Évaluation de la structure trabéculaire osseuse sur les radiographies péri-apicales et panoramiques

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Thèse préparée sous la direction du Professeur Stavros KILIARIDIS

ÉVALUATION DE LA STRUCTURE TRABECULAIRE OSSEUSE SUR LES RADIOGRAPHIES PERI-APICALES ET PANORAMIQUES.

Thèse

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par

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Intitulée :

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La Faculté de médecine, sur le préavis de Monsieur Stavros Kiliaridis, professeur ordinaire à la Section de médecine dentaire, autorise l'impression de la présente thèse, sans prétendre par là émettre d'opinion sur les propositions qui y sont énoncées.

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RÉSUMÉ

Des orthopantomogrammes (OPT), provenant de patients en contention orthodontique depuis au moins 2 ans, ont été utilisés pour évaluer qualitativement l'os alvéolaire de la mandibule et son évolution sur une durée moyenne de 8 ans, à l'aide d'un index visuel. Les données trouvées dans la littérature ont montré qu'un index visuel basé sur 3 grades de trabéculation osseuse peut être utilisé de façon fiable sur des radiographies intra-orales (aussi appelées péri-apicales). Une étude méthodologique préliminaire a donc été menée afin de déterminer si l'évaluation de la trabéculation osseuse de la mandibule observée sur les OPT, utilisant cet index visuel, correspondait à celle réalisée sur les radiographies péri-apicales. Dans cette étude, deux observateurs préalablement calibrés ont évalué deux fois 79 sites interdentaires (situés distalement aux deux prémolaires mandibulaires) sur 32 OPT et les péri-apicales correspondantes, et ce en appliquant l'index visuel déterminé à un intervalle de 60 jours. L'accord inter-obervateur était légèrement plus élevé pour les radiographies péri-apicales (0.82) que pour les OPT (0.78). Néanmoins, une corrélation appréciable a été trouvée entre les deux types de radiographies ($r = 0.736$, $p = 0.001$). Cette étude a montré que l'utilisation des radiographies panoramiques dans l'évaluation, à l'aide d'un index visuel, de la structure trabéculaire osseuse mandibulaire est possible, et ce bien que les résultats soient un peu moins fiables qu'avec les radiographies péri-apicales. À l'aide de cette méthodologie, l'évaluation longitudinale de la trabéculation osseuse de la mandibule a été réalisée sur les orthopantomogrammes de 39 patients pris à environ 8 ans d'intervalle. Deux groupes d'individus ont été étudiés: un groupe jeune (15.6 ± 0.9 ans à T1) et un groupe adulte (31.3 ± 9.7 ans à T1). L'analyse visuelle a montré une trabéculation de l'os alvéolaire mandibulaire généralement plus dense chez le groupe adulte. Chez le groupe adulte, sur une période de huit ans, cette trabéculation apparaît plus dense en comparaison à celle sur les OPT prises huit ans auparavant. La densification de la trabéculation osseuse alvéolaire mandibulaire d'un individu en croissance au jeune adulte reflète une possible adaptation du processus alvéolaire au développement des muscles masticatoires.

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Cette thèse de doctorat se base sur les publications originales suivantes**:**

I. Assessment of trabecular pattern in periapical and panoramic radiographs: a pilot study.

Diane Pham, Grethe Jonasson , Stavros Kiliaridis
Acta Odontologica Scandinavica 2010 ; volume 68, Issue 2 : pages 91-97.

II. Evaluation of changes in trabecular alveolar bone during growth using conventional panoramic radiographs.

Diane Pham, Stavros Kiliaridis
Acta Odontologica Scandinavica 2012; volume 70, Issue 2 : pages 127-132.

1. TEXTE DE SYNTHÈSE RÉSUMÉ (en français)

1.1 Introduction

L'os mandibulaire présente des caractéristiques particulières, tant anatomiques que fonctionnelles. Son origine intra-membraneuse conduit à la formation de deux parties osseuses distinctes: l'os basal et le processus alvéolaire (appelé communément l'os alvéolaire), ce dernier constituant le support des dents dans la mandibule. Dans chacune de ces parties se trouve une composante externe d'os compact et une composante interne d'os spongieux (trabéculaire). L'os mandibulaire est soumis au remodelage tout au long de la vie et ce processus peut être influencé par les demandes masticatoires, les mouvements orthodontiques et les extractions (White, 2002). Indépendamment de l'âge, on constate une grande variabilité dans le volume et les connexions trabéculaires entre les individus, conduisant à différents motifs de trabéculation osseuse dans l'os mandibulaire (Ulm et al., 1999). Récemment, plusieurs méthodes de mesure de la densité minérale osseuse ou de caractérisation de la microstructure osseuse ont été développées (Lespessailles et al., 2006 ; Moon et al., 2004), mais malgré les progrès réalisés, des problèmes techniques persistent (Genant et Jiang, 2004). De plus, le coût et la complexité de ces outils limitent encore leur utilisation routinière.

La spongieuse mandibulaire comporte des trabéculations osseuses visibles sur les radiographies. Dans le domaine dentaire, plusieurs types de radiographies sont utilisés à des fins diagnostiques, dont les radiographies apicales et OPT. Leur utilisation régulière et fréquente leur confère l'intérêt supplémentaire de ne pas se limiter seulement au domaine dentaire, mais de pouvoir également s'étendre au diagnostic de maladies osseuses et systémiques. De récentes études (Genant & Jiang, 2006; Moon et al., 2004; Couture et al., 2003; White et al., 2005; Nackaerts et al., 2008; Devlin & Horner, 2008; Geraets et al., 2007) ont utilisé des radiographies apicales conventionnelles pour évaluer les trabéculations de l'os alvéolaire de la mandibule, avec des méthodologies quantitatives (ex. : minéralo-densitométrie, analyse de la densité de pixels), ou qualitatives (ex. : tomodensitométrie ou image par résonance magnétique). Lindh et al. (1996) a proposé un index visuel, applicable sur les radiographies dentaires, qui classifie les types de trabéculations osseuses en 3 grades (clairsemé, alternance entre clairsemé et dense, et dense). Cette méthode qualitative a été employée dans des études transversales et longitudinales évaluant l'association entre la structure trabéculaire osseuse et la densité minérale osseuse squelettique chez des individus dentés (Jonasson et al., 2006; Jonasson et al. 2007; Lindh et al., 2008).

Chez les individus adultes, la réaction tissulaire à une force orthodontique est probablement différente dans de l'os alvéolaire à trabéculations plus denses ou plus clairsemées, comme pourraient le suggérer des études animales (Bridges et al., 1988; Goldie & King, 1984). Or, il serait intéressant de mieux connaître la manière dont la structure trabéculaire de l'os alvéolaire change avec l'âge, de l'adolescence à la vieillesse, afin que les orthodontistes puissent les intégrer dans leurs traitements. En orthodontie, les orthopantomogrammes remplacent aujourd'hui le status radiologique, constitué de radiographies apicales, lors de la documentation servant à la planification et au suivi d'un traitement orthodontique. Dans la littérature, c'est généralement la composante corticale du processus alvéolaire qui est étudiée sur les OPT. Très peu d'études se rapportent à la partie trabéculaire de l'os alvéolaire sur les orthopantomogrammes (Taguchi et al., 1997; Yalcinkaya et al., 2006; Bianchi et al., 2007). Ainsi, il n'est pas encore établi si l'index visuel qualitatif utilisé pour évaluer l'os alvéolaire trabéculaire sur les radiographies apicales est également applicable aux radiographies panoramiques.

1.2 Objectifs

1) Le premier but de cette étude (méthodologique) est de déterminer si l'évaluation de la structure trabéculaire de l'os alvéolaire mandibulaire sur les

radiographies OPT, se basant sur un index visuel, correspond à celle validée sur des radiographies apicales;

2) Le deuxième but de cette étude est d'utiliser la même méthodologie, si elle est confirmée dans de la première partie de l'étude, afin d'évaluer les changements de structure de l'os alvéolaire mandibulaire observés sur des orthopantomogrammes durant la croissance, et d'en mesurer les éventuelles différences entre des sujets d'âge et de genre variables.

1.3 Matériel et Méthode

1.3.1 Méthodologie

Une radiographie OPT et les radiographies péri-apicales correspondantes de la région des prémolaires et molaires mandibulaires ont été récoltées dans les dossiers de 32 patients (âge moyen 18.5 ans ± 5.5 ans). Deux examinateurs préalablement calibrés ont évalué aléatoirement, au moyen d'un index visuel et sur toutes les radiographies collectées, les sites interdentaires mandibulaires entre la 1ère molaire et la 2e prémolaire, et entre les prémolaires. Les évaluations ont été répétées après 60 jours, et ont permis de calculer la variabilité intra- et inter-observateurs, par le coefficient de Kappa. La concordance entre les évaluations faites sur les radiographies OPT et péri-apicales a été déterminée par la corrélation de Spearman.

1.3.2 Evaluation de la structure trabéculaire de l'os alvéolaire sur des orthopantomogrammes de sujets d'âge différent

Des OPT, issus de documentations prises 2 ans (T1) et 10 ans (T2) après la fin du traitement orthodontique, ont été extraits des dossiers de 18 sujets jeunes (8 femmes, 10 hommes) et de 21 sujets adultes (12 femmes, 9 hommes). À T1, l'âge moyen était de 15.6 ± 0.9 ans et de 31.3 ± 9.7 ans, respectivement dans les groupes jeune et adulte. Un index visuel à trois grades a été appliqué pour évaluer bilatéralement la structure trabéculaire de l'os alvéolaire de la mandibule. Les sites examinés sont les espaces interdentaires entre la première prémolaire (côté distal) et la seconde molaire (côté mésial) inférieures. Une analyse de la variance (ANOVA), combinée à des tests *t* de Student lorsqu'une valeur statistiquement significative est présente, ont été utilisés pour déterminer l'influence de l'âge, de la durée entre les prises radiologiques et du genre sur la structure trabéculaire osseuse.

1.4 Résultats

1.4.1 Métholodogie

Au total, 79 sites interdentaires ont été évalués sur les radiographies OPT et apicales. L'analyse visuelle appliquée sur les radiographies apicales a révélé un accord intra-observateur de 0.85 pour le premier examinateur et 0.93 pour le deuxième, et un accord inter-observateur de 0.82. Pour les radiographies OPT, l'accord intra-observateur était de 0.81 et 0.83, respectivement pour les premier et deuxième examinateurs, et l'accord inter-observateur était de 0.78. Une corrélation appréciable a été trouvée entre les deux types de radiographies (r=0.736, p= 0.001).

1.4.2 Evaluation de la structure trabéculaire de l'os alvéolaire sur des orthopantomogrammes de sujets d'âge différent

L'analyse de la variance n'a révélé aucun effet significatif du genre sur l'évaluation de la structure trabéculaire osseuse, seul ou en combinaison avec les autres facteurs. A l'inverse, les facteurs âge et temps (durée du suivi entre les prises radiologiques) ont montré un effet significatif sur l'évaluation osseuse, mais sans interaction entre eux. Ainsi, l'os alvéolaire de la mandibule chez les sujets du groupe adulte a démontré une structure trabéculaire plus dense en comparaison avec les sujets du groupe jeune [test t non-apparié, P = 0.012]. Cette observation se fait également lorsque les radiographies des sujets adultes prises à T2 sont comparées à celles prises huit ans auparavant (T1) [test t apparié, *P* = 0.011]. Cependant, il n'a pas été constaté de différence statistiquement significative dans le groupe de sujets jeunes.

