Facteurs influençant la localisation du foramen mandibulaire

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Section de médecine Dentaire
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" FACTEURS INFLUENÇANT LA LOCALISATION DU FORAMEN MANDIBULAIRE "

Thèse

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de l'Université de Genève

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par

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de

Penthalaz (VD)

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Intitulée :

Facteurs influençant la localisation du foramen mandibulaire

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

Genève, le 2 juin 2014

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RÉSUMÉ

L'anesthésie du nerf alvéolaire inférieur est l'un des actes dentaires les plus fréquents; il est obtenu par injection du liquide anesthésiant au niveau du foramen mandibulaire. La position de ce foramen par rapport au plan d'occlusion doit donc être connue pour obtenir une anesthésie efficace. Le but est d'évaluer si la distance entre le foramen et le plan d'occlusion dépend de l'âge et du type facial vertical ; les facteurs influençant cette distance à long terme seront également étudiés. La position du foramen par rapport au plan d'occlusion a été mesurée sur des radiographies céphalométriques latérales de façon transversale et longitudinale, avant et 10 ans après la fin du traitement orthodontique. Les radiographies initiales de 145 patients ont été analysées; 10 ans après la fin du traitement orthodontique, les mêmes mesures ont été à nouveau faites sur les radiographies de 50 patients. Les changements entre ces deux séries de mesure ont alors été calculés. Dans la partie transversale, des corrélations et des régressions linéaires ont été réalisées entre les différentes variables étudiées. La distance foramen-plan d'occlusion est spécialement corrélée avec l'âge du patient ($r=0.690$, $p<0.001$), l'angle inter-maxillaire ($r=-0.601$, $p<0.001$) et le rapport facial antéro-inférieur des tissus mous ($r=-0.764$, $p<0.001$). Plus un patient est âgé et a des caractéristiques de “face-courte”, plus la distance foramen-plan d'occlusion est petite. La régression linéaire explique plus de 70% de la variation de cette distance grâce à ces 3 variables. Dans la partie longitudinale, un effort a été fait pour tenter d'expliquer les raisons de cette variation de la distance foramen-plan d'occlusion. Une seconde régression linéaire a été conduite entre l'âge initial, l'angle inter-maxillaire initial, le changement d'inclinaison du plan d'occlusion et le changement de la distance Condyle-Gonion. En plus de l'âge et du type facial, plus la rotation du plan occlusal est faible, plus la distance foramen-plan d'occlusion est importante. 53% de la variation de la distance foramen-plan d'occlusion peut être expliquée par ces facteurs ($r=0.732$). L'âge, la morphologie faciale et l'inclinaison du plan d'occlusion devraient être pris en compte afin d'obtenir une anesthésie efficace du nerf alvéolaire inférieur.

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PRÉFACE

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

I. Influence of Age and Vertical Facial Type on the Location of the Mandibular Foramen

Jean-François Epars, Anestis Mavropoulos, Stavros Kiliaridis

Pediatric Journal of Dentistry 2013; volume 35 : pages 369-73.

II. Changes in the Location of the Human Mandibular Foramen as a Function of Growth and Vertical Facial Type

Soumis pour publication

Jean-François Epars, Anestis Mavropoulos, Stavros Kiliaridis

1. TEXTE DE SYNTHÈSE RÉSUMÉ (en français)

1.1 Introduction

L'anesthésie du nerf alvéolaire inférieur est l'un des actes dentaires les plus fréquents et est obtenu par injection du liquide anesthésiant au niveau du foramen mandibulaire. Le foramen est situé verticalement aux alentours du milieu du ramus, légèrement plus proche du bord inférieur de la mandibule (Nicholson, 1985; Jerolimov et al., 1998). Il peut être précisément identifié sur des radiographies céphalométriques et panoramiques (Afsar et al., 1998). Sa position est normalement symétrique entre le côté droit et gauche (Hayward et al., 1977; Narayana & Vasudha, 2004; Prado et al., 2010) sans différence entre les genres (Afsar et al., 1998; Trost et al., 2010). Finalement, l'ouverture de l'angle goniaque semble être corrélée avec la position verticale du foramen depuis le bord inférieur de la mandibule : plus cet angle est important, plus le foramen est proche du bord mandibulaire (Tsai, 2004 ; Poonacha et al., 2010). Malgré ces précisions concernant sa localisation, le taux d'échec rapporté pour l'anesthésie du nerf alvéolaire inférieur varie entre 5 et 15% (Wong & Jakobsen, 1992). Ceci est probablement dû à la variabilité de la position du foramen (Nicholson, 1985; Keros et al., 2001). Le consensus actuel pour une anesthésie efficace stipule que l'aiguille doit être insérée dans la surface interne du ramus, parallèlement au plan d'occlusion des dents mandibulaires, 6 à 10mm au-dessus du plan d'occlusion (Thoma, 1958; Steiner & Thompson, 1977; Benett 1978 ; Malamed, 2004).

D'une manière générale, la croissance a été étudiée de manière détaillée et nous savons que les différentes parties du complexe cranio-facial ne grandissent pas toutes de la même manière. Il serait donc étonnant que ces directives pour l'injection de produit anesthésiant, bien que correctement adapté pour les patients adultes, puissent être suivies pour des patients enfants. De nos jours, le consensus général est de déplacer le site d'injection vers le haut lorsque l'enfant devient plus âgé. La relation entre l'âge et la distance séparant le foramen du plan d'occlusion (*distance foramen-plan d'occlusion)* semble être acceptée par la majorité des auteurs (Pinkham et al., 2005; Hwang et al., 1990; Movahhed et al., 2011), mais il y a encore quelques auteurs qui vont à l'encontre de ces résultats (Afsar et al., 1998; Poonacha et al., 2010 ; Trost et al., 2010).

Etant donné que le plan d'occlusion est la seule référence clinique que le praticien peut utiliser, la distance foramen-plan d'occlusion est de la plus haute importance. Avec l'âge, l'augmentation de la hauteur alvéolaire déplace le plan d'occlusion loin du corpus de la mandibule : la distance foramen-plan d'occlusion devrait donc diminuer au lieu d'augmenter. Cette distance pourrait être donc modifiée par deux autres facteurs : par une combinaison de résorption et d'apposition osseuse au niveau du foramen lui-même ou par un changement de l'inclinaison du plan d'occlusion. Or, nous savons que le type de croissance faciale verticale modifie l'inclinaison du plan d'occlusion (Schendel & Bell, 1976; Opdebeeck et al. 1978), selon que la hauteur faciale antérieure inférieure est augmentée (face-longue, hyperdivergent, rotateur antérieur…) ou diminuée (face-courte, hypodivergent, rotateur postérieur…). Dans le syndrome face-longue, l'angle mandibulaire, l'angle inter-maxillaire, le plan d'occlusion et l'angle goniaque sont grands et la hauteur faciale postérieure est petite (Schendel & Bell, 1976). Dans le syndrome face-courte, les caractéristiques opposées existent (Opdebeeck et al. 1978). Ces deux morphologies faciales verticales opposées dépendent principalement de la modification des structures situées sous le plan palatin (Isaacson et al. 1971; Fields et al. 1984). Il semble donc probable que la distance foramen-plan d'occlusion soit influencée par le type facial et par le plan d'occlusion.

Bien que la technique recommandée pour l'obtention d'une anesthésie du nerf alvéolaire inférieure suppose que la distance foramen-plan d'occlusion soit constante, on peut s'interroger si cela est vraiment exact. L'hypothèse nulle est que la distance foramen-plan d'occlusion demeure inchangée indépendamment de l'âge ou du type facial vertical.

1.2 Objectifs

1) Le but premier de cette étude est de définir la distance foramen-plan d'occlusion dans un échantillon transversal de sujets de différents âges avec différentes morphologies faciales verticales.

2) Le deuxième but est d'expliquer pourquoi la distance foramen-plan d'occlusion varie selon l'âge, le type de croissance spécifique et le plan d'occlusion, de façon longitudinale entre les enregistrements initiaux et 10 ans après traitement.

1.3 Matériel et Méthode

1.3.1 Matériel

Cette étude rétrospective a été réalisée sur des radiographies céphalométriques et panoramiques de patients qui ont subi un traitement orthodontique dans notre clinique universitaire. Puisqu'un traitement orthodontique ne commence habituellement qu'après éruption des premières molaires permanentes, seules des radiographies d'enfants âgés d'au moins 6 ans et plus n'ont pu être obtenues. Tout d'abord, nous avons choisi les cas avec des enregistrements complets initiaux et à 10 ans après la fin du traitement. Puis nous avons appliqué les critères d'exclusion suivants :

a. radiographies de qualité insuffisante,

b. patients avec des signes d'asymétrie évidente (plus de 5mm au niveau du bord inférieur du ramus), avec des syndromes ou une histoire de traumatisme maxillo-facial,

c. patients non-Caucasiens afin d'obtenir un échantillonnage homogène de population,

d. patients âgés de plus de 12 ans lors des enregistrements initiaux afin de se concentrer sur les patients présentants le plus de croissance.

Cette étude a été soumise et a reçu l'approbation de la commission centrale d'éthique de la recherche sur l'être humain des HUG (Hôpitaux Universitaires de Genève) (12-066R / Psy 12-004R).

Toutes les radiographies ont été prises avec le même équipement radiologique. Elles ont été digitalisées et un tracé céphalométrique a été spécifiquement réalisé afin de mesurer des variables prédéfinies.

1.3.2 Précision de l'identification du foramen

Localiser le foramen sur des radiographies céphalométriques peut se révéler quelques fois difficile suite à la superposition de structures doubles et/ou au manque de netteté de l'image. Afin de vérifier cette localisation, nous avons comparé les mesures obtenues sur les radiographies céphalométriques avec celles obtenues sur les radiographies panoramiques. Une corrélation de Pearson et un t-test ont démontré une haute corrélation et une absence de différence entre les mesures faites sur ces deux types de radiographies. Ces résultats nous ont permis de confirmer la position du foramen dans les quelques cas où le foramen n'était pas évident à localiser.

