a high frequency of false-negative results for bone dehiscences. In other words, when bone dehiscences are apparent in CBCT 3D reconstructions, it means that they really exist. However, in the regions that bone dehiscences are not visualized, one cannot conclude that they do not exist.

When the visualization of small anatomical structures (as the buccal and lingual bone plates) in CBCT is desirable, the exam should be performed following some requirements for obtaining good image definition. The spacial definition of the CBCT image (smaller distance for the identification of two different structures) does not correspond to the voxel dimension (CT smaller image unit).[19] Some properties of CT images as the partial volume mean, the artifacts and the noise can interfere to the spacial resolution.[19] For obtaining a good spatial resolution, the Field of View (FOV) and the voxel dimension should be both the smallest possible.[19] Moreover, the patient should be oriented to avoid movements during the CT exam, preventing movement artifacts.

FINAL CONSIDERATIONS

Since the last decade, with the introduction of CBCT, Orthodontics has widened its potential for performing a more realistic diagnosis and prognosis. The morphology of the alveolar bone, visualized in CT images, can alter usual orthodontic goals. The repercussions of tooth movements on the alveolar bone, analyzed by means of CBCT, will point the limits of Orthodontics, defining the procedures which can and cannot be performed in each patient individually.

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