1.5 Discussion

1.5.1 Méthodologie

Le nombre limité de dossiers d'archives utilisé s'explique par la difficulté de trouver une casuistique associant des radiographies péri-apicales, représentant la région prémolaire-molaire inférieure, à un orthopantomogramme pris à la même date (à plus ou moins 6 mois). De plus, les radiographies périapicales ne sont pas toujours prises bilatéralement. Il aurait été idéal de disposer d'un status radiologique ainsi que d'un orthopantomogramme, de qualité adéquate et sans lésion pathologique active. Cependant, pour des raisons éthiques, une telle exposition radiologique de nos patients ne peut être admise lors d'un contrôle dentaire routinier.

Seuls deux examinateurs ont évalué les radiographies : afin d'obtenir une puissance statistique suffisante, le nombre d'évaluations a été augmenté (Hintze et al., 2003). Préalablement aux évaluations, une calibration des radiographies s'est faite à l'aide d'un programme de traitement d'image. Une référence arbitraire (fixée à 55% du niveau de gris) était établie au niveau des cuspides de la seconde prémolaire, bien qu'il existe des variations interindividuelles de forme, de largeur et d'épaisseur énamélaire. L'étude étant rétrospective, une standardisation de cette calibration via une échelle de gris radio-opaque présente sur toutes les radiographies, et rendant cette procédure plus précise, n'a pu être effectuée (Nackaerts et al., 2008).

Les différences inhérentes à la réalisation des deux types de radiographies utilisées dans l'étude impliquent certaines limitations. La précision des radiographies OPT est restreinte en comparaison aux radiographies péri-apicales du fait qu'une « couche » limitée de l'os est représentée sur l'orthopantomogramme, et non une « addition » des éléments osseux comme sur le cliché péri-apical. Par conséquent, la netteté des structures visibles sur l'orthopantomogramme dépend fondamentalement du positionnement correct du sujet radiographié. La distorsion géométrique de certaines régions anatomiques (notamment des prémolaires) ainsi qu'un effet d'agrandissement font obstacle à l'application de méthodes de mesures objectives (comme par exemple celle de la densité optique), qui sont par contre possibles sur les radiographies péri-apicales (Jonasson et al., 2006). Les orthopantomogrammes présentent toutefois quelques intérêts les rendant plus populaires dans la pratique dentaire actuelle (Rushton et al., 2002; Martínez Beneyto et al., 2007) : en effet, depuis ces dernières années, les images panoramiques sont de meilleure qualité, réalisées avec des doses de radiation réduites et d'une plus grande facilité d'utilisation.

La méthode d'évaluation décrite dans cette étude donne une appréciation qualitative de la trabéculation du processus alvéolaire de la mandibule. Malgré les différences évoquées précédemment, une concordance suffisante existe entre les évaluations qualitatives faites sur les deux types de radiographies, en utilisant le même index visuel. On peut noter que l'un des examinateurs, ayant utilisé depuis plus longtemps cet index visuel, a montré une plus grande reproductibilité des scores obtenus lors des évaluations : l'apprentissage de la méthode s'avère donc nécessaire pour améliorer l'accord intra-observateur.

1.5.2 Evaluation de la structure trabéculaire de l'os alvéolaire sur des orthopantomogrammes de sujets d'âge différent

L'évolution de la trabéculation osseuse en fonction de l'âge a été examinée de façons transversale et longitudinale. Pour une meilleure appréciation des changements à long terme, une période d'observation plus longue que celle de l'étude aurait été préférable. Ainsi, sur une durée de 8.2 ans, la structure trabéculaire du processus alvéolaire mandibulaire a révélé une tendance marquée de densification, mais non-significative. Néanmoins, l'évaluation transversale, comparant des sujets avec un écart d'âge d'en moyenne 23.9 années, a montré une structure trabéculaire significativement plus dense chez les sujets âgés.

Parmi les 39 cas sélectionnés pour l'étude, quatre ont eu un traitement orthodontique avec des extractions de prémolaires à l'arcade inférieure. Bien que la fermeture orthodontique d'espace implique un remodelage osseux considérable, il est peu envisageable que ce processus ait une influence sur la trabéculation visible sur l'image radiographique deux après la fin des mouvements dentaires.

Aucune différence liée au sexe n'a été détectée. Cette constatation est également confirmée par Chun and Lim (2008), dont l'échantillon étudié comportait des sujets de 25 à 35 ans. La taille de l'échantillon de la présente étude n'est de façon évidente pas suffisante pour être représentatif. Dans le groupe adulte, l'âge moyen des sujets féminins est plus élevé que celui des sujets masculins (tandis qu'il est similaire dans le groupe jeune), quatre des 12 femmes étant même âgées de plus de 50 ans à T2 (52-55 ans). Cependant, la possibilité qu'une de ces quatre femmes présente une maladie métabolique de type ostéoporose post-ménopausique, pouvant altérer la structure osseuse, a été exclue dans l'anamnèse médicale prise à T2. Ceci peut expliquer l'absence de disparité entre les deux genres dans le groupe adulte. Avec une taille d'échantillon plus large et une tranche d'âge plus étendue, des différences statistiquement significatives pourraient être observées.

Pendant la croissance, le remodelage osseux implique une évolution dans la taille et la forme des os. Après la fin de la croissance, chez le jeune adulte, les os subissent encore un remaniement avec les processus de résorption par les ostéoclastes et d'apposition par les ostéoblastes (Wang & Seeman, 2008). L'enrichissement en minéral osseux a lieu durant l'enfance et l'adolescence, et continue jusqu'à atteindre un pic maximal ("masse osseuse maximale" ou "peak bone mass" en anglais) à l'âge adulte jeune (Bonjour et al., 2009). À l'âge adulte avancé (> 65ans), une baisse de la densité de cette masse osseuse est habituellement observée, en raison d'un déséquilibre dans le processus de remaniement osseux (Seeman et al., 2008). Dans la présente étude, les sujets sélectionnés représentent l'âge adolescent (pubertaire) et l'âge adulte jeune. En considérant que la densité minérale osseuse du squelette est liée à la structure de l'os alvéolaire mandibulaire et à son épaisseur (Jonasson et al., 2001; Jonasson et al., 2006), un accroissement de la densité trabéculaire de cet os durant la puberté jusqu'à l'âge adulte jeune à moyen devient prévisible. L'adaptation du squelette à la charge mécanique durant la croissance pourrait également expliquer les résultats obtenus dans cette étude (Turner, 1998; Turner & Pavalko, 1998; Klein-Nulend et al., 2005). En effet, le processus alvéolaire de la mandibule faisant aussi partie du squelette, il est sujet à des contraintes répétitives lors de la mastication. Ainsi, une structure osseuse plus dense serait liée au développement musculaire (augmentation de la masse et de la puissance) de la puberté à l'âge adulte (Kiliaridis et al., 1993; Raadsheer et al., 1996).

1.6 Conclusions

- Les orthopantomogrammes peuvent être utilisés pour l'évaluation de la structure trabéculaire de l'os alvéolaire située entre les dents postérieures de la mandibule à l'aide d'un index visuel.
- L'application de la méthode nécessite de l'entrainement afin d'obtenir des résultats reproductibles.
- La densité de la trabéculation osseuse du processus alvéolaire s'avère être liée à l'âge. Ainsi, une structure trabéculaire plus dense est observée chez des sujets plus âgés. L'évaluation qualitative de la trabéculation de l'os alvéolaire a montré des différences sur le long terme dans le groupe adulte, avec une augmentation de la densité trabéculaire osseuse.

2. TEXTE DE SYNTHÈSE COMPLET (en anglais)

2.1 Introduction

Mandibular bone shows exclusive particularities, anatomical as well as functional. The intramembranous origin leads to formation of two distinct bony parts: the basal bone and the alveolar process (commonly called the alveolar bone), the latter constituting support for mandibular teeth. Both parts include an external dense cortical bone, and an internal trabecular bone. Like the skeletal bone system, the mandibular alveolar bone is subjected to remodeling process. Mechanical stimulation, originating from muscular function, is a major regulatory factor in bone homeostasis (White, 2002). It superimposes on and interacts with all other systemic and local mediators of bone metabolism. The alveolar bone is a skeletal part that is dependent on the presence of teeth and masticatory function, since, in the absence of teeth (Carlsson, 2004) or lack of mechanical stimulation transmitted by implant supported overdenture, it undergoes disuse atrophy (Doundoulakis et al., 2003). Independently of the age, there is a great interindividual variation in trabecular volume and interconnections, leading to variable trabecular bone patterns (Ulm et al., 1999). Variation in the trabecular bone microstructure is also site-dependent within individuals (Amling et al., 1996; Moon et al., 2004).

Several techniques have been lately developed to measure bone mineral density (BMD), as well as to characterize bone microstructure (Lespessailles et al., 2006; Moon et al., 2004). Despite progress, technical problems remain. The cost and complexity of these methods also limit their availability and accessibility to routine use. Panoramic and periapical radiographs are common diagnostic tool in dentistry. Their periodic and rapid acquisition, their effectiveness and the spreading use of digital radiology make them of great interest now for clinical practice. However, although they were made for dental diagnosis first, they may provide other useful information as well. For example, dental radiographs showing mandibular or maxillary bone may also be used for the diagnosis of bone-related diseases, such as osteoporosis or osteonecrosis. Several recent studies (Genant & Jiang, 2006; Moon et al., 2004; Couture et al., 2003; White et al., 2005; Nackaerts et al., 2008; Devlin & Horner, 2008; Geraets et al., 2007) used conventional intraoral radiographs for assessing mandibular trabecular bone, analyzing them by either quantitative methods, such as microdensitometry and pixel density analysis, or qualitative methods using computed tomography and magnetic resonance. Lindh et al. (1996) proposed a simple method of screening alveolar bone by a visual index to assess qualitatively the trabeculation pattern on dental radiographs. This method consists of three classifications of bone trabeculation density (sparse, alternating dense and sparse, and dense trabeculation), and it has been employed in both cross-sectional and longitudinal studies that evaluated the association between trabecular bone structure and skeletal bone mineral density (BMD) in dentate men and women (Jonasson et al., 2006; Jonasson et al. 2007; Lindh et al., 2008).

Panoramic radiographs have been used to evaluate mandibular bone in different dental research fields, as are orthodontics, implantology, periodontology or oral pathology. They have been used much more frequently than periapical radiographs in routine orthodontic planning, mostly to control the number of non-erupted teeth. In adult orthodontics, a different tissue reaction could be expected when moving teeth in bone with sparse or dense trabeculation. This could be supported by the findings that rats with lower initial bone density have a faster orthodontic tooth movement than rats with significantly higher initial bone density (Bridges et al., 1988). Orthodontic tooth movement was also found to be faster in rats on a calcium-deficient diet than in rats on a normal diet (Goldie & King, 1984). Thus, it may be useful to add further knowledge on how the alveolar trabecular pattern changes with aging, from adolescence, through adulthood to old age and how orthodontists can use this knowledge in their treatments. Previously, panoramic radiographs have been used to give information on the cortical part of both jaws (Taguchi et al., 2008). Very few studies have described trabecular bone on panoramic radiographs, but a correlation has also been found between mandibular trabecular patterns depicted in panoramic radiographs and the density of the same region as measured on CT scans (Taguchi et al., 1997; Yalcinkaya et al., 2006; Bianchi et al., 2007). However, it is not known if the qualitative visual index used on periapical radiographs is efficient to assess alveolar trabecular bone on panoramic radiographs.

The alveolar bone density has been quantitatively measured on computed tomographic (CT) images (Turkyilmaz et al., 2007; De Oliveira et al., 2008; Park et al., 2008; Choi et al., 2009; Chun & Lim, 2009). Results showed significant differences of bone density values between the alveolar and basal bone of both maxilla and mandible, with progressively increasing values from anterior to posterior areas, and with higher values in the mandible. Thus, bone densities may vary when different areas of jaws are compared.