1.3.3 Méthodes

Les variables suivantes ont été mesurées : la distance foramen-plan d'occlusion, l'âge, l'angle inter-maxillaire, le rapport facial antéro-inférieur des tissus mous, l'inclinaison du plan occlusal et la distance Condyle-Gonion. Ces mesures ont été réalisées sur les radiographies initiales et sur les radiographies 10 ans après traitement ; les changements survenants durant cette période ont également été mesurés.

1.3.4 Erreur de la méthode et analyse statistique

Toutes les variables étaient distribuées de façon normale ; des corrélations et des régressions linéaires multiples ont été utilisées afin d'établir le degré de corrélation entre les différentes variables. Le niveau de signification a été fixé à $p<0.05$. L'erreur de la méthode pour l'évaluation de la position du foramen mandibulaire a été évaluée en analysant à nouveau 4 semaines plus tard 15 radiographies choisies au hasard. Aucune différence n'a été détectée ($p = 0.21$, corrélation de Pearson = 0.99) et le coefficient de fiabilité était excellent (CR = 0.996).

1.4 Résultats

1.4.1 Etude transversale

a. Statistiques descriptives

145 Patients (76 filles et 69 garçons) remplissaient nos critères d'inclusion lors des enregistrements initiaux. L'âge moyen initial était de 10.4 ± 1.6 ans ; la distance foramen-plan d'occlusion, de 3.1 ± 2.6 mm. Une valeur positive signifie que le foramen est au-dessus du plan d'occlusion alors qu'une valeur négative signifie qu'il est en dessous. L'angle inter-maxillaire était de 29.6 ± 5.3° et le rapport des tissus mous antéro-inférieurs de 58.0 ± 3%.

b. Corrélation entre la distance foramen-plan d'occlusion et l'âge, l'angle inter-maxillaire et le rapport des tissus mous antéro-inférieurs

Une corrélation positive a été trouvée entre la distance foramen-plan d'occlusion et l'âge du patient ($r = 0.690$, $p<0.001$). Plus un patient est âgé, plus cette distance sera grande.

L'angle inter-maxillaire est corrélé de manière négative avec la distance foramen-plan d'occlusion ($r = -0.601$, $p<0.001$) : plus cet angle est grand, plus la distance est petite. Nous pouvons conclure de ces résultats que le foramen devrait se trouver proche du plan d'occlusion chez les patients face-longue alors qu'il serait bien au-dessus chez les patients face-courte.

Nous avons également trouvé une corrélation négative ($r = -0.764$, $p<0.001$) entre le rapport des tissus mous antéro-inférieurs et la distance foramen-plan d'occlusion : plus le tiers inférieur est allongé, plus cette distance est importante. Cela démontre également que le foramen devrait se trouver plus proche du plan d'occlusion chez les patients face-longue que chez les patients face-courte.

c. Régression linéaire multiple avec la distance foramen-plan d'occlusion comme variable dépendante et comme variables indépendantes :

1) l'angle inter-maxillaire et l'âge : nous avons trouvé que 70% de la distance foramen-plan d'occlusion était expliquée par les facteurs disponibles (r = 0.830).
2) le rapport des tissus mous antéro-inférieurs : le résultat était encore un peu meilleur avec plus de 70% expliquant la variabilité de la distance foramen-plan d'occlusion (r = 0.845).

1.4.2 Etude longitudinale

a. Statistiques descriptives

50 patients (29 femmes et 21 hommes) parmi les 145 patients que nous avions vus lors de l'enregistrement initial sont revenus 10 ans après la fin de leur traitement orthodontique.

Initialement, l'âge moyen initial était de 9.5 ± 1.4 ans ; la distance foramen-plan d'occlusion, de 2.9 ± 2.4 mm. La rotation du plan d'occlusion était de 20.0 ± 4.4° et l'angle inter-maxillaire, de 28.3 ± 4.7°. La distance Condyle-Gonion était de 49.0 ± 4.6 mm.

10 ans après traitement, l'âge moyen initial était de 24.2 ± 1.6 ans ; la distance foramen-plan d'occlusion, de 5.5 ± 2.2 mm. La rotation du plan d'occlusion était de 17.4 ± 5.3° et l'angle inter-maxillaire, de 24.6 ± 6.0°. La distance Condyle-Gonion était de 64.1 ± 7.1 mm.

b. Changements entre les mesures initiales et 10 ans après traitement

Nous avons testé les changements entre les mesures initiales et 10 ans après traitement pour chaque variable étudiée avec un t-test. Cela nous a permis de conclure qu'il y avait une différence significative pour chacune d'entre elles ($p<0.001$). Nous avons vérifié si le sexe des patients avait une influence sur le changement de la distance foramen-plan d'occlusion entre les radiographies initiales et 10 ans après traitement : il n'en avait aucune (p = 0.513).

Une régression linéaire multiple a été conduite en utilisant l'âge initial, l'angle inter-maxillaire initial, le changement de l'inclinaison du plan occlusal et le changement de la distance Condyle-Gonion comme variables indépendantes et la distance foramen-plan d'occlusion comme variable dépendante. Nous avons obtenu un résultat de 53% expliquant la variabilité du changement de la distance foramen-plan d'occlusion (r = 0.732).

2.1 Discussion

Nous avons trouvé dans cette étude que la distance foramen-plan d'occlusion diminuait avec la croissance et ceci de manière encore plus marquée chez les patients face-longue. Ce changement est influencé par le type de croissance faciale verticale. Une petite augmentation ou même une diminution de cette distance est aussi liée à une rotation plus importante du pan d'occlusion. L'hypothèse nulle est rejetée.

Les raisons de l'échec de l'anesthésie du nerf alvéolaire inférieur ne sont pas complètement comprises et la littérature actuelle les attribue à différents facteurs. Ces facteurs comprennent des problèmes psychologiques et d'anxiété qui diminueraient le seuil de douleur. Des variations anatomiques telles que la présence de canaux mandibulaires bifides ou une innervation directe depuis le nerf mylo-hyoidien peuvent aussi contribuer à ces échecs (Potočnik and Bajrovič, 1999). L'utilisation d'un CBCT (cone beam computed tomography) peut être avantageuse dans des cas de chirurgie maxillo-faciale mandibulaire car une vue en trois dimensions fournit davantage d'informations concernant le tracé du canal mandibulaire. La proximité du nerf alvéolaire inférieur avec des troisièmes molaires incluses inférieures, des kystes ou tumeurs peut aussi être particulièrement bien analysée sur ces images (Ahmad et al., 2012). Par contre, la détection de variations anatomiques pouvant influencer l'obtention d'une bonne anesthésie ne semble pas être meilleure avec un CBCT qu'avec une radiographie panoramique (Neves et al., 2013). En outre, un CBCT ne peut être indiqué comme examen de routine pour la détection du foramen mandibulaire pour des raisons éthiques évidentes de radio-protection. Finalement, des réponses physiologiques anormales aux produits anesthésiants dans des situations inflammatoires aigues peuvent aussi empêcher l'anesthésie du nerf alvéolaire : les neurones et leur axones innervant un tissu inflammé ont des seuils de repos et des seuils d'excitation modifiés (Potočnik and Bajrovič, 1999).

Dans cette étude, nous avons mesuré que la distance foramen-plan d'occlusion devient plus importante entre les enregistrements initiaux et ceux réalisés 10 ans après la fin de traitement. Ces différences pourraient être suffisantes pour être responsable de cas inexpliqués d'échec de l'anesthésie. Dans notre échantillon, nous avons observé que le foramen était sous le plan d'occlusion chez les patients les plus jeunes et qu'il s'élevait progressivement chez les patients plus âgés, atteignant le niveau du plan d'occlusion vers l'âge de 8.5 ans. Le changement de cette distance est corrélé et augmente avec l'âge initial du patient, mais cela ne se retrouve évidemment pas chez les patients 10 ans après traitement. Ce résultat n'est pas étonnant puisque de la croissance est encore en cours lors des enregistrements initiaux, mais plus lors de la deuxième série d'enregistrements. Nos résultats qui concernent le rôle de l'âge sont en accord avec des auteurs précédents (Kanno et al., 2005), particulièrement avec Hwang (Hwang et al., 1990) qui a aussi décrit cette augmentation de la distance foramen-plan d'occlusion, mais sans relier ces changements avec une quelconque modification du type de croissance. Ce dernier a établi que le foramen croisait le plan d'occlusion à l'âge de 9 ans et que dès lors il s'éloignait du plan d'occlusion, vers le haut. Olsen (Olsen, 1956) recommande d'injecter sous le plan d'occlusion chez les patients avec des dents de lait et Benham (Benham, 1976) à son niveau ou légèrement en dessous. D'autres auteurs ont trouvé des résultats opposés avec le foramen se trouvant toujours au niveau du plan d'occlusion (Mbajiorgu, 2000) ou en dessous (Nicholson, 1985; Mwaniki & Hassanali, 1992). Deux facteurs pourraient expliquer ces différences par rapport à nos résultats : la technique utilisée pour localiser le foramen et l'origine des patients. De manière plus détaillée, les mesures des trois dernières études ont été faites directement sur des mandibules sèches, ce qui pourrait induire des différences lorsqu'on étudie des structures situées sur des radiographies. De plus, Mbajiorgu (2000), Mwaniki et Hassanali (1992) ont étudié des populations africaines, respectivement du Zimbabwe et du Kenya et Nicholson (1985) a travaillé avec des mandibules d'Indiens de la partie Est.

La deuxième partie de nos résultats présente l'importance de la morphologie faciale par rapport à la distance foramen-plan d'occlusion ; à notre connaissance, il n'y a pas d'autre étude longitudinale analysant son influence. Une petite modification de la distance foramen-plan d'occlusion est corrélée avec un grand angle inter-maxillaire initial, une rotation importante du plan d'occlusion et une distance Condyle-Gonion courte. Ces caractéristiques sont typiques de patients face-longue. La morphologie cranio-faciale est liée à la capacité fonctionnelle des muscles masticateurs (Kiliaridis *et al.*, 1993). Des rats nourris avec une alimentation molle développent une fonction masticatrice réduite, ce qui mène à une augmentation de la hauteur du processus alvéolaire et à une sur-éruption des molaires (Mavropoulos et al., 2010). La même situation est retrouvée chez les humains : les patients face-longue ont des muscles plus fins et sont d'habitude caractérisés par une activité musculaire réduite ; leur os est, par conséquent, moins stimulé (Proffit & Fields, 1983). Leur ramus est plus court, l'angle goniaque plus grand et le plan d'occlusion est plus raide (Odegaard, 1970; Fields et al., 1984) ; le processus alvéolaire osseux est également plus grand avec une sur-éruption des dents (Schendel *et al.*, 1976). Ces changements affectent directement le plan d'occlusion : sa localisation et sa relation avec les structures mandibulaires osseuses sont modifiées. Chez ces patients face-longue, la sur-éruption des dents déplace le plan d'occlusion vers le haut dans le ramus. De plus, un plan d'occlusion plus raide est le résultat d'une augmentation de sa rotation. La partie antérieure du plan d'occlusion est déplacée loin de la base du crâne alors que la partie distale s'en rapproche. Ces mouvements vers le haut rapprochent le plan d'occlusion du foramen mandibulaire et ceci pourrait expliquer pourquoi la distance foramen-plan d'occlusion est réduite chez les patients face-longue.

L'extrapolation à la population entière des résultats obtenus dans cette étude doit se faire avec prudence. En fait, deux aspects n'ont pas été investigués : le premier est le fait que nous avons utilisé les données de patients qui ont suivi un traitement orthodontique. On pourrait argumenter que la relation entre le foramen et le plan occlusal a été artificiellement crée par les appareils orthodontiques. D'autre part, un traitement orthodontique pourrait aussi avoir diminué l'importance de cette relation. Bien qu'une modification de l'inclinaison du plan d'occlusion puisse arriver, Van der Linden (2008) a montré que ce n'était que temporaire et que le plan occlusal revenait finalement à sa situation initiale. La seconde question concerne le groupe ethnique des patients : les patients Caucasiens faisaient partie d'un des critères d'inclusion de cette étude : les patients non-Caucasiens ont été exclus afin d'obtenir une population homogène. Mais comme beaucoup de structures de la face moyenne varie selon les groupes ethniques, la position du plan d'occlusion et donc la distance foramen-plan d'occlusion pourraient présenter des différences chez les patients non-Caucasiens.

Cette étude a démontré que la distance foramen-plan d'occlusion changeait avec l'âge et avec le type facial vertical du patient. Il semble donc que les recommandations pour obtenir une anesthésie du nerf alvéolaire inférieur, qui considèrent que cette distance est constante, devraient être réévaluées. Un médecin-dentiste connait l'âge de son patient et est capable de distinguer un patient face-courte d'un patient face-longue sans prendre de radiographie céphalométrique. La présente étude a été réalisée de façon rétrospective et, bien que ses implications cliniques soient évidentes, son application et sa validité clinique doivent être confirmées.

2.2 Conclusion

1. La distance foramen-plan d'occlusion varie avec l'âge chez les jeunes patients mais plus chez les patients adultes. La distance foramen-plan d'occlusion devient plus importante avec l'âge chez les patients en croissance.
2. La distance foramen-plan d'occlusion varie selon la morphologie faciale verticale, qu'elle soit mesurée sur des tissus durs (angle inter-maxillaire) ou sur des tissus mous (rapport des tissus mous antéro-inférieurs). Les patients face-longue avec un angle inter-maxillaire important auront une distance foramen-plan d'occlusion plus courte.
3. Les variations de la distance foramen-plan d'occlusion selon le type de croissance verticale semblent dépendre principalement du changement de la position du plan d'occlusion : la partie distale du plan d'occlusion s'éloigne ou se rapproche du foramen.
4. La prise en considération de l'âge et du type facial du patient pourrait fournir au praticien une meilleure appréciation de la position du foramen mandibulaire, ce qui est un pré-requis afin de diminuer un échec lors de l'anesthésie. En d'autres mots, l'insertion de l'aiguille devrait être faite plus loin du plan d'occlusion chez des patients face-courte et adultes comparé à des patients face-longue et plus jeunes.

2. TEXTE DE SYNTHÈSE COMPLET (en anglais)

2.1 Introduction

Inferior alveolar nerve block is one of the most common dental procedures. It is achieved by injecting the anesthetic solution next to the mandibular foramen through which the inferior alveolar nerve enters the mandibular ramus. Some studies have shown that this foramen lies vertically around the middle of the ramus, between the mandibular notch and the lower surface, slightly to the lower border (Nicholson, 1985; Jerolimov et al., 1998). The foramen can be accurately identified on cephalometric and panoramic radiographs (Afsar et al., 1998). Its position is normally symmetric between the right and left sides (Hayward et al., 1977; Narayana & Vasudha, 2004; Prado et al., 2010) with no gender differences (Afsar et al., 1998; Trost et al., 2010). At the end, the goniac angle seems to be related to the vertical location of the mandibular foramen from the lower surface of the mandible: the larger this angle, the closer the foramen is to the mandibular rim (Tsai, 2004 ; Poonacha et al., 2010). Despite these details about its location, reported failure rates for the inferior alveolar nerve block vary from 5 to 15% (Wong & Jakobsen, 1992). This is very probably due to the variability of the position of the foramen (Nicholson, 1985; Keros et al., 2001).

The current consensus for an effective inferior nerve block stipulates that the needle must be inserted at the inner surface of the ramus, parallel to the occlusal plane of the mandibular teeth, at a level bisecting the fingernail (Steiner & Thompson, 1977; Benett 1978) or 6 to 10mm (Thoma, 1958; Malamed, 2004) above the occlusal plane. In a general manner, growth has been extensively studied and we know that the different parts of the craniofacial complex do not grow all in the same manner. It is consequently doubtful that these guidelines for the injection of the anesthetic product, although well adapted for adult patients, can be followed for children patients. For that reason, it is essential to know the precise location of the foramen. Nowadays, the general consensus is to move the injection site for the needle in an upward direction as the child is getting older. The relationship between the age and the distance separating the foramen from the occlusal plane (the *foramen-occlusal plane distance*) seems to be accepted by the majority (Pinkham et al., 2005; Hwang et al., 1990; Movahhed et al., 2011) but there are still some authors that go against these findings (Afsar et al., 1998; Trost et al., 2010).

As the occlusal plane is the only reference structure the clinician can use in everyday practice, the foramen-occlusal plane distance is of major importance. With ageing, the increase of the alveolar height moves the occlusal plane away from the body of the mandible. As the occlusal plane is brought upward in the ramus, the foramen-occlusal plane distance should decrease. But two others factors could also influence the foramen-occlusal plane distance. A combination of bone resorption and bone apposition at the foramen itself could change its vertical position in the ramus, independently of the elevation of the occlusal plane. A change of the inclination of the occlusal plane could also modify the foramen-occlusal plane distance: a forward or a backward rotation would bring its posterior extremity closer or further from the foramen. We know that the inclination of the occlusal plane depends on the vertical facial growth pattern of the patient (Schendel & Bell, 1976; Opdebeeck et al. 1978). The vertical facial growth pattern is basically divided in two categories: either increased (long-face, hyperdivergent, forward rotators…) or reduced (short-face, hypodivergent, counterclockwise rotators…) lower anterior vertical facial height. In the long-face syndrome, the mandibular plane angle, the inter-maxillary angle, the occlusal plane angle and the Go angle are big, and the posterior facial height is small (Schendel & Bell, 1976). In the short-face syndrome, the opposite features are seen (Opdebeeck et al. 1978). These two opposite vertical facial morphologies depend mainly of the structures located below the palatal plane (Isaacson et al. 1971; Fields et al. 1984) and the position of the palatal plane itself may have an influence on the facial pattern. It seems then probable that the foramen-occlusal plane distance is different according to the growth pattern and the facial type of the patient; moreover, it is likely that the occlusal plane has also an influence on it.

Despite the fact that the currently recommended technique for an inferior alveolar nerve block assumes that the foramen-occlusal plane distance is constant, it can be inferred from the above that this might not be true. The aim of this longitudinal study was to define the foramen-occlusal plane distance in a sample of subjects of different ages with different vertical facial morphologies. If the age, some specific growth pattern or the occlusal plane modify the foramen-occlusal plane distance, the reasons why they have an influence will also be investigated. The null hypothesis was that regardless of the age or the vertical facial growth pattern the foramen-occlusal plane distance remains the same.

2.2 Aims

1) To define the foramen-occlusal plane distance in a sample of subjects of different ages with different vertical facial morphologies.

2) To explain the reasons why the foramen-occlusal plane distance changes according to age, to some specific growth pattern and to the occlusal plane, between initial records and 10-year post-treatment records.

2.3 Material and methods

2.3.1 Material

This retrospective investigation was performed on the cephalometric and panoramic radiographs of patients who underwent orthodontic treatment in our university clinic. Since orthodontic treatment usually starts only after the eruption of the first permanent molars, only radiographs of children of 6 years of age and older were available. We first selected those cases with complete initial and 10-year post-treatment records. Then we applied the following exclusion criteria:

a. radiographic records of inferior quality,
b. patients with obvious asymmetry (more than 5mm at the lower border of the ramus), with syndromes or history of maxillofacial injury,
c. non-Caucasian patients in order to have a homogenous population sample,
d. patients older than 12 years old at the initial radiographic examination in order to focus on the patients who showed the major part of growth.

This investigation was submitted and received the approval of the Research Ethics Committee of the University Hospital of Geneva (12-066R / Psy 12-004R).