Recently in orthodontics, the focus has been on miniscrew implants as skeletal anchorage system that does not require patient compliance. Many studies have investigated the factors related to stability because the failure rate of mini-implants, ranging from 9% to 30%, is high compared to that of osseointegrated endosseous implants (Miyawaki et al., 2003; Cheng et al., 2004; Park et al., 2006; Reynders et al., 2009). Among the factors related to failure, it has been reported that the implantation site has an important role (Park et al., 2006; Hoste et al., 2008). A review on endosseous implants has shown that jaw bone with reduced density correlates with a reduced primary stability and a significantly higher implant failure rate (Molly, 2006). Consequently, the density and architecture of the trabecular host bone are crucial to the stability of an endosseous implant in the alveolar ridge. Regarding mini-implants, younger patients seem to exhibit a greater risk of failing compared to adult patients (Chen et al., 2007).

To date, no study comparing the functioning alveolar bone of a young (growing) group to an adult (non-growing) group has been found in the literature. Also, no conclusions have been established when looking for possible gender differences in the healthy alveolar bone.

2.2 Aims

1) To determine whether the mandibular trabecular bone assessment on panoramic radiographs, using a visual index, corresponds to the evaluation obtained from periapical radiographs.

2) To assess changes of the alveolar trabecular bone during growth using panoramic radiographs, and to detect possible differences in trabecular bone patterns when comparing individuals of various ages and gender.

2.3 Materials and Methods

2.3.1 Methodological study

2.3.1.1 Subjects. The material consisted of radiographs found in the files of patients previously treated in our dental school (University Dental School of Geneva, Switzerland). For each patient, a panoramic radiograph (Kodak T-Mat G/RA film, 15x30 cm, Carestream Health, Inc. France) and corresponding periapical radiographs (Kodak Ultra-speed film, 31x41 mm, Carestream Health, Inc. France) of the region of the lower premolars and molars were collected. These radiographs have been made for clinical reasons by several radiological technicians and at disparate dates, between years 2001 and 2008. The radiographs were taken with the same radiological devices. For the panoramics, Scanora® was used (Soredex, Orion Corporation, Helsinki, Finland), with the exposition parameters recorded on radiographs as a standardized procedure. For the periapical radiographs, Heliodent MD® was used (Sirona, Benzheim, Germany). However, the exposition parameters were not recorded. The selection criteria were defined as follows:

- The patient presented permanent dentition (complete until first molars) in mandibular posterior regions

- Both types of radiographs were taken during the same period (± 3 months)
- The radiographs were diagnostically acceptable, showing a distinct trabecular pattern in the premolar and molar regions
- No orthodontic device in the lower arch was in use at that period
- The radiographs were taken before the beginning of orthodontic treatment or two years after the end of treatment.

32 patients (21 females, 11 males) were eligible following the selection criteria. The age of the patients when the panoramic radiography was taken was on average 18.5 years (± 5.5 years). Among the 32 subjects, 10 were from the orthodontic clinic, and 22 were treated in the dental school for other clinical indications. Radiographs of subjects selected from the orthodontic clinic were taken before the beginning of any orthodontic treatment, or at least two years after the end of treatment, to insure that no additional bone remodeling due to extraction or tooth movement occurred at the time of radiography.

Of the 32 cases, 24 presented periapical radiograph of one side, thus the remaining 8 cases had periapical radiographs on both sides. Interdental sites mesial and distal to the second premolar were examined, which corresponds to 2 sites for evaluation per side. The 24 cases with one periapical radiograph had then 48 evaluable sites, and the 8 cases with periapical radiographs of both sides had 32 evaluable sites. In one case, an interdental site distal to the second premolar was not evaluable due to closeness of the roots. Consequently, 79 homologous sites in total were assessed on both kinds of radiographs in our study.

2.3.1.2 Evaluation of the reliability of the method on periapical radiographs. As the radiographs have not been realized in a standardized manner, a preliminary methodological part of the study was needed in order to determine the validity of the heterogeneous data. In that purpose, two dried human mandibles with all lower teeth present were chosen and radiographs have been taken on each side (Insight film, Kodak F/E-speed, 31x41mm). The films were stabilized with a Hawe Super-Bite film holder (Hawe Neos Dental SA, Switzerland) and adjusted with hard wax (Moyco

Extra-Hard Wax, Moyco Technologies Inc.) on the mandibles to standardize image geometry, and the same radiological device (Heliodent MD®, Sirona, Benzheim, Germany) took the radiographs at 7mA. The device allowed variable voltages and exposure times. A reference radiograph was arbitrarily made at 60 kV and 0.12 s. Then, in order to create a heterogeneous pool of radiographs, other radiographs were taken by varying the voltages and exposure times. The same operator took all the radiographs (DP). Finally, 20 radiographs have been taken on each side of the mandibles, and in total 80 radiographs of differently determined exposure parameters were taken.

The radiographs were then digitized at 600 dpi and in grayscale mode, with a flatbed scanner (Epson Expression 1600 Pro, Seiko Epson Corp., Japan) and a non-compressed TIFF format was used for disk storage. The images were examined with image software allowing a combined adjustment of the light intensity and the contrast (Adobe Photoshop 7.0, Adobe Systems Corporation Inc, USA). A gray level calibration was achieved between the reference radiograph and the other radiographs by altering the whole gray level of the latter until the enamel gray level at the second premolar matches with that one of the reference radiograph (Figure 1).

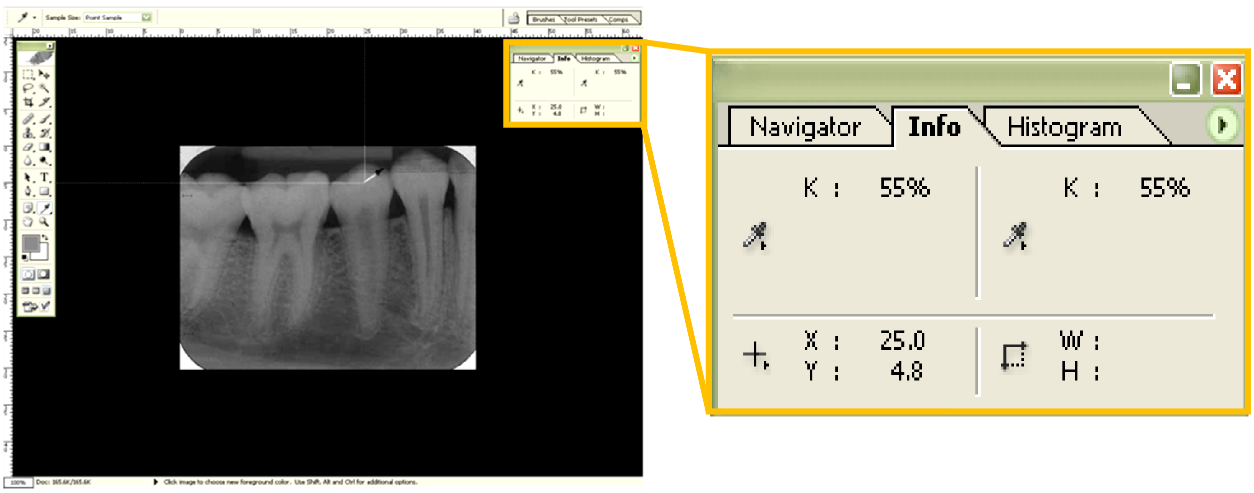

Figure 1. Schematic demonstration of enamel gray-level calibration using the eyedropper tool of Photoshop-based image analysis on the reference radiograph (taken at 7mA and 60 kV, with an exposure time of 0.12 s). The reference coordinates used for all radiographs are x: 25.0 mm and y: 4.8 mm (see "info" window in the inset). The reference enamel gray-level for all radiographs was arbitrarily chosen at the level of 55%.

Comparisons were accomplished by one observer (DP). A careful visual inspection of the radiograph quality, the bone trabeculae appearance, the sharpness and the contrast of seen structures was then conducted in a dark room and on a black background.

As a result of this preliminary stage, radiographs taken under varying conditions of radiological exposition showed no noticeable difference to the naked eye after gray level calibration. This statement is based on one observer subjective judgment and was strictly not evidenced-based. Thus, we assumed that this method of luminosity and contrast adjustments could be employed on radiographs realized in non-standardized conditions, in order to compare the displayed alveolar bone trabeculation with improved visibility.

2.3.1.3 Assessment of bone trabeculation. The interdental sites evaluated were located between the lower first molar and second premolar, and between the two lower premolars. Two evaluators used the following three-scale visual index: when the trabecular pattern was evaluated as sparse (score 1), the criterion was large intertrabecular spaces especially in the cervical dentate premolar area; when the trabecular pattern was evaluated as dense (score 3), the entire radiographed area had an equal degree of trabeculation and the intertrabecular spaces were small even under the roots; when the trabecular pattern was assessed as alternating dense and sparse (score 2) the trabeculation was normally denser cervically and sparser apically (Figure 2).

Figure 2. The three-scale visual analysis for assessment of bone trabeculation. Score 1 corresponds to a sparse trabeculation, score 2 to an alternating dense and sparse trabeculation, and score 3 to a dense trabeculation.

The calibration of radiographs was based on the density of the enamel of the cuspids of the second premolar. We applied the same three-scale visual index on the panoramic radiographs. Often, the trabecular pattern apically of the molars was extremely sparse (Jonasson et al., 2006, 2007). When it was difficult to classify the trabecular pattern, score 2 was chosen. Bone areas with pathological lesions such as sclerotic bone and apical destruction around apices of teeth were not evaluated. The assessors calibrated themselves using 10 additional panoramic radiographs with their corresponding periapicals, selected with the same criteria as previously described. Those radiographs used for inter-observer calibration have not been employed for assessing the bone trabeculation on the periapical and panoramic radiographs. After inter-observer calibration, the two assessors examined both the periapical and panoramic radiographs.

2.3.1.4 Statistical analysis. To appreciate the reliability of the method, a second assessment of all radiographs was performed after 60 days, by both evaluators. Kappa (κ) statistics were used to calculate the intra-observer and inter-observer agreements, with SPSS version 13.0 (SPSS Incorporated, Chicago, Ill). Kappa (κ) values equal to 0 represent agreement equivalent to that expected by chance, while 1 represents perfect agreement. In accordance with Landis and Koch (1977), the following Kappa (κ) interpretation scale was used: poor to fair (below 0.4), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1).

A two-tailed Spearman's correlation analysis was used to compare results (of the second evaluation) of periapical radiographs with those of panoramic radiographs.

2.3.2 Evaluation of the trabecular alveolar bone in respect to age on panoramic radiographs

2.3.2.1 Subjects. The material consisted of 39 sets of two panoramic radiographs from patients treated in our dental school, divided into two groups: the young group (growing individuals) and the adult group (non-growing individuals). For each subject selected, the panoramic radiographs were taken at 2 years (T1) and 10 years (T2) after completion of their orthodontic treatment. In the young group, the mean age at T1 was 15.6 ± 0.9 years (range, 14.2-16.8 years) and 23.9 ± 1.1 at T2 (range, 21.1-25.4 years). The mean age difference between T2 and T1 (ΔT2-T1) was 8.3 ± 1.3 years. The mean age of the adult group at T1 was 31.3 ± 9.7 years (range, 20.1-46.4 years) and 39.5 ± 10.1 years at T2 (range, 27.4-55.1 years). The mean age difference between T2 and T1 (ΔT2-T1) was 8.2 ± 1.3 years. The panoramic radiographs were examined at two years (T1) and at 10 years after completion of orthodontic treatment (T2). 18 subjects for the young group (8 females, 10 males), and 21 subjects for the adult group (12 females, 9 males) met the following inclusion criteria:

- Panoramic radiographs diagnostically acceptable at T1 and at T2
- Age at T1 must be up to 17 years in the young group and over 20 years in the adult group
- No active orthodontic treatment and no tooth extraction (except for third molars) between T1 and T2
- No periodontal disease with no alveolar bone loss
- Healthy general conditions, with no medication or disease according to the medical history.