All radiographs were taken with the same radiological equipment. The cephalometric radiographs were taken using a Cranex3+ Ceph (Soredex, Tuusula, Finland) with Konika X-ray 24x30cm films (Konica Minolta Medical & Graphic Inc., Tokyo, Japan). For the panoramic radiographs, Scanora was used (Soredex, Tuusula, Finland) with Kodak X-ray 15x30cm films (Carestream Health Inc., Bagnolet, France). All radiographs were digitized (300 dpi, grayscale mode) using a flatbed scanner (Epson Expression 1600Pro; Seiko Epson Corp., Nagano, Japan) and stored in a jpeg format. They were finally traced on screen using a cephalometric program (Viewbox3.0, DHal, Kifisia, Greece) and custom-made analyses were created in order to measure sets of predefined variables.

2.3.2 Accuracy of the identification of the foramen

Locating the foramen on a cephalometric radiograph can be sometimes difficult due to double structure superimposition and/or image blurring. It is substantially easier to do so on a panoramic radiograph. However, the structures we measured in this investigation can only be traced on cephalometric radiographs and this obliged us to locate the foramen on this type of radiographs. In order to test our accuracy in locating the foramen we calculated and compared the vertical location of the mandibular foramen, defined by the same vertical ratio (Pco-Pmf/Pco-Pma) (Figure 1) on both cephalometric and panoramic radiographs. On panoramic radiographs there is the additional problem of possible lack of symmetry between the right and left foramens; therefore, we first compared the ratio of the two sides. This ratio was 65±3% (range 57-75%) for the left side, and 65±3% (range 57-74%) for the right one. A high correlation was found ($r=0.891$, $p<0.001$) and a paired t-test showed no statistically significant differences ($p=0.72$) between them.

This enabled us to use the average panoramic ratio (65±3%; range 57-74%) for the comparison with the cephalometric ratio (65±3%; range 57-75%) which was measured on all cephalometric radiographs except for eleven in which the identification of the foramen was uncertain. A Pearson's correlation test and a Student's t-test showed a high correlation ($r=0.905$; $p<0.001$) and no significant difference between the panoramic and the cephalometric ratios ($p=0.79$). These results allowed the identification of the mandibular foramen in the eleven previously excluded cephalograms by using the panoramic ratio.

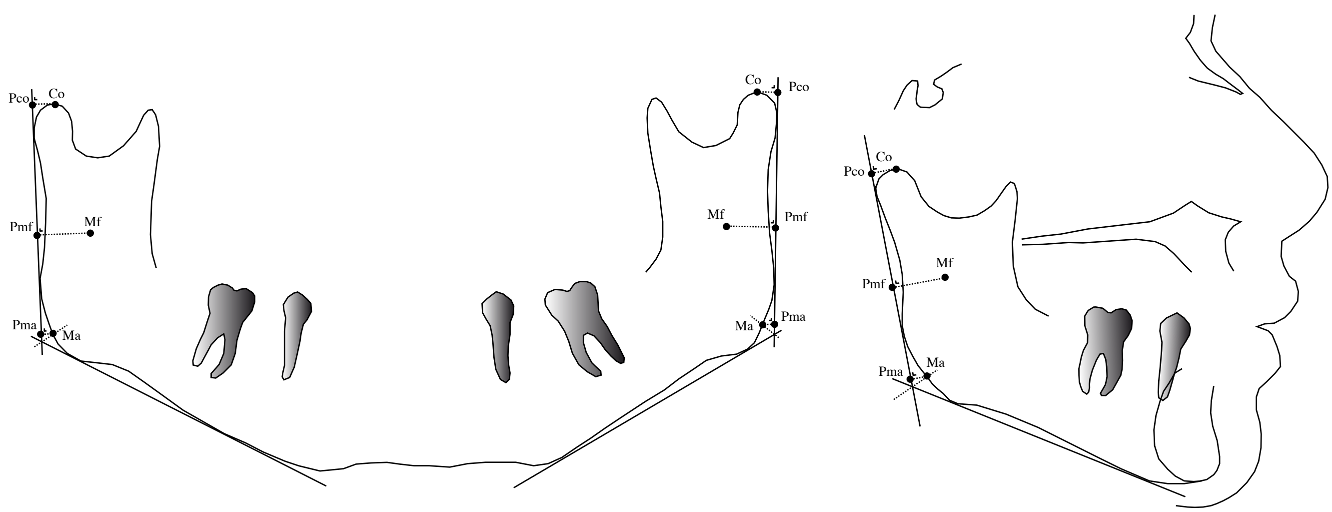

Figure 1. Cephalometric points used to compare the vertical ratio of the mandibular foramen between panoramic and cephalometric radiographs
Co (Condyle) indicates the top of the condyle; *Mf*, mandibular foramen; *Ma (Mandibular angle)*, point on the contour of the mandible obtained by bisecting the tangents to the corpus and ramus of the mandible; *Pco, Pmf, Pma*, projection of, repectively, Co, Mf and Ma on the vertical tangent to the ramus

1 a. Panoramic radiograph **1 b.** Cephalometric radiograph

2.3.3 Methods

In Figure 2 are shown all the cephalometric landmarks employed in order to calculate the location of the foramen as a function of its distance to the functional occlusal plane (*Foramen-occlusal plane distance, F-F'*) as well as the other variables under study: another one linear, two angular and one ratio variables (Table 1). These variables are all hard variables except one soft tissue variable (*lower anterior soft tissue ratio)*. All these measurements were performed on both the initial and 10-year post-treatment radiographs and the differences between these two sets of measurements were calculated as well.

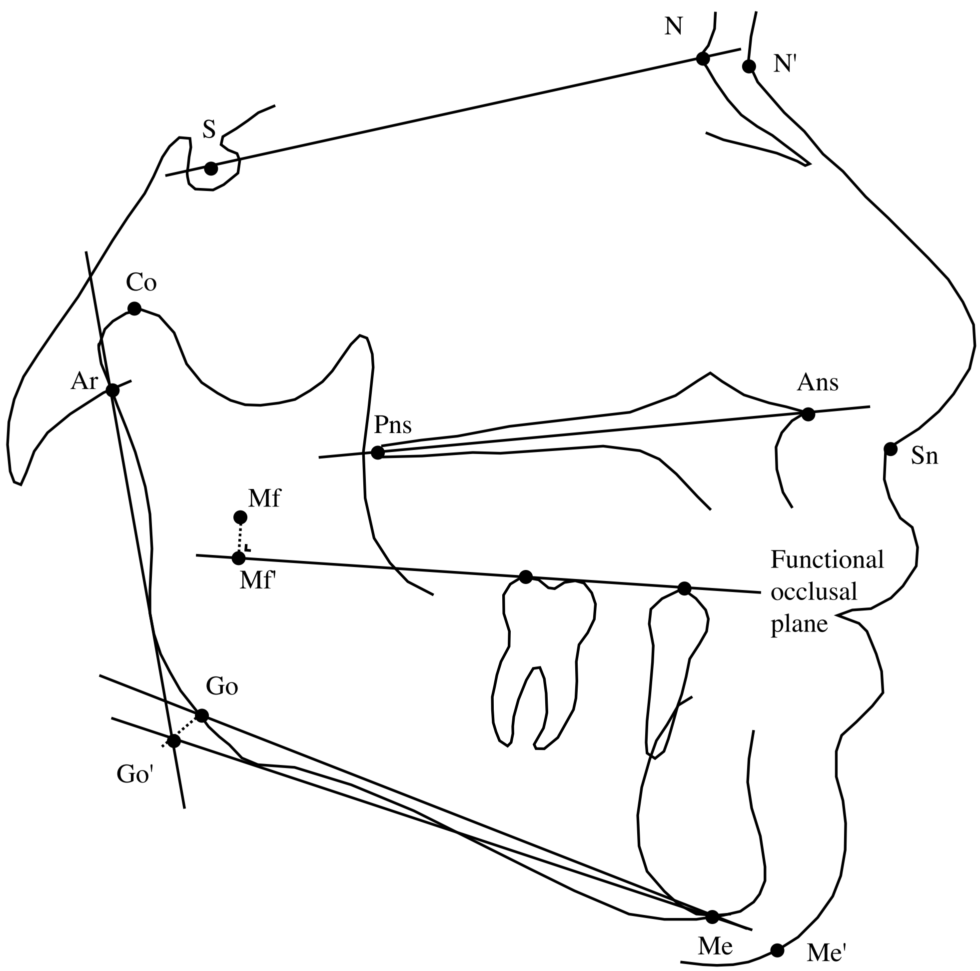

Fig. 2 Cephalometric landmarks used in the variables under study:
Ans (Anterior nasal spine), apex of the anterior nasal spine;
Pns (Posterior nasal spine), intersection point of soft palate, hard palate and pterygopalatinal fissure;
Ar (Articulare), radiographic intersection of the posterior margin of the ramus with the basion;
N (Nasion), anterior limit of the nasofrontal suture; *S (Sella),* center of sella turcica;
Co (Condyle), top of the condyle; *Me (Menton),* lowest point of the symphysis;
Go' (Gonion marked), point on the contour of the mandible obtained by bisecting the angle Ar-Go'-Me;
Go (Gonion), point on the contour of the mandible obtained by bisecting the angle Ar-Go'-Me;
Mf, mandibular foramen; *Mf',* projection of Mf on the functional occlusal plane
N' (Soft nasion), deepest point of the profile;
Sn (Subnasale), point at which the nasal septum merges with the upper cutaneous lip;
Me' (Soft menton), point on the contour of the chin obtained by bisecting the angle formed by Go'-Me and N-Po.

Table 1. Variables used in this study

	Variable	Name as it appears in the manuscript
Linear	Mf-Occlusal plane	Foramen-Occlusal plane distance
	Go-Co	Gonion-Condyle distance
Angular	Ans-Pns // Go-Me	Inter-maxillary angle
	S-N // occlusal plane	Rotation of the occlusal plane
Ratio	Sn-Me' / N'-Me'	Lower anterior soft tissue ratio

2.3.4 Method's error and statistical analysis

The Shapiro-Wilk test revealed that all variables. Two-tailed Pearson's correlation analysis and multiple linear regression analysis were used in order to determine the degree of correlation between the various variables under study.

The significance level was set at $p<0.05$ (two tailed). The Statistical Package for Social Sciences for Windows, version 17.0 (SPSS Inc., Chicago, USA) was used to perform all statistical evaluation.

On the basis of the expected difference in the changes of the location of mandibular foramen that could affect a nerve block, given the sample size (n=145) and a p value of 0.05, the power of this study was 92%.

In order to evaluate the systematic error of the vertical and horizontal position of mandibular foramen, the cephalometric radiographs of 15 subjects were randomly selected and analyzed 4 weeks later by the same operator (JFE). No differences were detected at a significance level of 0.05 (p=0.21, Pearson's correlation = 0.99). Dahlberg's formula (Houston, 1983) was used to calculate the coefficient of reliability, which was excellent (CR=0.996).

2.4 Results

A. Cross-sectional study

A hundred and forty-five patients (76 females and 69 males) fulfilled our inclusion criteria at initial records

1. Descriptive statistics

The average age before treatment was 10.4 ± 1.6 years (range 6.3 - 14.6). The foramen-occlusal plane distance was found to be 3.1 ± 2.6mm (range -3.1 - 9.6mm), on average. A positive value denotes a position above the occlusal plane, whereas a negative one a position below it. For males, the mean value was 3.3 ± 2.7mm (range -2.9 - 8.5 mm) and for females, 3.0 ± 2.5mm (range -3.1 - 9.6mm): there was no significant difference between them (t-test: $p=0.61$).

2. Correlation of the initial foramen-occlusal plane distance with the age, the inter-maxillary angle and the lower anterior soft tissue ratio:

A positive correlation ($r = 0.690$, $p<0.001$) was reported between the foramen-occlusal plane distance with the patient's age: the older the patient, the bigger the foramen-occlusal plane distance. It means that in older patients the foramen is located above the occlusal plane, while in younger patients it is below it.

Hard tissue variables: each of the skeletal variables describing the vertical facial morphology presented a significant correlation ($p<0.001$) with the foramen-occlusal plane distance. These correlations ranged from 0.344 to 0.601 and the variable with the best correlation factor was the inter-maxillary angle ($r = -0.601$, $p<0.001$): the smaller the inter-maxillary angle, the bigger the value of the foramen-occlusal plane distance. We can conclude from these data that in a hypodivergent patient we should expect the foramen to be well above the occlusal plane, while in a hyperdivergent patient the foramen will be at or below the occlusal plane level.

Soft tissue variable: the lower anterior soft tissue ratio was negatively correlated (r = -0.764, p<0.001) with the foramen-occlusal plane distance: the shorter the lower third of the patient's face, the bigger the foramen-occlusal plane distance. It denotes that the foramen is above the occlusal plane in short face patients whereas it will be below it in long face patients.

3. Multiple regression analysis using the foramen-occlusal plane distance as dependent variable and as independent variables:

a) The inter-maxillary angle (hard tissue variable) and the age:

Each of the variables describing the vertical facial morphology was significantly related to the foramen-occlusal plane distance but we couldn't include them into one single multiple linear regression analysis because there are all inter-independent. For that reason, we chose only the skeletal variable showing the best correlation factor: the inter-maxillary angle. We conducted a multiple linear regression analysis by using this previous variable (inter-maxillary angle) in conjunction with the age as independent variable, and the foramen-occlusal plane distance as dependent variable. A substantial 70% of the foramen-occlusal plane distance was explained by the available factors (r = 0.830) (Table 2a).

b) the lower anterior soft tissue ratio (soft tissue variable) and the age:

The second multiple regression analysis we carried out included as independent variable, and the foramen-occlusal plane distance as dependent variable. We obtained a slightly better result with more than 70% explaining the variability of the foramen-occlusal plane distance (r = 0.845) (Table 2b).

In summary, the major part of the variation of the foramen-occlusal plane distance can be explained by the age, by the inter-maxillary angle, and by the lower anterior soft tissue ratio of the patient.

Table 2. Multiple regression analysis using as dependent variable the vertical position of the mandibular foramen and as independent variables (n=145):

(a) the patient's age and inter-maxillary angle ($R= 0.830$, $p < 0.001$)

$$Y = 2.385 + b_1 age + b_2 intermaxillary\ angle$$

Independent variables	Coefficient β	Standard Error	*P* value
Age	0.586	0.060	< 0.001
Inter-maxillary angle	-0.472	0.024	< 0.001

(b) the patient's age and lower anterior soft tissue ratio ($R = 0.845$, $p < 0.001$)

$$Y = 27.554 + b_1 age + b_2 lower\ anterior\ soft\ tissue\ ratio$$

Independent variables	Coefficient β	Standard Error	*P* value
Age	0.415	0.064	< 0.001
Lower anterior soft tissue ratio	-0.559	0.048	< 0.001

B. Longitudinal study

Fifty patients (29 females and 21 males) from the hundred and forty-five patients we had at initial recording came back 10 years after the end of their orthodontic treatment.

1. Descriptive statistics

a. Initial records

The average age before treatment was 9.5 ± 1.4 years (range 6.3 - 11.8 years). The foramen-occlusal plane distance was 2.9 ± 2.4mm (range -3.7 - 6.8mm). A positive value means the foramen is above the occlusal plane, whereas a negative value means the foramen is below it. The Condyle-Gonion distance was 49.0 ± 4.6mm (range 37.7 - 59.2mm). The mean inter-maxillary angle was 28.3 ± 4.7° (range 14.0 - 37.9°) and the rotation of the occlusal plane was 20.0 ± 4.4° (range 10.2 - 28.8°).

b. 10-year post-treatment records

The average age was 24.2 ± 1.6 years (range 20.1 - 27.8). The foramen-occlusal plane distance was 5.5 ± 2.2mm (range 0.0 - 9.9mm). The Condyle-Gonion distance was 64.1 ± 7.4mm (range 47.7 - 81.5mm). The mean inter-maxillary angle was 24.6 ± 6.0° (range 13.2 - 35.7°) and the rotation of the occlusal plane was 17.4 ± 5.3° (range 8.3 - 28.5°).

2. Changes between initial and 10-years post-treatment measurements

a. Paired t-test

We tested the changes between the initial and 10-years values with a Student's t-test for each variable under study. There was a significant difference ($p<0.001$) for each of them (Table 3).

b. Changes of the foramen-occlusal plane distance:

We investigated if the sex of the patient had an influence on the change of the foramen-occlusal plane distance between initial and 10-years radiographs: it had none ($p=0.513$).

Table 3. Changes in the variables under study during the 10-years follow-up period (paired t-test):

Variable	Mean	Std dev	Confidence interval (95%)		*P* value
			Superior	Inferior	
Foramen-Occlusal plane distance (mm)	2.61	3.23	1.69	3.52	< 0.001
Gonion-Condyle distance (mm)	15.00	6.05	13.28	16.72	< 0.001
Inter-maxillary angle (°)	-3.29	3.63	-4.32	-2.25	< 0.001
Rotation of the occlusal plane (°)	-2.64	3.77	-3.71	-1.57	< 0.001

We conducted a multiple linear regression analysis by using the initial age, the initial inter-maxillary angle, the change in the rotation of the occlusal plane and the change in Condyle-Gonion distance as independent variables, and the change of foramen-occlusal plane distance as dependent variable. We obtained a result of 53% explaining the variability of the change of the foramen-occlusal plane distance ($r = 0.659$) (Table 4). Half of the variation of the foramen-occlusal plane distance can be explained by these variables.

Table 4. Multiple regression analysis using as dependent variable the change of foramen-occlusal plane distance (R = 0.732, p < 0.001) and as independent variables the initial age, the initial inter-maxillary angle, the rotation of the occlusal plane and the change of the Condyle-Gonion distance (n=50, df =49)

$Y = 10.630 + b_1$initial age + $b_2$initial inter-maxillary angle + $b_3$rotation of the occlusal plane + $b_4$change in Condyle-Gonion distance

Independent variables	Coefficient β	Standard Error	*P* value
Initial age	-0.337	0.244	= 0.003
Initial inter-maxillary angle	-0.218	0.073	= 0.048
Rotation of the occlusal plane	-0.410	0.091	< 0.001
Change of the Condyle-Gonion distance	0.301	0.059	= 0.009

2.5 Discussion

In this investigation we found that the foramen-occlusal plane distance decreases with growth and even more so in patients with a long-face growth pattern. This change was influenced by the vertical facial growth pattern. A smaller increase or even a decrease of this distance was also related with a more important rotation of the occlusal plane. The null hypothesis was rejected.

The reasons for a failure of the inferior alveolar nerve block are not completely well understood and the current literature provides many different explanations. Among them, psychological factors and anxiety could directly lower the pain threshold. Anatomical considerations like the presence of bifid mandibular canals or direct accessory innervation from the mylohyoid nerve have been implicated in the inferior alveolar nerve block failure (Potočnik and Bajrovič, 1999). The use of a cone beam computed tomography (CBCT) provides better viewing of anatomical structures, especially in orthognathic surgery cases where the location of the mandibular canal must be precisely defined. The relationship of the inferior alveolar nerve block with impacted mandibular third molars, cysts or tumours can also accurately be assessed with this kind of image (Ahmad et al., 2012). But a CBCT does not seem to detect the anatomical variations more easily than a panoramic radiograph (Neves et al., 2013). Moreover, CBCT examination should not be used in order to detect the mandibular foramen for obvious ethical reasons (radiation protection). At the end, abnormal physiological responses to the anesthetic agents in the presence of acute inflammation can also impede the inferior alveolar nerve block: neurons and their axons innervating an inflamed tissue have altered resting potentials and excitability thresholds. (Potočnik and Bajrovič, 1999).