2.3.2.2 Evaluation of changes in trabecular alveolar bone during growth using conventional panoramic radiographs. The panoramic radiographs were digitized at 600 dpi and in grayscale mode, with a flatbed scanner (Epson Expression 1600 Pro, Seiko Epson Corp., Japan) and a non-compressed TIFF format was used for disk storage. The images were examined with image software allowing a combined adjustment of the light intensity and the contrast (Adobe Photoshop 7.0, Adobe Systems Corporation Inc, USA). The panoramic radiographs of both groups and at both T1 and T2 have been previously mixed in a random way and blinded for examination. One operator (DP) did all evaluations of the trabeculation of alveolar bone using the following three-scale visual analysis: when the trabecular pattern was evaluated as sparse (score 1), the criterion was large intertrabecular spaces especially in the cervical dentate premolar area; when the trabecular pattern was evaluated as dense (score 3), the entire radiographed area had an equal degree of trabeculation and the intertrabecular spaces were small even under the roots; when the trabecular pattern was assessed as alternating dense and sparse (score 2) the trabeculation was normally denser cervically and sparser apically.

The assessment was performed at the level of six interdental sites located bilaterally, from the distal side of the first premolars to the mesial side of the second molars of the lower arch (Figure 3). Whenever the root proximity or any anatomical characteristics (such as idiopathic osteosclerosis) hindered accurate evaluation of the interdental site, the latter was not taken into account. All corresponding panoramic radiographs at T1 and at T2 had the same interdental sites evaluated.

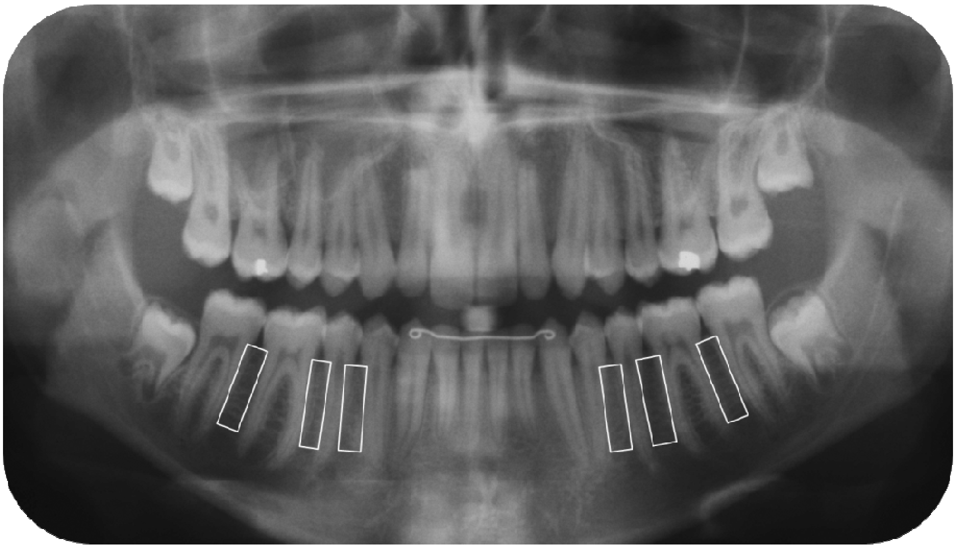

Figure 3. Example of panoramic radiograph selected for bone trabeculation evaluation. The six white rectangles represent the interdental spaces examined, when this was possible. Panoramic radiographs at T1 and at T2 of the same subject had the same interdental sites evaluated.

2.3.2.3 Statistical analysis. The scores given for each interdental site of each jaw have been averaged. The mean values were then used for statistical analysis. An analysis of variance (ANOVA) was first undertaken to assess differences between and within the groups according to three variables: the age group, the time spent between examinations (from T1 to T2), and the gender, after confirming normal distribution with the Shapiro-Wilk test. In addition, for each significant result following the ANOVA test, paired and unpaired t-tests were planned for pair comparisons: paired t-tests for longitudinal assessment of the alveolar bone trabeculation in each group, unpaired t-tests for cross-sectional assessment of the alveolar bone trabeculation between the groups, and unpaired t-tests for assessment of gender discrepancy. The significance level was set at 0.05. The Statistical Package for Social Science for Windows, version 13.0 (SPSS Inc., Chicago, Illinois, USA) was used for these statistical tests.

2.4 Results

2.4.1 Results of the assessment of trabecular pattern

2.4.1.1 In periapical radiographs. The kappa values (κ) for intra-observer agreement, issued from the scores of the first and the second evaluations, was 0.88 for assessor 1 (DP) and 0.93 for assessor 2 (GJ). For the inter-observer agreement, obtained with the second measurements, a Kappa (κ) of 0.82 was found.

2.4.1.2 In panoramic radiographs. The kappa values (κ) for intra-observer agreement, issued from the scores of the first and the second evaluations, was 0.79 for assessor observer 1 and 0.83 for assessor 2. For the inter-observer agreement, obtained with the second measurements, a Kappa (κ) of 0.79 was found.

Table I. Intraobserver and interobserver agreements of assessment of the trabecular pattern on periapical radiographs and panoramic radiographs.

Type of radiograph	*Intra-observer assessor 1*		*Intra-observer assessor 2*		*Inter-observer agreement*	
	kappa	*95% CI*	*kappa*	*95% CI*	*kappa*	*95% CI*
Periapical	0.88	0.82-0.94	0.93	0.87-0.98	0.82	0.73-0.93
Panoramic	0.79	0.70-0.87	0.83	0.73-0.92	0.79	0.70-0.88

2.4.1.3 Comparison between periapical and panoramic radiographs. The Spearman's coefficient showed substantial correlation between periapical and panoramic radiographs (rho=0.737, p=0.001).

Details of the assessment of the trabecular pattern evaluated on periapical radiographs compared to the one evaluated on panoramics are shown in the following table.

Table II. Contingency table of scores obtained from the assessment of trabecular pattern between periapical and panoramic radiographs.

		Panoramic radiographs			
		Score 1	*Score 2*	*Score 3*	***total***
Periapical radiographs	*Score 1*	7	0	0	7
	Score 2	18	35	0	53
	Score 3	1	2	16	19
	total	26	37	16	79

2.4.2 Results of the evaluation of changes in trabecular alveolar bone during growth using conventional panoramic radiographs

The analysis of variance assessing the main effects of the three variables (age, extent of the following period, and gender) on the alveolar bone trabeculation scores revealed that only the factor gender did not show a significant effect on bone trabeculation scores, neither alone nor in interaction with other factors. In contrast, the factors age and time showed to have a significant effect, but there was no interaction.

For the cross-sectional assessment of the alveolar bone trabeculation scores, the more extreme age groups studied were compared, (which means the young group at T1 [15.6 ± 0.9 years] with the adult group at T2 [39.5 ± 10.1 years]) using unpaired t –test. It was found that the adult group at T2 had a higher alveolar bone trabeculation score than the young group at T1 (P = 0.012).

*Table III. Unpaired t-test to assess the alveolar bone trabeculation of the groups having the highest mean age difference: the comparison is between the alveolar bone trabeculation of the young on the first radiographs and the adults on the second radiograph (Values are the mean of the scores given with the three-scale visual analysis ; * $P \leq 0.05$).*

Young T1			Adults T2			
n	Mean	SD	n	Mean	SD	*P*-value
18	1.73	0.37	21	2.04	0.35	.012 *

For longitudinal assessment of the alveolar bone trabeculation scores, paired t-tests comparing each group from T1 to T2 indicated significant differences only in the adult group. Namely, the alveolar bone trabeculation became denser during the eight years follow-up of this adult group (P = 0.011).

*Table IV. Paired t-tests to assess the alveolar bone trabeculation scores in the adult group and the young group, from T1 to T2. (Values are the mean of the scores given with the three-scale visual analysis ; * P ≤ 0.05).*

		T1		***T2***		***ΔT2-T1***		
Groups	*n*	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***P-value***
Young	18	1.73	0.37	1.69	0.39	-0.04	0.38	.664
Adult	21	1.88	0.32	2.04	0.35	0.17	0.24	.011 *

2.5 Discussion

In this study, we have shown that it is possible to qualitatively assess the mandibular trabecular bone, mesially and distally of the second premolar, using a three-scale visual index on panoramic radiographs. Although the periapical radiography is superior to panoramic radiography for the evaluation of BMD, the present study has shown that the mandibular trabecular bone, as detected on panoramic radiographs, was denser in adult individuals than in young individuals. When comparing subjects of various ages, significant differences in trabecular bone patterns were found only in the adult group after a mean follow-up of 8 years. Gender differences were not found to be significant according to our results, in both groups of the present sample.

2.5.1 Differing characteristics of periapical and panoramic radiographs

There are differences between the imaging technique of panoramic radiographs and that of the periapical radiographs. The parallel technique was used for the periapical radiographs, whereas panoramic images are created by a rotational technique. The differences between panoramic and periapical radiographs are the greater value of panoramics for screening than for diagnosis purposes, and the geometric distortion of panoramic images, due to the rotational technique. Furthermore, the region of focus initially created within a generic jaw form and size is limited in size and some structures that are not centered in the focal trough may be “lost”. Thus, the accuracy of the panoramic technique is more limited than the intraoral radiography since it presents a “layer” of the bone and not a “summation” of the bone elements. Furthermore, the correct positioning of the patients is fundamental for obtaining a sharp and useful panoramic image.

The geometric distortion made the premolar roots seem closer to each other on the panoramics. This fact plus the magnification factor for the panoramics precluded the use of objective methods such as measurements of optical density and gray level assessment in a standard location to support our findings. These techniques can be used in periapical radiographs (Jonasson et al., 2006) but are not easily transferred for use on panoramics. Despite differences of the rotational panoramic radiographs, which is an image layer radiograph, and that of the conventional intra-oral radiographs, there was an agreement between the two evaluations when the bone structure was studied.

2.5.2 Qualitative assessment of the trabecular bone on dental radiographs

In previous studies, the feasibility of a similar visual index has been demonstrated on periapical radiographs (Lindh et al., 1996; Jonasson et al., 2006; Jonasson et al., 2007; Lindh et al., 2008). Our results showed that inter-observer agreement was somehow lower when evaluating the mandibular trabecular bone on panoramic radiographs than periapical radiographs, and a correlation did exist when evaluating the bone density using these two different kinds of radiographs.

Only radiographs with full posterior lower dentition have been compared, as it was intended to assess the functioning alveolar bone that is under mechanical stimulation. Loss of teeth is known to be followed by irreversible alveolar bone resorption.

The method used provides a qualitative evaluation of mandibular trabecular bone characteristics, in contrast to other methods that can give quantitative values of bone density, like dual energy X-ray absortiometry (DXA) (Nackaerts et al., 2006) or computerized tomography (Turkyilmaz et al., 2007), or information on trabecular bone microarchitecture, which is possible with magnetic resonance imaging (MRI) (Choël et al., 2004) or also micro-computed tomography (μ-CT) (Giesen & van Eijden, 2000; Moon et al., 2004). Because of their improved quality, reduced radiation dose and ease of use, panoramic radiographs have become popular in dental diagnosis (Rushton et al., 2002; Martínez Beneyto et al., 2007). This kind of radiograph can bring a collection of information about the patient and the bone status. It is a relatively costless, rapid and simple tool and it seems useful for assessment of the alveolar trabecular bone.

Evaluating the bone structure through the present method showed that the senior assessor, who worked with the visual index for longer, had somehow higher reliability than the junior assessor, in assessing both the periapical and the panoramic radiographs. Training of the technique seems then to improve the intra-observer agreement.