In this study, we found that the foramen-occlusal plane distance became larger between initial records and 10-years records. These differences could be enough to be responsible for some unexpected cases of nerve block failure. In our sample, the foramen was observed to be below the occlusal plane level in younger patients and to be gradually located above it in older patients, reaching the occlusal plane level by the age of 8.5. The change of this distance is correlated and increases with the initial age of the patients but not with the 10-year post-treatment age. This finding is not surprising since growth is still occurring at initial records but not at 10-year post-treatment records any more. Our findings at initial records are in agreement with previous authors (Kanno et al., 2005), particularly with Hwang (Hwang et al., 1990) who also described an increase of the foramen-occlusal plane distance with age, but without relating this change to any growth pattern. He assessed that the foramen was crossing the occlusal plane level by the age of 9 and that it was moving upward from the occlusal plane since then. Olsen (Olsen, 1956) recommended injecting below the occlusal plane in patients with primary teeth and Benham (Benham, 1976) at the level or slightly below it. Some others authors found opposite findings with the foramen at the level of the occlusal plane (Mbajiorgu, 2000) or even below it (Nicholson, 1985; Mwaniki & Hassanali, 1992). Two factors could explain these differences with our results: the technique used to locate the foramen and the origin of the patients. More specifically, the measurements in these last three studies were done directly on dry mandibles, which could induce some differences when studying structures located on radiographs. Furthermore, Mbajiorgu (2000) and Mwaniki and Hassanali (1992) studied African people, from Zimbabwe and Kenya, respectively, and Nicholson (1985) worked on mandibles of East Indians.

A small change of the foramen-occlusal plane distance was also correlated with a large initial inter-maxillary angle, an important rotation of the occlusal plane and a short Condyle-Gonion distance. These morphologic features are typical of long-face patients. Craniofacial morphology was found to be related to the functional capacity of the masticatory muscles (Kiliaridis *et al.*, 1993). Rats fed with soft diet develop a reduced masticatory function, which lead to increase of the alveolar process height and overeruption of the molars (Mavropoulos et al., 2010). The same situation is seen in humans: long-face patients have thinner muscles and are usually characterized by reduced muscular activity; their bone is consequently less stimulated (Proffit & Fields, 1983). Their ramus is shorter, the goniac angle is larger and the occlusal plane is steeper (Odegaard, 1970; Fields et al., 1984); the alveolar bone processes are also higher with an over-eruption of the teeth (Schendel *et al.*, 1976). These changes directly affect the occlusal plane: its location and its relation to the bony mandibular structures are modified. In these long-face patients, the over-eruption of the teeth moves the occlusal plane upward in the ramus. Moreover, a steeper occlusal plane is the result of an increased rotation of the occlusal plane. The anterior part of the occlusal plane is moving away from the cranial base whereas the distal part is coming closer to the cranial base. These upwards movements bring the occlusal plane closer to the mandibular foramen and this could explain why the foramen-occlusal plane distance is decreased in long-face patients.

One should be cautious extrapolating the results found in this study to the whole population. Our sample is comprised exclusively of individuals who received an orthodontic treatment. One could argue that the relationship between the foramen and the occlusal plane was influenced by the orthodontic treatment itself. Although orthodontic appliances can cause moderate changes of the occlusal plane cant, Van der Linden (2008) showed that this was only temporary and that the occlusal plane returned eventually to its initial situation. Our sample consisted exclusively of Caucasian individuals. This was found preferable in order to have a more homogeneous population sample. It is possible, since many structures of the lower face vary according to the ethnic group, that our result do not apply to non-Caucasian individuals.

The present study has shown that the foramen-occlusal plane distance changes with age and with the vertical facial type of the patient. It seems that the current guidelines for an efficient inferior alveolar nerve block, which consider this distance a constant, should be updated. A dentist knows the age of his patient and is able to distinguish a short-face from a long-face patient without taking a cephalometric radiograph. The current investigation was performed retrospectively on longitudinal observations and, although its clinical implications are evident, its clinical applicability and validity need to be confirmed.

2.6 Conclusions

1. At initial records, the mandibular foramen lies at 3.1±2.6mm above the occlusal plane, on average. Its position ranges from 3.1mm below the occlusal plane up to 9.6mm above it. At 10-years records, it lies at 5.47 ± 2.3mm, from 0.0 to 9.9mm above the occlusal plane.

2. The mandibular-occlusal plane distance changes with age in young patients but not in adult patients. The mandibular foramen moves upwards relative to the occlusal plane during growth.

3. The mandibular-occlusal plane distance changes on the vertical facial growth pattern, whether it is measured on hard tissues (inter-maxillary angle) or on soft tissues (lower anterior soft tissue ratio). Long-face patients with a large inter-maxillary angle, an increased rotation of the occlusal plane and a short Condyle-Gonion distance will have a shorter foramen-occlusal plane distance. This distance depends on the type of facial growth.

4. The variations of the foramen-occlusal plane distance according to the vertical growth pattern seem to depend mainly on the change of the position of the occlusal plane: the distal part of the occlusal plane moves away or nearer from the foramen. For example, patients with a small occlusal plane rotation have a bigger foramen-occlusal plane distance.

5. Taking into consideration the age and the facial type of the patient could provide the clinician with a better appreciation of the mandibular foramen position, which is a prerequisite to reduce inferior alveolar nerve block failure. In other words, in short-face and adult patients, the insertion of the needle should be made further from the occlusal plane than in long-face and younger patients.

2.7 References

Afsar A, Haas DA, Rossouw PE, Wood RE. Radiographic localization of mandibular anesthesia landmarks. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998 Aug;86(2):234-41.

Ahmad M, Jenny J, Downie M. Application of cone beam computed tomography in oral and maxillofacial surgery. Aust Dent J. 2012 Mar ;57 Suppl 1:82-94.

Arat ZM, Rübendüz M. Changes in dentoalveolar and facial heights during early and late growth periods: a longitudinal study. Angle Orthod. 2005 Jan;75(1):69-74.

Benham NR. The cephalometric position of the mandibular foramen with age. ASDC J Dent Child.1976 Jul-Aug;43(4):233-7.

Bennett CR. Monheim's local anesthesia and pain control in dental practice. 6th ed. Saint Louis, Mo: Mosby; 1978.

Bjork A. Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand. 1955 Jun;13(1):9-34

Björk A, Skieller V. Facial development and tooth eruption. An implant study at the age of puberty. Am J Orthod. 1972 Oct;62(4):339-83.

Fields H, Proffit R, Nixon W, Phillips C, Stanek E. Facial pattern differences in long-faced children and adults. Am J Orthod. 1984 Mar;85(3):217-23.

Hayward J, Richardson ER, Malhotra SK. The mandibular foramen: its anteroposterior position. Oral Surg Oral Med Oral Pathol. 1977 Dec;44(6):837-43.

Houston WJ. Analyses of errors in orthodontic measurements. Am J Orthod. 1983;83 (5):382-90.

Hwang TJ, Hsu SC, Huang QF, Guo MK. [Age changes in location of mandibular foramen]. Zhonghua Ya Yi Xue Hui Za Zhi 1990;9 (3):98-103.

Isaacson JR, Isaacson RJ, Speidel TM, Worms FW. Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. Angle Orthod. 1971;41 (3):219-29.

Jerolimov V, Kobler P, Keros J, Stanicić T, Bagić I. Foramen mandibulae as an indicator of successful conduction anesthesia. Coll Antropol. 1998 Jun;22(1):169-77.

Kanno CM, de Oliveira JA, Cannon M, Carvalho AA. The mandibular lingula's position in children as a reference to inferior alveolar nerve block. J Dent Child (Chic). 2005 May-Aug;72(2):56-60.

Karlsen AT. Association between facial height development and mandibular growth rotation in low and high MP-SN angle faces: a longitudinal study. Angle Orthod. 1997;67(2):103-10

Keros J, Kobler P, Baucić I, Cabov T. Foramen mandibulae as an indicator of successful conduction anesthesia. Coll Antropol. 2001 Jun;25(1):327-31.

Kiliaridis S, Engström C, Thilander B. The Relationship between masticatory function and craniofacial morphology. I. A cephalometric longitudinal analysis in the growing rat fed a soft diet. Eur J Orthod. 1985 Nov ;7(4) :273-83

Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. Acta Odontol Scand. 1993 Oct;51(5):323-31.

Malamed SF. Handbook of Local Anesthesia. 5th ed. St. Louis, Mo: Mosby; 2004.

Mavropoulos A, Odman A, Ammann P, Kiliaridis S. Rehabilitation of masticatory function improves the alveolar bone architecture of the mandible in adult rats. Bone. 2010 Sep;47(3):687-92.

Mbajiorgu EF. A study of the position of the mandibular foramen in adult black Zimbabwean mandibles. Cent Afr J Med. 2000 Jul;46(7):184-90.

Movahhed T, Makarem A, Imanimogha M, Anbiaee N, Sarrafshir AR, Shakeri MT. Locating the mandibular foramen relative to the occlusal plane using panoramic radiography. J Applied Sciences 2011;11 (3):573-578.

Mwaniki DL, Hassanali J. The position of mandibular and mental foramina in Kenyan African mandibles. East Afr Med J. 1992 Apr;69(4):210-3.

Narayana K, Vasudha S. Intraosseous course of the inferior alveolar (dental) nerve and its relative position in the mandible. Indian J Dent Res. 2004 Jul-Sep;15(3):99-102.

Neves FS, Nascimento MC, Oliveira ML, Almeida SM, Bóscolo FN. Comparative analysis of mandibular anatomical variations between panoramic radiography and cone beam computed tomography. Oral Maxillofac Surg. 2013 Aug 24. [Epub ahead of print]

Nicholson ML. A study of the position of the mandibular foramen in the adult human mandible. Anat Rec. 1985 May;212(1):110-2.

Olsen NH. Anesthesia for the child patient. J Am Dent Assoc. 1956 Nov;53(5):548-55.

Odegaard J. Mandibular rotation studies with the aid of metal implants. Am J Orthod. 1970 Nov;58(5):448-54.

Opdebeeck H, Bell WH. The short face syndrome. Am J Orthod. 1978;73 (5):499-511.

Pinkham JR. Local Anesthesia and Oral Surgery in Children. In: Pinkham JR, Casamassimo PS, Fields HW Jr, McTigue DJ, Nowak AJ, eds. Pediatric Dentistry - Infancy through Adolescence. 4th ed. St Louis, Mo. Elsevier-Saunders Co: 2005;447-462.