2.5.3 Trabecular alveolar bone changes in the mandible over 8 years

The mandibular trabecular bone, as detected on panoramic radiographs, was determined to be denser in adult individuals than in young individuals. When comparing subjects of various ages, significant differences in trabecular bone patterns were found in the adult group after a mean follow-up of 8 years, and between the youngest and the eldest individuals in this study. Gender differences were not found to be significant according to our results, in both groups of the present sample.

During growth, bone modeling is taking place with changes of bone size and shape. After the end of the growth period, in early adulthood, the bone is still remodeled by resorption performed by osteoclasts and apposition by osteoblasts (Wang & Seeman, 2008). Acquisition of bone mineral continues throughout childhood and adolescence, reaching a lifetime maximum (“peak bone mass”) in early adulthood (Bonjour et al., 2009). In old adulthood (> 65 years), decrease in bone mass density is usual, due to an unbalanced remodeling process (Seeman et al., 2008). In our study, the subjects selected were representative of the young age (pubertal) and the early adulthood age. Knowing that the skeletal bone mineral density has been found to be associated with the mandibular alveolar bone structure and the alveolar thickness (Jonasson et al., 2001; Jonasson et al., 2006), an increase in the alveolar mandibular trabeculation density can thus be expected from the puberty to early/middle age adulthood. Furthermore, our findings could be related to the adaption of the skeleton to mechanical loads during growth (Turner, 1998; Turner & Pavalko, 1998; Klein-Nulend et al., 2005). The mandibular alveolar process is part of the skeleton and is subjected to repetitive loads during mastication, thus a denser bone structure could be expected from puberty to adulthood as the mechanical loading increases with muscular mass and strength (Kiliaridis et al., 1993; Raadsheer et al., 1996).

2.5.4 Data collection and analysis

In the methodological study, the sample was small because it was difficult to find periapical radiographs of the premolar and molar regions taken within the same period as the panoramics, and not all the subjects had a periapical radiograph on both sides. Ideally, subjects with a full-mouth radiographic examination and a panoramic radiograph, of adequate quality and without active pathologic lesions, were sought for the study. However, ethical reasons do not permit to perform such an exposure of the patient in a routine dental control. 10 of the 32 subjects were from the orthodontic clinic. Orthodontic patients mostly have sound oral conditions before treatment. A panoramic radiograph is usually taken at initial documentation, completed by anterior periapical when necessary. There is little indication to take a periapical radiograph of the posterior lower teeth, on one or both sides, and this explains the small number of orthodontic subjects in our study. The remaining 22 were treated in the dental clinic for other clinical indications than orthodontic reasons (carious or periodontal lesions).

The study design included only two observers. Thus, the number of evaluations to obtain sufficient statistical power has been increased (Hintze et al., 2003).

A calibration of the radiographs was conducted before assessment, with the image software used and based on the enamel at the cuspids of the second premolar (arbitrarily set at 55 % of gray level), although individual variation exists in tooth form, width and enamel thickness. It is possible that a radio-opaque stepwedge in every radiograph may have standardized more precisely the calibration procedure (Nackaerts et al., 2008), but the present study was a retrospective study, and the calibration tool was not used.

Possible age discrepancies in a cross-sectional and in a longitudinal way were assessed. To better describe long term changes in the alveolar trabecular bone, the period of observation should have been longer. Since our samples did not allow this, a young (growing) and an adult (non-growing) groups were followed and a comparison of the bone trabeculation between the youngest and the eldest subjects was undertaken. Thus, when considering the bone trabeculation over a period of about 8.2 years in both groups, a slight increase is observed but is not significant. Nevertheless, in the cross-sectional assessment, groups with a mean age difference of 23.9 years were compared, and the older age group appeared to have a significantly denser bone trabeculation scores than the younger one.

Among the 39 cases selected for the study, 4 cases presented a previous orthodontic treatment with premolars extractions in the mandibular arch. Although space closure involved considerable bone remodeling, it was unlikely that the orthodontic treatment influenced the bone trabeculation depicted on the panoramic radiograph two years after its completion.

No gender difference was detected. This was consistent with Chun and Lim (2008), whose study samples were ranging between 25 and 35 years of age. The small sample size certainly was not representative enough. Moreover, in the adult group, the mean age of the female subjects is higher than the mean age of the male subjects, whilst it is approximately the same in the young group. Four of the twelve female subjects in the adult group were more than 50 years of age at T2 (52-55 years). However, the risk of postmenopausal osteoporosis, which would alter the bone trabeculation faster, was excluded according to the answers given in their medical history taken at T2. This can explain the absence of sex-based discrepancy in our adult group even though mean ages were unfavorable for the female subjects. With larger samples and wider range of age, statistical significant differences are probably to be expected.

2.5.5 Areas of further studies

The results of the present study may give an insight to the variations in tooth movement rate observed with age. In adult orthodontics, a different tissue reaction could be expected when moving teeth in bone with sparse or dense trabeculation, as was shown in an experimental animal study, in which rats with lower initial bone density have a faster orthodontic tooth movement than rats with significantly higher initial bone density (Bridges et al., 1988). Our findings may be in line with the previous investigation made on the mandibular bone and its possible influence on orthodontic treatment stability (Rothe et al., 2006). Furthermore, the observed changes in bone density taking place with age may be related to the success rate of mini-implants. Kim et al. (2010) concluded that the patient's age is an influencing factor for success rates of midpalatal miniscrews used for orthodontic anchorage. Additionally, Molly et al. (2006) stated that a reduced density of the jaw bone was correlated to a significantly higher failure rate of endosseous implants. The results of the present work can apparently be linked to these observations, as they showed a significant difference in the bone trabeculation between young and adult individuals.

2.6 Conclusions

- Panoramic radiographs can be used for the assessment of trabecular bone pattern between lower posterior teeth with the help of a visual index, provided that the interdental sites are assessable (not narrowed by roots proximity).
- Training on the method is recommended to obtain higher reproducibility of the results.
- The trabecular bone structure in the alveolar process appears to be related to the age, thus a denser trabeculation was found in older subjects. The longitudinal qualitative assessment of the alveolar trabecular bone has shown increasing bone density within the adult group.

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ORIGINAL ARTICLE

Assessment of trabecular pattern on periapical and panoramic radiographs: A pilot study

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Abstract

Objective. This methodological study aimed to determine whether the mandibular trabecular bone assessment from panoramic radiographs, using a visual index, corresponds to the evaluation obtained from periapical radiographs. ***Material and methods.*** A panoramic radiograph and corresponding periapical radiographs of the region of the lower premolars and molars were collected from each of 32 patients (mean age 18.5 ± 5.5 years). Two calibrated observers assessed randomly the interdental sites between the first molar and second premolar and between the two premolars on all the radiographs using a visual index. Evaluations were repeated with an interval of 60 days. The results of the repeated evaluations were used to assess intra- and inter-observer agreements, employing Kappa statistics. Spearman's correlation was used to determine the association between assessments of panoramic and periapical radiographs. ***Results.*** In total, 79 interdental sites were evaluated on the panoramic and periapical radiographs. The visual analysis of periapical radiographs revealed intra-observer agreements of 0.88 for observer 1 and 0.93 for observer 2, and an inter-observer agreement of 0.82. The intra-observer agreement for panoramic radiographs was 0.79 and 0.83 for observers 1 and 2, respectively, and the inter-observer agreement was 0.79. A substantial correlation was found between periapical and panoramic radiographs (rho = 0.737, p = 0.001). ***Conclusions.*** Although panoramic radiographs are less reliable than periapical radiographs, they can be used for assessment of the trabecular bone pattern with the aid of a visual index. Training on the method is recommended to obtain results with a high reproducibility.

Key Words: *Alveolar trabecular bone, assessment, panoramic radiographs, periapical radiographs*

Introduction

Mandibular bone shows exclusive particularities, both anatomical and functional. The intramembraneous origin leads to formation of two distinct bony parts: the basal bone and the alveolar process (commonly called the alveolar bone), the latter constituting support for the mandibular teeth. Both parts include an external dense cortical bone and an internal trabecular bone.

The mandibular trabecular bone is subject to physiologic remodeling throughout life, and can be influenced by masticatory demands, orthodontic movements, and extractions [1]. Independently of age, there is great interindividual variation in trabecular volume and interconnections, leading to variable trabecular bone patterns in the mandible [2,3].

Several techniques have lately been developed to measure bone mineral density (BMD), as well as to characterize bone microstructure [4,5]. Despite progress, technical problems remain. The cost and complexity of these methods also limit their availability and accessibility for routine use. Panoramic and periapical radiographs are common diagnostic tools in dentistry. Their periodic and rapid acquisition, their effectiveness and the spreading use of digital radiology make them of great interest in current clinical practice. However, although they were intended primarily for dental diagnosis, they may provide other useful information as well. For example, dental radiographs showing mandibular or maxillary bone may also be used for the diagnosis of bone-related diseases, such as osteoporosis or osteonecrosis. Several recent studies [3,5–10] used conventional intraoral radiographs

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for assessing mandibular trabecular bone, analyzing them by means of either quantitative methods, such as microdensitometry and pixel-density analysis, or qualitative methods using CT and MRI. Lindh et al. [11] proposed a simple method of screening alveolar bone by means of a visual index to assess qualitatively the trabeculation pattern on dental radiographs. This method consists of three classifications of bone trabeculation density (sparse, alternating dense and sparse, and dense), and it has been employed in both cross-sectional and longitudinal studies that evaluated the association between trabecular bone structure and skeletal BMD in dentate men and women [12–14].

Panoramic radiographs have been used to evaluate mandibular bone in different dental research fields, such as orthodontics, implantology, periodontology, and oral pathology. They have been used much more frequently than periapical radiographs in routine orthodontic planning, mostly to control the number of non-erupted teeth. In adult orthodontics, a different tissue reaction can be expected when moving teeth in bone with sparse or dense trabeculation. This may be supported by the finding that rats with lower initial bone density have a faster orthodontic tooth movement than rats with significantly higher initial bone density [15]. Orthodontic tooth movement was also found to be faster in rats on a calcium-deficient diet than in rats on a normal diet [16]. Thus, it may be useful to add further knowledge of how the alveolar trabecular pattern changes with aging from adolescence through adulthood to old age and to consider how orthodontists can use this knowledge in their treatments. Previously, panoramic radiographs have been used to give information on the cortical part of both jaws [17]. Very few studies have described trabecular bone on panoramic radiographs [18–20]. Thus, it is not known whether the qualitative visual index used on periapical radiographs is efficient to assess alveolar trabecular bone on panoramic radiographs.

Therefore, the aim of the present methodological study was to determine whether the mandibular trabecular bone assessment on panoramic radiographs, using a visual index, corresponds to the evaluation obtained from periapical radiographs.

Material and methods

Material

The material consisted of radiographs found in the files of patients previously treated at our dental school (University Dental School of Geneva, Switzerland). For each patient, a panoramic radiograph (Kodak T-Mat G/RA film, 15×30 cm; Carestream Health, Inc., Bagnolet, France) and corresponding periapical radiographs (Kodak Ultra-speed film, 31×41 mm; Carestream Health, Inc.) of the region of the lower premolars and molars were collected. These radiographs had been obtained for clinical reasons by several radiological technicians and at various dates between 2001 and 2008. The radiographs were taken with the same radiological devices. For the panoramics, Scanora® was used (Soredex; Orion Corporation, Helsinki, Finland), with the exposition parameters recorded on radiographs as a standardized procedure. For the periapical radiographs, Heliodent MD® was used (Sirona, Benzheim, Germany). However, the exposition parameters were not recorded. The selection criteria were defined as follows: (1) the patient presented permanent dentition (complete until first molars) in the mandibular posterior regions; (2) both types of radiograph were taken during the same period (± 3 months); (3) the radiographs were diagnostically acceptable, showing a distinct trabecular pattern in the premolar and molar regions; (4) no orthodontic device in the lower arch was in use during that period; and (5) the radiographs were taken before the beginning of orthodontic treatment or 2 years after the end of treatment.

A total of 32 patients (21 females, 11 males) met the selection criteria. The age of the patients when the panoramic radiographs were taken was on average 18.5 years (± 5.5 years). Among the 32 subjects, 10 were from the orthodontic clinic, and 22 were treated in the dental school for other clinical indications. Radiographs of subjects selected from the orthodontic clinic were taken before the beginning of any orthodontic treatment, or at least 2 years after the end of treatment, to insure that no additional bone remodeling due to extraction or tooth movement occurred at the time of radiography.

Of the 32 cases, 24 presented periapical radiographs of one side, and thus the remaining eight had periapical radiographs of both sides. Interdental sites mesial and distal to the second premolar were examined, which corresponds to two sites for evaluation per side. The 24 cases with one periapical radiograph then had 48 evaluable sites, and the eight cases with periapical radiographs of both sides had 32 evaluable sites. In one case, an interdental site distal to the second premolar was not evaluable due to closeness of the roots. Consequently, 79 homologous sites in total were assessed on both types of radiographs in our study.

Methods

Evaluation of the reliability of the method—on periapical radiographs. As the radiographs had not been realized in a standardized manner, a preliminary methodological part of the study was needed in order to determine the validity of the heterogeneous data. For that

Table I. Voltages and exposure times used for the preliminary methodological study. The exposure time can be varied (either increased or decreased) by the operator before performing the radiograph. Exposure time values are pre-programmed into the device. Numbers in bold correspond to the parameters used for the reference radiograph.

Voltage (kV)	Exposure time (s)						
60	0.08	0.10	**0.12**	0.16	0.20	0.25	0.32
70	0.04	0.05	0.06	0.08	0.10	0.12	0.16

purpose, two dried human mandibles with all lower teeth present were chosen and radiographs were taken on each side (Insight film, Kodak F/E-speed, 31×41 mm). The films were stabilized with a Hawe Super-Bite film holder (Hawe Neos Dental SA, Bioggio, Switzerland) and adjusted with hard wax (Moyco Extra-Hard Wax; Moyco Technologies Inc., Montgomeryville, PA) on the mandibles to standardize image geometry, and the same radiological device (Heliodent MD®) took the radiographs at 7 mA. The device allowed the use of variable voltages and exposure times. A reference radiograph was arbitrarily obtained at 60 kV and 0.12 s. Then, in order to create a heterogeneous pool of radiographs, other radiographs were taken by varying the voltage and exposure time (Table I). The same operator (D. P.) took all the radiographs. Finally, 20 radiographs were taken on each side of the mandibles and, in total, 80 radiographs with differently determined exposure parameters were taken.

The radiographs were then digitized at 600 dpi and in grayscale mode, with a flatbed scanner (Epson Expression 1600 Pro; Seiko Epson Corp., Nagano, Japan) and a non-compressed TIFF format was used for disk storage. The images were examined with image software allowing combined adjustment of the light intensity and contrast (Adobe Photoshop 7.0; Adobe Systems Inc., San Jose, CA, USA). A gray-level calibration was achieved between the reference radiograph and the other radiographs by altering the whole gray level of the latter until the enamel gray level at the second premolar matched that of the reference radiograph (Figure 1). An example of assessment between the reference radiograph and extremely under- or overexposed radiographs is shown in Figure 2. Comparisons were accomplished by one observer (D. P.). A careful visual inspection of the radiograph quality, the bone trabeculae appearance, and the sharpness and contrast of the observed structures was then conducted in a dark room and on a black background.

As a result of this preliminary stage, radiographs taken under varying conditions of radiological exposition showed no noticeable difference to the naked eye after gray-level calibration. This statement is based on one observer's subjective judgment and was strictly not evidenced-based. Thus, we assumed that this method of luminosity and contrast adjustments could be employed on radiographs realized in non-standardized conditions, in order to compare the displayed alveolar bone trabeculation with improved visibility.

Assessment of bone trabeculation. The interdental sites evaluated were located between the lower first molar and second premolar, and between the two lower premolars. Two evaluators (D. P. and G. J.) used the following three-scale visual index: when the trabecular pattern was evaluated as sparse (score 1), the criterion was large intertrabecular spaces, especially in the cervical dentate premolar area; when the trabecular pattern was evaluated as dense (score 3), the entire radiographed area had an equal degree of trabeculation and the intertrabecular spaces were

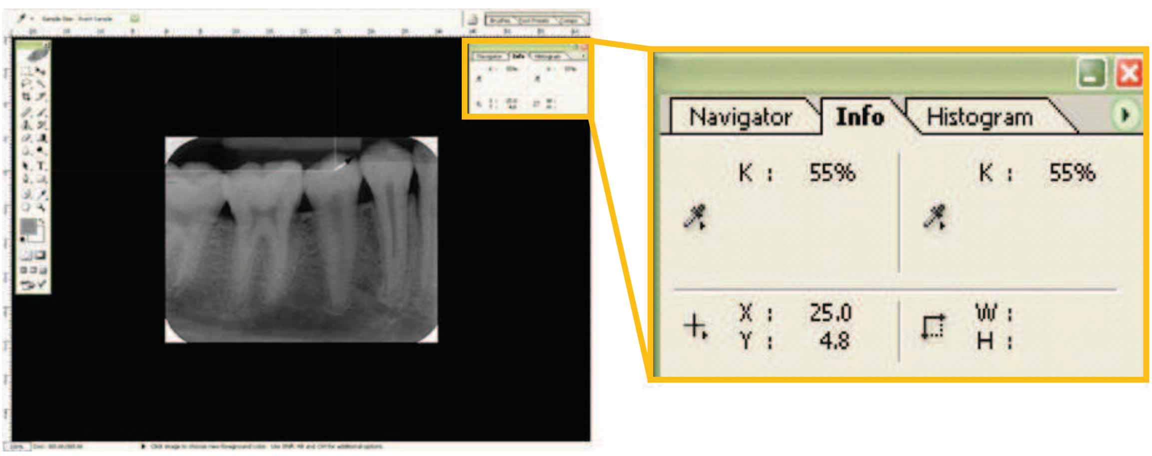

Figure 1. Schematic demonstration of enamel gray-level calibration using the eyedropper tool of the Photoshop-based image analysis on the reference radiograph (taken at 7 mA and 60 kV, with an exposure time of 0.12 s). The reference coordinates used for all radiographs are x = 25.0 mm and y = 4.8 mm (see "Info" window in the inset). The reference enamel gray-level for all radiographs was arbitrarily chosen as 55%.

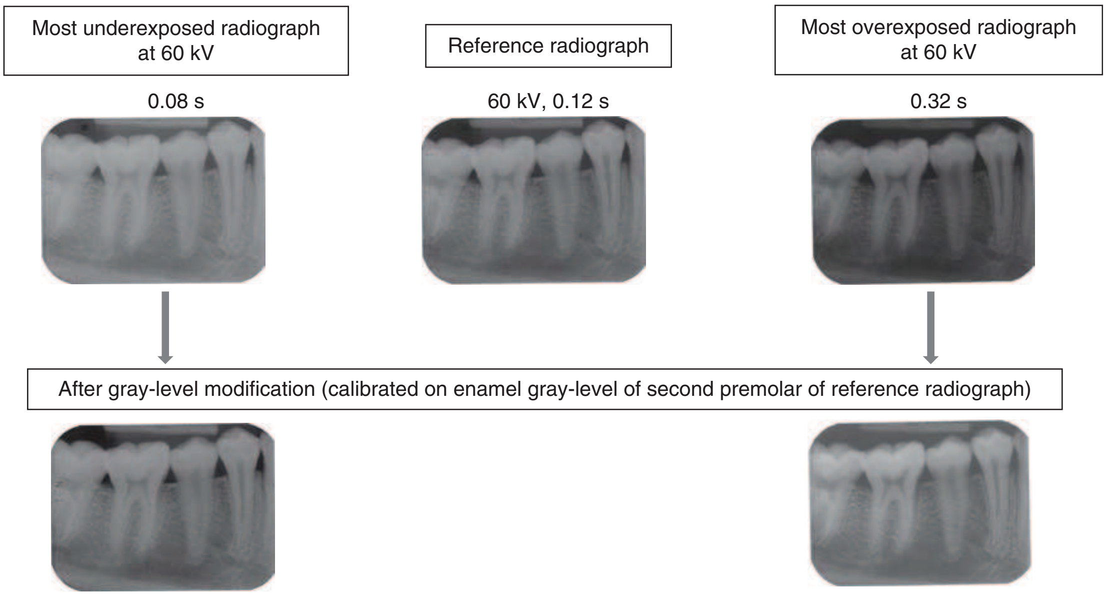

Figure 2. Example of comparison between the reference radiograph and either an extremely under- or overexposed radiograph, as well as the results after calibration using as reference the gray-level of the enamel of the second premolar.

small, even under the roots; and when the trabecular pattern was assessed as alternating dense and sparse (score 2), the trabeculation was normally denser cervically and sparser apically (Figure 3). The calibration of radiographs was based on the density of the enamel of the cuspids of the second premolar. We applied the same three-scale visual index to the panoramic radiographs. Often, the trabecular pattern apically of the molars was extremely sparse [12,13]. When it was difficult to classify the trabecular pattern, score 2 was chosen. Bone areas with pathological lesions such as sclerotic bone and apical destruction around apices of teeth were not evaluated. The assessors calibrated themselves using 10 additional panoramic radiographs with their corresponding periapicals, selected using the same criteria as previously described. Those radiographs used for inter-observer calibration were not employed for assessing the bone trabeculation on the periapical and panoramic radiographs. After inter-observer calibration, the two assessors examined both the periapical and panoramic radiographs.

Statistical analyses. To appreciate the reliability of the method, a second assessment of all radiographs was performed after 60 days, by both evaluators. Kappa (κ) statistics were used to calculate the intra- and inter-observer agreements, using SPSS version 13.0 (SPSS Inc., Chicago, IL). κ values equal to zero represent agreement equivalent to that expected by chance, while one represents perfect agreement. In accordance with Landis and Koch [21], the following κ interpretation scale was used: poor to fair (below 0.4), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1).

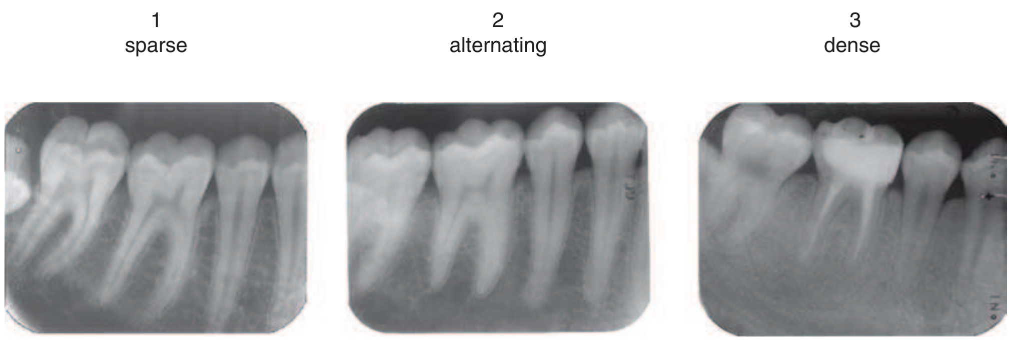

Figure 3. The three-scale visual analysis for assessment of bone trabeculation: 1 = sparse trabeculation; 2 = alternating dense and sparse trabeculation; 3 = dense trabeculation.

Table II. Intra- and interobserver agreements of assessment of the trabecular pattern on periapical and panoramic radiographs.