Poonacha KS, Shigli AL, Indushekar KR. Relative position of the mandibular foramen in different groups of children: a radiographic study. J Indian Soc Ped Prev Dent. 2010 Jul-Sep;28(3):173-8.

Potočnik I, Bajrovič F. Failure of inferior alveolar nerve block in endodontics. Endod Dent Traumatol. 1999 Dec;15(6):247-51.

Prado FB, Groppo FC, Volpato MC, Caria PH. Morphological changes in the position of the mandibular foramen in dentate and edentate Brazilian subjects. Clin Anat. 2010 May;23(4):394-8.

Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. J Dent Res. 1983 May;62(5):566-70.

Schendel S, Eisenfeld J, Bell W, Epker B, Mishelevich D. The long face syndrom: vertical maxillary excess. Am J Orthod. 1976;70 (4):398-408.

Steiner RB, Thompson RD. Oral surgery and anesthesia. Philadelphia : Saunders; 1977.

Thoma KH. Oral surgery, 3rd ed. St Louis, Mo: Mosby; 1958.

Trost O, Salignon V, Cheynel N, Malka G, Trouilloud P. A simple method to locate mandibular foramen: preliminary radiological study. Surg Radiol Anat. 2010 Dec;32(10):927-31. Epub 2010

Tsai HH. Panoramic radiographic findings of the mandibular foramen from deciduous to early permanent dentition. J Clin Pediatr Dent. 2004 Spring;28(3):215-9.

Van der Linden FP. Sheldon Friel memorial lecture 2007: myths and legends in orthodontics. Eur J Orthod. 2008 Oct;30(5):449-68.

Wong MK, Jacobsen PL. Reasons for local anesthesia failures. J Am Dent Assoc. 1992 Jan;123(1):69-73.

3. PUBLICATION ORIGINALE I

Clinical Article

CROSS SECTIONAL

Influence of Age and Vertical Facial Type on the Location of the Mandibular Foramen

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Abstract: ***Purpose:*** *A successful inferior alveolar nerve block anesthesia necessitates knowledge of the exact location of the mandibular foramen. The aim of this study was to determine whether the location of the mandibular foramen is related to the age or the vertical facial morphology of the patient.* ***Methods:*** *Lateral cephalometric radiographs from 145 patients (average age 10.4 years; range 6.3 to 14.6 years) were collected. The position of the mandibular foramen was investigated both antero-posteriorely and vertically in relation to the occlusal plane. Pearson's correlation and multiple regression analysis were performed between the variables under study.* ***Results:*** *The mandibular foramen was horizontally located at 60 percent of the ramus width from its anterior border. The vertical distance of the mandibular foramen from the occlusal plane was significantly correlated to all examined variables, especially to the patient's age (r=0.69, P<0.001), the inter-maxillary angle (r=-0.60, P<0.001), and the lower facial anterior soft tissue ratio (r=-0.76, P<0.001). Multiple regression analysis explained more than 70 percent of the variation of the vertical position of the mandibular foramen.* ***Conclusions:*** *Taking into consideration the age and the facial morphology of the patient may help better locate the mandibular foramen, which is a prerequisite for a successful and safe inferior alveolar nerve block. (Pediatr Dent 2013;35:369-73)* *Received January 30, 2012 | Last Revision May 17, 2012 | Accepted June 20, 2012*

KEYWORDS: MANDIBULAR NERVE BLOCK, CEPHALOMETRY, VERTICAL DIMENSION, DENTAL OCCLUSION, AGE FACTORS

Inferior alveolar nerve block is one of the most common dental procedures. It is achieved by injecting the anesthetic solution next to the mandibular foramen through which the inferior alveolar nerve enters the mandibular ramus. Some studies have shown that the mandibular foramen lies vertically around the middle of the ramus, between the mandibular notch and the lower surface, slightly closer to the lower border and horizontally, between one-half and two-thirds distance from the anterior border.[1,2]

The mandibular foramen can be accurately identified on cephalometric and panoramic radiographs.[3] Its position is normally symmetric between the right and left sides,[4-6] with no gender differences.[3,7] Despite these details about its location, reported failure rates for the inferior alveolar nerve block vary from five percent to 15 percent.[8] This is very probably due to the variability of the position of the mandibular foramen.[1,9]

The current consensus for an effective inferior nerve block stipulates that the needle must be inserted at the inner surface of the ramus, parallel to the occlusal plane of the mandibular teeth, at a level bisecting the fingernail[10,11] or six to 10 mm[12,13] above the occlusal plane. In a general manner, growth has been extensively studied and we know that the different parts of the craniofacial complex do not grow all in the same manner. Consequently, it is doubtful that these guidelines for the injection of the anesthetic product, although well adapted for adult patients, can be followed for child patients. For this reason, it is essential to know the precise location of the mandibular foramen. Nowadays, the general consensus is to move the injection site for the needle in an upward direction as the child is getting older. The relationship between the age and the position of mandibular foramen seems to be accepted by most, [14-16] but there are still some authors who did not find any relation between the position of the mandibular foramen with any factor.[3,7]

We know as well that the modification of the structures located below the palatal plane is responsible for different vertical facial morphologies between individuals, from hyperdivergent (long-face) to hypodivergent (short-face) type.[17,18] In the long-face syndrome, the mandibular plane angle, intermaxillary angle, occlusal plane angle, and gonial angle are large while the posterior facial height is small.[19] In the short-face syndrome, the opposite features are observed.[20] Hence, it seems probable that the location of the mandibular foramen is different, according to the patient's growth pattern and facial type.

Despite the fact that the currently recommended technique for an inferior alveolar nerve block assumes that the relative position of the mandibular foramen to the occlusal plane is constant, it can be inferred from the aforementioned that this might not be true. Therefore, the purpose of this study was to locate the mandibular foramen in relation to the occlusal plane in a sample of subjects of different ages with different vertical facial morphologies. The null hypothesis was that, regardless of the age or the vertical facial morphology, the distance between the mandibular foramen and the occlusal plane would remain the same.

Methods

This investigation was submitted and received the approval of the Research Ethics Committee of the University of Geneva. This investigation was performed on the initial cephalometric and panoramic radiographs of patients who underwent orthodontic treatment in the clinic of the Department of Orthodontics, School of Dentistry, University of Geneva, Geneva, Switzerland. Since orthodontic treatment usually starts only after the eruption of the permanent first molars, only radiographs of children who were at least six years old were available. Patients whose radiographic records were of inferior quality, and with obvious asymmetry (>5 mm at the lower border of the ramus) and syndromes or history of maxillofacial injury, were excluded from the study; only Caucasian patients were included in order to have a homogenous population sample.

All radiographs were taken with the same radiological equipment. The cephalometric radiographs were taken using a Cranex3+

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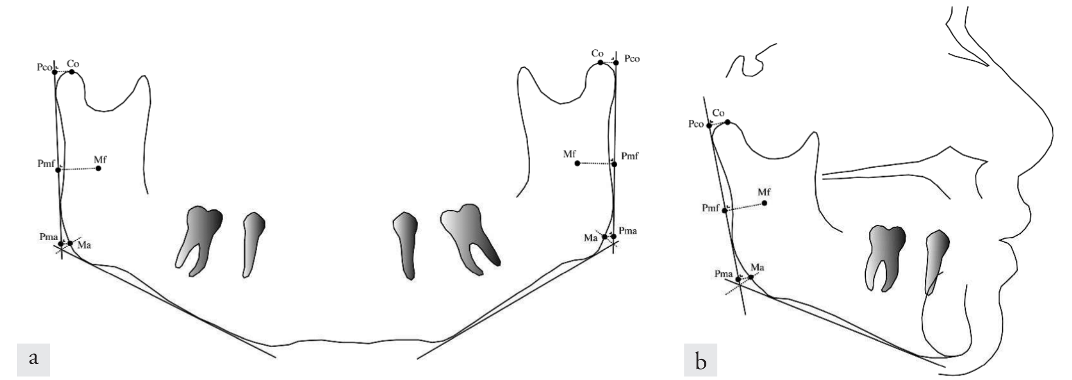

Figure 1. Cephalometric points used to compare the vertical ratio of the mandibular foramen between panoramic and cephalometric radiographs. (a) Panoramic radiograph; (b) Cephalometric radiograph.

Co (*Condyle*) indicates the top of the condyle; Mf, mandibular foramen; Ma (Mandibular angle), point on the contour of the mandible obtained by bisecting the tangents to the corpus and ramus of the mandible; Pco, Pmf, Pma, projection of, respectively, Co, Mf and Ma on the vertical tangent to the ramus.

Ceph (Soredex, Tuusula, Finland) with Konika X-ray 24 x 30 cm film (Konica Minolta Medical and Graphic Inc, Tokyo, Japan). For the panoramic radiographs, a Scanora device (Soredex, Tuusula, Finland) was used with Kodak X-ray 15 x 30 cm film (Carestream Health Inc, Bagnolet, France). All radiographs were digitized (300 dpi, grayscale mode) using a flatbed scanner (Epson Expression 1600 Pro; Seiko Epson Corp, Nagano, Japan) and stored in a jpeg format. They were finally traced on screen using a cephalometric program (Viewbox 3.0, DHal, Kifisia, Greece), and custom-made analyses were created to measure sets of predefined variables.

Accuracy of the identification of the mandibular foramen. Locating the mandibular foramen on a cephalometric radiograph can sometimes be difficult due to double structure superimposition and/or image blurring. It is substantially easier to do so on a panoramic radiograph. The occlusal plane, however, can only be traced on cephalometric radiographs, and this obliged us to locate the mandibular foramen on this type of radiographs. To test our accuracy in locating the mandibular foramen, we calculated and compared the same vertical ratio (Pco-Pmf/Pco-Pma; Figure 1) on both cephalometric and panoramic radiographs. On panoramic radiographs, there was the additional problem of possible lack of symmetry between the right and left foramens; therefore, we first compared the ratio of the two sides. This ratio was 65.0±3.0 percent (range=57-75 percent) for the left side and 65.0±3.0 percent (range=57-74%) for the right side. A high correlation was found (r=0.891, *P*<.001), and a paired *t* test showed no statistically significant differences (*P*=.72) between them.