	Intra-observer agreement (assessor 1)		Intra-observer agreement (assessor 2)		Inter-observer agreement	
Type of radiograph	κ	95% CI	κ	95% CI	κ	95% CI
Periapical	0.88	0.82–0.94	0.93	0.87–0.98	0.82	0.73–0.93
Panoramic	0.79	0.70–0.87	0.83	0.73–0.92	0.79	0.70–0.88

A two-tailed Spearman's correlation analysis was used to compare results (of the second evaluation) of periapical radiographs with those of panoramic radiographs.

Results

Periapical radiographs

The κ values for intra-observer agreement, based on the scores for the first and second evaluations, were 0.88 for assessor 1 (D. P.) and 0.93 for assessor 2 (G. J.). For the inter-observer agreement, obtained using the second measurements, a κ value of 0.82 was found (Table II).

Panoramic radiographs

The κ values for intra-observer agreement, based on the scores for the first and second evaluations, were 0.79 for assessor 1 and 0.83 for assessor 2. For the inter-observer agreement, obtained using the second measurements, a κ value of 0.79 was found (Table II).

Comparison between periapical and panoramic radiographs

The assessment of the trabecular pattern evaluated on periapical radiographs compared to that evaluated on panoramic radiographs is shown in Table III. The Spearman's coefficient showed substantial correlation between periapical and panoramic radiographs (rho = 0.737, $p = 0.001$).

Table III. Contingency table of scores obtained from the assessment of trabecular pattern between periapical and panoramic radiographs.

	Panoramic radiographs			
Periapical radiographs	Score 1	Score 2	Score 3	Total
Score 1	7	0	0	7
Score 2	18	35	0	53
Score 3	1	2	16	19
Total	26	37	16	79

Discussion

In this study, we have shown that it is possible to qualitatively assess the mandibular trabecular bone, mesially and distally of the second premolar, using a three-scale visual index on panoramic radiographs. Periapical radiography is superior to panoramic radiography for the diagnosis of common dental pathology (i.e. caries, periodontal and periapical pathology), and is indicated when particular local information is needed from an orthodontic perspective, such as dental or periodontal health, root length, shape and form, and position of impacted or erupting teeth.

In previous studies, the feasibility of a similar visual index has been demonstrated on periapical radiographs [11–14]. Our results showed that inter-observer agreement was somehow lower when evaluating the mandibular trabecular bone on panoramic compared to periapical radiographs, and a correlation did exist when evaluating the bone density using these two different types of radiograph.

Only radiographs with full posterior lower dentition were compared, as we intended to assess the functioning alveolar bone, which is under mechanical stimulation. Loss of teeth is known to be followed by irreversible alveolar bone resorption.

The sample was small because it was difficult to find periapical radiographs of the premolar and molar regions taken within the same period as the panoramics, and not all the subjects had a periapical radiograph on both sides. Ideally, subjects with a full-mouth radiographic examination and a panoramic radiograph of adequate quality and without active pathologic lesions would have been sought for the study. However, ethical reasons do not permit one to perform such an exposure of the patient as part of routine dental control. Of the 32 subjects, 10 were from the orthodontic clinic. Orthodontic patients mostly have sound oral conditions before treatment. A panoramic radiograph is usually taken at initial documentation, with anterior periapical radiographs being taken when necessary. There is little clinical indication to take a periapical radiograph of the posterior lower teeth, on one or both sides, and this explains the small number of orthodontic subjects in our study. The remaining 22 subjects were treated in the dental clinic for other clinical indications than orthodontic reason (carious or periodontal lesions).

There are differences between the imaging techniques used for panoramic and periapical radiographs. The parallel technique was used for the periapical radiographs, whereas panoramic images are created by a rotational technique. The differences between panoramic and periapical radiographs are the greater value of panoramics for screening than for diagnostic purposes, and the geometric distortion of panoramic images, due to the rotational technique. Furthermore, the region of focus initially created within a generic jaw form and size is limited in size and some structures that are not centered in the focal trough may be "lost". Thus, the accuracy of the panoramic technique is more limited than that of intraoral radiography since it presents a "layer" of the bone and not a "summation" of the bone elements. Moreover, the correct positioning of the patients is fundamental for obtaining a sharp and useful panoramic image.

Geometric distortion made the premolar roots seem closer to each other on the panoramic radiographs. This fact, plus the magnification factor for the panoramic radiographs, precluded the use of objective methods such as measurements of optical density and gray-level assessment in a standard location to support our findings. These techniques can be used in periapical radiographs [12] but are not easily transferred for use on panoramic radiographs. Despite differences between the rotational panoramic radiographs, which are image-layer radiographs, and the conventional intra-oral radiographs, there was an agreement between the two evaluations when the bone structure was studied.

Our study design included only two observers. However, we increased the number of evaluations to obtain sufficient statistical power [22].

A calibration of the radiographs was conducted before assessment using the image software and based on the enamel at the cuspids of the second premolar (arbitrarily set at 55% of gray level; Figure 1), although individual variation exists in tooth form, width, and enamel thickness. It is possible that a radio-opaque stepwedge in every radiograph may have standardized more precisely the calibration procedure [8], but the present study was a retrospective study, and the calibration tool was not used.

Our method provides a qualitative evaluation of mandibular trabecular bone characteristics, in contrast to other methods that can give quantitative values of bone density, like dual-energy X-ray absorptiometry [23] or CT [24], or information on trabecular bone microarchitecture, which is possible with MRI [25] and also with micro-CT [5,26]. Because of their improved quality, reduced radiation dose and ease of use, panoramic radiographs have become popular in dental diagnosis [27,28]. This kind of radiograph can provide a range of information about the patient and their bone status. It is a relatively inexpensive, rapid, and simple tool and it seems useful for assessment of the alveolar trabecular bone.

Evaluating the bone structure using the present method showed that the senior assessor (G. J.), who had worked with the visual index for longer, somehow had higher reliability than the junior assessor (D. P.), in assessing both the periapical and panoramic radiographs. Training with the technique therefore seems to improve the intra-observer agreement.

Conclusions

It is possible to use panoramic radiographs for the assessment of trabecular bone pattern between lower posterior teeth with the aid of a visual index, provided that the interdental sites are not narrowed by root proximity. Training with the method is recommended to obtain high reproducibility of the results.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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4. PUBLICATION ORIGINALE II

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ORIGINAL ARTICLE

Evaluation of changes in trabecular alveolar bone during growth using conventional panoramic radiographs

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Abstract

Objective. To assess changes of the alveolar trabecular bone during growth using panoramic radiographs and to detect possible differences in trabecular bone patterns when comparing individuals of various ages and genders. ***Materials and methods.*** Conventional panoramic radiographs of 18 young (eight females, 10 males) and 21 adult (12 females, nine males) subjects were taken at 2 years (T1) and 10 years (T2) after the end of orthodontic treatment. At T1, mean ages were 15.6 ± 0.9 years and 31.3 ± 9.7 years in the young and the adult groups, respectively. A three-scale visual analysis was used to evaluate bilaterally the alveolar bone trabeculation in the interdental spaces, from the distal side of the first mandibular premolar to the mesial side of the second lower molar. An analysis of variance (ANOVA), associated with *t*-tests whenever significance was found, was used to appraise the role of the age, the extent of the follow-up period and the gender on trabecular bone structure. ***Results.*** The adult group had a denser alveolar bone trabeculation, compared to the young group. This was also observed in the 8 years follow-up recordings among the adults, but no statistically significant differences were found in the growing individuals. No gender discrepancy was detected. ***Conclusions.*** From puberty to the middle age adulthood, denser alveolar bone trabeculation in the mandible seems to be related to the age. No differences were found between male and female subjects in the sample.

Key Words: *assessment, alveolar trabecular bone, growth, panoramic radiographs*

Introduction

The mandible shows anatomical and functional characteristics different of the skeletal bones. The intramembranous origin leads to formation of two distinct bony parts: the basal bone and the alveolar process (commonly called the alveolar bone), the latter constituting support for teeth. Both parts are made of an external dense cortical bone and an internal trabecular bone. Like the skeletal bone system, the mandibular alveolar bone is subjected to a remodeling process. Mechanical stimulation, originating from muscular function, is a major regulatory factor in bone homeostasis [1]. It superimposes on and interacts with all other systemic and local mediators of bone metabolism. The alveolar bone is a skeletal part that is dependent on the presence of teeth and masticatory function, since, in the absence of teeth [2] or lack of mechanical stimulation transmitted by implant supported overdenture, it undergoes disuse atrophy [3]. Independently of the age, there is a great inter-individual variation in trabecular volume and interconnections, leading to variable trabecular bone patterns [4]. Variation in the trabecular bone microstructure is also site-dependent within individuals [5,6]. Recently in orthodontics, the focus has been on miniscrew implants as a skeletal anchorage system that does not require patient compliance. Many studies have investigated the factors related to stability because the failure rate of mini-implants, ranging from 9 to 30%, is high compared to that of osseointegrated endosseous implants [7–10]. Among the factors related to failure, it has been reported that the implantation site has an important role [9,11]. A review on endosseous implants has shown that jaw bone with reduced density correlates with a reduced primary stability and a significantly higher implant failure rate [12]. Consequently, the density and architecture of the trabecular host bone are crucial to the stability of an endosseous implant in the alveolar ridge. Regarding mini-implants, younger patients seem to exhibit a greater risk of failing compared to adult patients [13].

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The alveolar bone density has been quantitatively measured on computed tomographic (CT) images [14–18]. Results showed significant differences of bone density values between the alveolar and basal bone of both maxilla and mandible, with progressively increasing values from anterior to posterior areas and with higher values in the mandible. Thus, bone densities may vary when different areas of jaws are compared.

Dental radiographs are not exclusively used in dentistry and their utilization has been extended to other domains. For example, periapical radiographs have been used to assess the trabecular alveolar bone in relation to bone disease [19–21]. Panoramic radiographs have been routinely made for diagnosis purposes in many dental fields. However, this radiologic tool could be used to add further knowledge on how the alveolar trabecular pattern changes with aging, from adolescence, through adulthood to old age. In a previous study, it has been shown that the mandibular trabecular bone assessment on panoramic radiographs, using a visual index, fairly corresponds to the evaluation obtained from periapical radiographs [22]. A correlation has also been found between mandibular trabecular patterns depicted in panoramic radiographs and the density of the same region as measured on CT scans [23].

To date, no study comparing the functioning alveolar bone of a young (growing) group to an adult (non-growing) group has been found in the literature. Also, no conclusions have been established when looking for possible gender differences in the healthy alveolar bone.

Thus, the aims of the present study are to assess changes of the alveolar trabecular bone during growth using panoramic radiographs and to detect possible differences in trabecular bone patterns when comparing individuals of various ages and gender.

Materials and methods

Material

The material consisted of 39 sets of two panoramic radiographs from patients treated in our dental school, divided into two groups: the young group (growing individuals) and the adult group (non-growing individuals). For each subject selected, the panoramic radiographs were taken at 2 years (T1) and 10 years (T2) after completion of their orthodontic treatment. In the young group, the mean age at T1 was 15.6 ± 0.9 years (range = 14.2–16.8 years) and 23.9 ± 1.1 at T2 (range = 21.1–25.4 years). The mean age difference between T2 and T1 (ΔT2–T1) was 8.3 ± 1.3 years. The mean age of the adult group at T1 was 31.3 ± 9.7 years (range = 20.1–46.4 years) and 39.5 ± 10.1 years at T2 (range = 27.4–55.1 years). The mean age difference between T2 and T1 (ΔT2-T1) was 8.2 ± 1.3 years. The age distribution within each group is shown in Table I. The panoramic radiographs were examined at 2 years (T1) and at 10 years after completion of orthodontic treatment (T2). Eighteen subjects for the young group (eight females, 10 males) and 21 subjects for the adult group (12 females, nine males) met the following inclusion criteria:

- Panoramic radiographs diagnostically acceptable at T1 and at T2;
- Age at T1 must be up to 17 years in the young group and over 20 years in the adult group;
- No active orthodontic treatment and no tooth extraction (except for third molars) between T1 and T2;
- No periodontal disease with no alveolar bone loss; and
- Healthy general conditions, with no medication or disease according to the medical history.

Methods

The radiographs were digitized at 600 dpi and in grayscale mode, with a flatbed scanner (Epson Expression 1600 Pro, Seiko Epson Corp., Japan) and a non-compressed TIFF format was used for disk storage. The images were examined with image software allowing a combined adjustment of the light intensity and the contrast (Adobe Photoshop 7.0, Adobe Systems Corporation Inc, San Jose, California, USA). The panoramic radiographs of both groups and at both

Table I. Age distribution of the female and male subjects when the first (T1) and second (T2) panoramic radiographs were obtained, in the adult and the young group.

		T1 (years) ± SD	T2 (years) ± SD	ΔT2–T1 (years) ± SD
Adult	12 f	34.5 ± 9.4	43.0 ± 10.1	8.5 ± 1.4
	9 m	27.0 ± 6.8	34.8 ± 8.4	7.8 ± 1.1
	Total 21	31.3 ± 9.7	39.5 ± 10.1	8.2 ± 1.3
Young	8 f	15.3 ± 0.9	23.7 ± 0.8	8.3 ± 0.5
	10 m	15.9 ± 0.9	24.2 ± 1.3	8.3 ± 1.7
	Total 18	15.6 ± 0.9	23.9 ± 1.1	8.3 ± 1.3

T1 and T2 have been previously mixed in a random way and blinded for examination. One operator (DP) did all evaluations of the trabeculation of alveolar bone using the following three-scale visual analysis: when the trabecular pattern was evaluated as sparse (score 1), the criterion was large inter-trabecular spaces especially in the cervical dentate premolar area; when the trabecular pattern was evaluated as dense (score 3), the entire radiographed area had an equal degree of trabeculation and the inter-trabecular spaces were small even under the roots; when the trabecular pattern was assessed as alternating dense and sparse (score 2) the trabeculation was normally denser cervically and sparser apically, as described in the previous study (Figure 1) [22]. The reliability of this method, as introduced earlier, has been shown to be sufficient, with a Kappa value of 0.79 obtained for the assessor (DP) based on 32 panoramic radiographs evaluated twice at an interval of 60 days.

The assessment was performed at the level of six inter-dental sites located bilaterally, from the distal side of the first premolars to the mesial side of the second molars of the lower arch. Whenever the root proximity or any anatomical characteristics (such as idiopathic osteosclerosis) hindered accurate evaluation of the inter-dental site, the latter was not taken into account. All corresponding panoramic radiographs at T1 and at T2 had the same inter-dental sites evaluated. Figure 2 demonstrates an example of a case with inter-dental sites selected for the examination.

Statistical analyses

The scores given for each inter-dental site of each jaw have been averaged. The mean values were then used for statistical analysis. An analysis of variance (ANOVA) was first undertaken to assess differences between and within the groups according to three variables: the age group, the time spent between examinations (from T1 to T2) and the gender, after confirming normal distribution with the Shapiro-Wilk test. In addition, for each significant result following the ANOVA test, paired and unpaired *t*-tests were planned for pair comparisons: paired *t*-tests for longitudinal assessment of the alveolar bone trabeculation in each group, unpaired *t*-tests for cross-sectional assessment of the alveolar bone trabeculation between the groups and unpaired *t*-tests for assessment of gender discrepancy. The significance level was set at 0.05. The Statistical Package for Social Science for Windows, version 13.0 (SPSS Inc., Chicago, IL) was used for these statistical tests.

Results

The analysis of variance assessing the main effects of the three variables (age, extent of the following period and gender) on the alveolar bone trabeculation scores revealed that only the factor gender did not show a significant effect on bone trabeculation scores, neither alone nor in interaction with other factors. In contrast, the factors age and time were shown to have a significant effect, but there was no interaction.

For the cross-sectional assessment of the alveolar bone trabeculation scores, the more extreme age groups studied were compared (which means the young group at T1 (15.6 ± 0.9 years) with the adult group at T2 (39.5 ± 10.1 years)) using unpaired *t*-test. It was found that the adult group at T2 had a higher alveolar bone trabeculation score than the young group at T1 ($p = 0.012$; Table II).

For longitudinal assessment of the alveolar bone trabeculation scores, paired *t*-tests comparing each group from T1 to T2 indicated significant differences only in the adult group. Namely, the alveolar bone trabeculation became denser during the 8 years follow-up of this adult group ($p = 0.011$; Table III).

Discussion

The present study has shown that the mandibular trabecular bone, as detected on panoramic radiographs, was determined to be denser in adult individuals than in young individuals. When comparing subjects of various ages, significant differences in trabecular bone patterns were found in the adult group after a mean follow-up of 8 years and between the youngest and the eldest individuals in this study. Gender differences were not found to be significant according to our results, in both groups of the present sample.

Figure 1. The three-scale visual analysis for assessment of bone trabeculation. 1 = sparse trabeculation, 2 = alternating dense and sparse trabeculation, 3 = dense trabeculation.

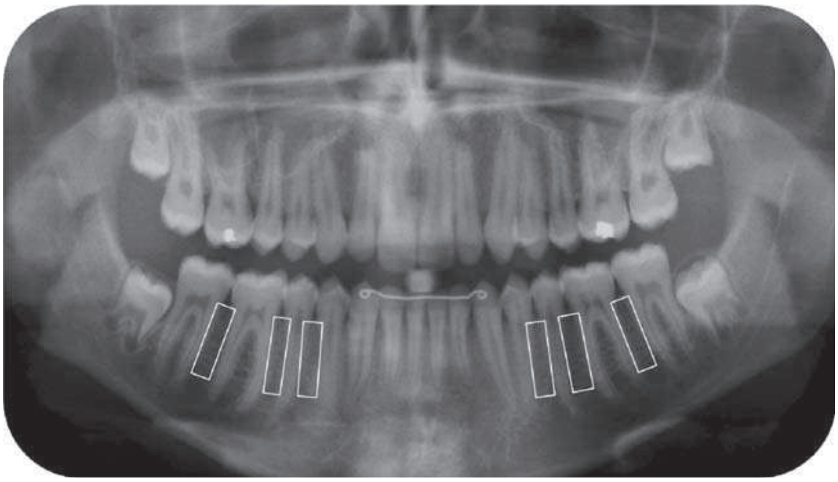

Figure 2. Example of panoramic radiograph selected for bone trabeculation evaluation. The six white rectangles represent the interdental spaces examined, when this was possible. Panoramic radiographs at T1 and at T2 of the same subject had the same interdental sites evaluated.

In a previous study, it was shown that it is possible to qualitatively assess the mandibular trabecular bone, mesially and distally of the second premolar, using a three-scale visual index on panoramic radiographs. In the present study, we used the same methodology to evaluate differences in age groups regarding the trabecular alveolar bone over a mean time of 8 years. We assessed possible age discrepancies in a cross-sectional and in a longitudinal way. To better describe long-term changes in the alveolar trabecular bone, the period of observation should have been longer. Since our samples did not allow this, a young (growing) and an adult (non-growing) group were followed and a comparison of the bone trabeculation between the youngest and the eldest subjects was undertaken. Thus, when considering the bone trabeculation over a period of ~ 8.2 years in both groups, a slight increase is observed but is not significant. Nevertheless, in the cross-sectional assessment, groups with a mean age difference of 23.9 years were compared, and the older age group appeared to have a significantly denser bone trabeculation scores than the younger one. During growth, bone modeling is taking place with changes of bone size and shape. After the end of the growth period, in early adulthood, the bone is still remodeled by resorption performed by osteoclasts and apposition by osteoblasts [24]. Acquisition of bone mineral continues throughout childhood and adolescence, reaching a lifetime maximum ('peak bone mass') in early adulthood [25]. In old adulthood (>65 years), decrease in bone mass density is usual, due to an unbalanced remodeling process [26]. In our study, the subjects selected were representative of the young age (pubertal) and the early adulthood age. Knowing that the skeletal bone mineral density (BMD) has been found to be associated with the mandibular alveolar bone structure and the alveolar thickness [20,21], an increase in the alveolar mandibular trabeculation density can thus be expected from the puberty to early/middle age adulthood. Furthermore, our findings could be related to the adaptation of the skeleton to mechanical loads during growth [27–29]. The mandibular alveolar process is part of the skeleton and is subjected to repetitive loads during mastication, thus a denser bone structure could be expected from puberty to adulthood as the mechanical loading increases with muscular mass and strength [30,31].

Table II. Unpaired *t*-test to assess the alveolar bone trabeculation of the groups having the highest mean age difference: the comparison is between the alveolar bone trabeculation of the young on the first radiographs and the adults on the second radiograph (values are the mean of the scores given with the three-scale visual analysis).

Young T1			Adults T2			
n	*M*	SD	*n*	*M*	SD	*p*-value
18	1.73	0.37	21	2.04	0.35	0.012*

*$p \leq 0.05$.

No gender difference was found in our study. This was consistent with Chun and Lim [18], whose study samples were ranging between 25–35 years of age. The small sample size certainly was not representative enough. Moreover, in the adult group, the mean age of the female subjects is higher than the mean age of the male subjects, whilst it is approximately the same in the young group. Four of the 12 female subjects in the adult group were more than 50 years of age at T2 (52–55 years). However, the risk of post-menopausal osteoporosis, which would alter the bone trabeculation faster, was excluded according to the answers given in their medical history taken at T2. This can explain the absence of sex-based discrepancy in our adult group even though

Table III. Paired *t*-tests to assess the alveolar bone trabeculation scores in the adult group and the young group, from T1 to T2 (values are the mean of the scores given with the three-scale visual analysis).

		T1		T2		ΔT2–T1		
Groups	*n*	*M*	SD	*M*	SD	*M*	SD	*p*-value
Young	18	1.73	0.37	1.69	0.39	–0.04	0.38	0.664
Adult	21	1.88	0.32	2.04	0.35	0.17	0.24	0.011*

*$p \leq 0.05$.

mean ages were unfavorable for the female subjects. With larger samples and a wider range of age, more significant variations are probably to be expected.

Among the 39 cases selected for the study, four cases presented a previous orthodontic treatment with premolars extractions in the mandibular arch. Although space closure involved considerable bone remodeling, it was unlikely that the orthodontic treatment influenced the bone trabeculation depicted on the panoramic radiograph 2 years after its completion.

The results of the present study may give an insight to the variations in tooth movement rate observed with age. In adult orthodontics, a different tissue reaction could be expected when moving teeth in bone with sparse or dense trabeculation, as was shown in an experimental animal study, in which rats with lower initial bone density have a faster orthodontic tooth movement than rats with significantly higher initial bone density [32]. Our findings may be in line with the previous investigation made on the mandibular bone and its possible influence on orthodontic treatment stability [33]. Furthermore, the observed changes in bone density taking place with age may be related to the success rate of mini-implants. Kim et al. [34] concluded that the patient's age is an influencing factor for success rates of midpalatal miniscrews used for orthodontic anchorage. Additionally, Molly [12] stated that a reduced density of the jaw bone was correlated to a significantly higher failure rate of endosseous implants. The results of the present study can apparently be linked to these observations, as they showed a significant difference in the bone trabeculation between young and adult (middle age) individuals.

Conclusions

Our study showed that a denser trabecular bone structure in the alveolar process appears related to the age. The qualitative assessment of the alveolar trabecular bone has shown longitudinal differences within the young and the adult groups, with a more significant change in the adult group.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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