This enabled us to use the average panoramic ratio (65.0±3.0 percent; range=57-74 percent) for the comparison with the cephalometric ratio (65.0±3.0 percent; range=57-75 percent) which was measured on all cephalometric radiographs, except for 11 in which the identification of the foramen was uncertain. A Pearson's correlation test and student's *t* test showed a high correlation (r=0.905; *P*<.001) and no significant difference between the panoramic and cephalometric ratios (*P*=.79). These results allowed the identification of the mandibular foramen in the 11 previously excluded cephalograms by using the panoramic ratio.

The cephalometric radiographs were traced, and the vertical and anteroposterior location of the mandibular foramen was measured (Figure 2). The vertical location was measured as the distance between the mandibular foramen and the occlusal plane (vertical position of mandibular foramen=Mf-Mfo). The anteroposterior location was measured as the ratio of the distance of the foramen from the ramus anterior border to the total ramus width (anteroposterior position of mandibular foramen=Ap-Mf:Ap-Pp). An additional six hard and one soft tissue variables were also calculated:

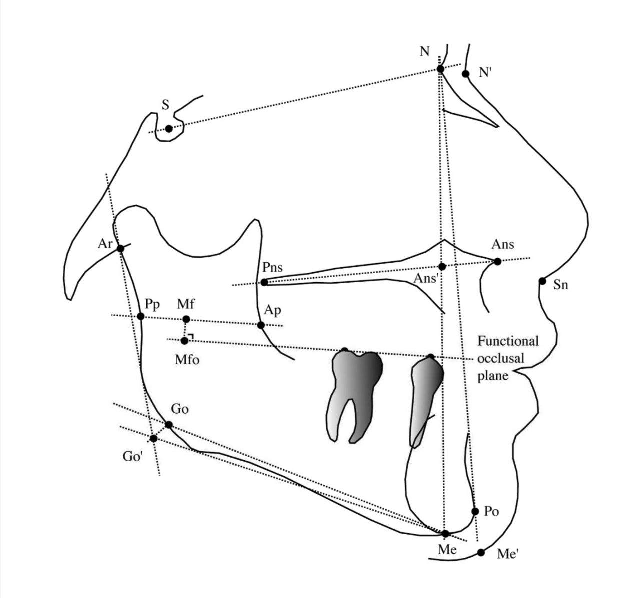

Figure 2. Cephalometric points used to measure vertical and horizontal position of mandibular foramen and 6 hard and 1 soft tissue variables.

Ans (*Anterior nasal spine*) indicates the apex of the anterior nasal spine;
Ans', intersection of NMe with Ans-Pns;
Pns (*Posterior nasal spinMeM sa*), the intersection point of soft palate, hard palate, and pterygopalatinal fissure;
N (*Nasion*), anterior limit of the nasofrontal suture;
S (*Sella*), center of sella turcica;
Me (*Menton*), lowest point of the symphysis;
Po (*Pogonion*), most anterior point of the symphysis;
Ar (*Articulare*), radiographic intersection of the posterior margin of the ramus with the basion;
Mf, mandibular foramen;
Mfo, projection of Mf on the functional occlusal plane;
Go' (*Gonion marked*);
Go (*Gonion*), point on the contour of the mandible obtained by bisecting the angle Ar-Go'-Me';
N' (*Soft nasion*), deepest point of the profile;
Sn (*Subnasale*), point at which the nasal septum merges with the upper cutaneous lip;
Me' (*Soft menton*), point on the contour of the chin obtained by bisecting the angle formed by Go'-Me and N-Po;
Ap, intersection of a line parallel to the occlusal plane through Mf with the anterior margin of the ramus;
Pp, intersection of a line parallel to the occlusal plane through Mf with the posterior margin of the ramus.

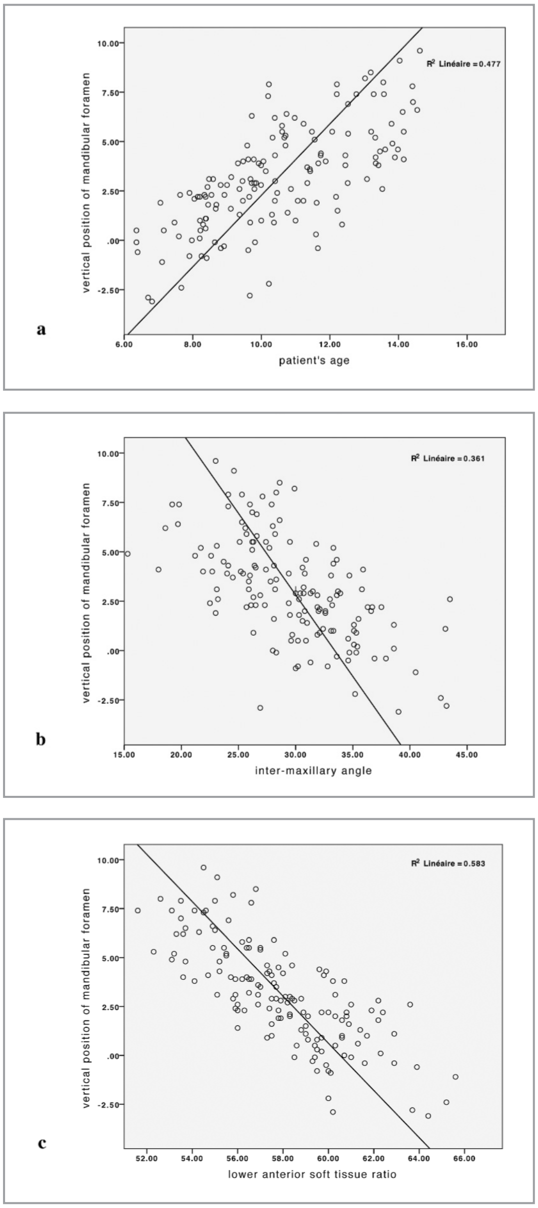

Figure 3. Linear correlation between vertical position of mandibular foramen; (a) patient's age; (b) inter-maxillary angle; and (c) lower anterior soft tissue ratio.

the intermaxillary angle (formed by Ans-Pns and Me-Go); mandibular angle (formed by S-N and Me-Go); Gonial angle (formed by Ar-Go'-Me); Jarabak ratio (S-Go':N-Me); lower anterior height ratio (N-Ans':N-Me); and lower anterior soft tissue ratio (Sn-Me':N'-Me').

Method's error and statistical analysis. The Shapiro-Wilk test revealed that all variables, except the patient's age, were normally distributed. Two-tailed Pearson's correlation analysis and multiple linear regression analysis were used to determine the degree of correlation between age, gender, and different variables measuring the vertical facial morphology as prognostic factors of the mandibular foramen's vertical and anteroposterior position.

The significance level was set at $P<.05$ (2-tailed). SPSS 17.0 software (SPSS Inc, Chicago, Ill., USA) was used to perform all statistical evaluations. On the basis of the expected difference in the changes of the location of mandibular foramen that could affect a nerve block, given the sample size (N=145) and a *P*-value of .05, the power of this study was 92 percent.

To evaluate the systematic error of the vertical and anteroposterior position of the mandibular foramen, the cephalometric radiographs of 15 subjects were randomly selected and analyzed four weeks later by the same operator. No differences were detected at a significance level of 0.05 ($P=.21$, Pearson's correlation=0.99). Dahlberg's formula[21] was used to calculate the coefficient of reliability (**CR**), which was excellent (CR=0.996).

Results

Descriptive statistics. A total of 145 patients (76 females and 69 males) fulfilled our inclusion criteria; their average age was 10.4 years old (range=6.3 to 14.6 years old). The mandibular foramen lay at 60.0±3.0 percent (range=49-68 percent) of the total ramus width from its anterior border. The vertical position of the mandibular foramen was found to be 3.1±2.6 mm (range=-3.1 to 9.6mm) above the occlusal plane, on average. A positive value denotes a position above the occlusal plane, whereas a negative one indicates a position below it. For males, the mean value was 3.3±2.7 mm (range=-2.9 to 8.5 mm); for females, it was 3.0±2.5 mm (range=-3.1 to 9.6mm): there was no significant difference between them (*t* test: $P=.61$). The mean intermaxillary angle was 29.6±5.3° (range=15.3 to 43.5°), and the mean lower anterior soft tissue ratio was 58.0±3.0 percent (range=52-66 percent).

Correlation of the foramen's vertical position to the patient's age (Pearson's correlation). A positive correlation (r=0.69, $P<.001$) was reported between the vertical position of the mandibular foramen with the patient's age: the older the patient, the bigger the value of the vertical position of the mandibular foramen (Figure 3a). This means that, in older patients, the foramen is located above the occlusal plane, while in younger patients it is below.

Correlation of the foramen's vertical position to vertical facial morphology (Pearson's correlation). Regarding hard tissue variables, each of the skeletal variables describing the vertical facial morphology presented a significant correlation ($P<.001$) with the vertical position of the mandibular foramen. These correlations ranged from 0.34 to 0.60, and the variable with the best correlation factor was the intermaxillary angle (r=-0.60, $P<.001$): the smaller the intermaxillary angle, the larger the value of the mandibular foramen's vertical position (Figure 3b). These data indicate in a hypodivergent patient, the foramen will be well above the occlusal plane, while in a hyperdivergent patient the foramen will be at or below the occlusal plane level.

For soft tissue variables, the lower anterior soft tissue ratio was negatively correlated (r=-0.76, $P<.001$) with the vertical position of the mandibular foramen: the shorter the lower third of the patient's face, the larger the value of the mandibular foramen's vertical position (Figure 3c). This denotes that the foramen is above the occlusal plane in short-face patients, whereas it will be below it in long-face patients.

Multiple regression analysis. Each of the variables describing the vertical facial morphology was significantly related to the vertical position of the mandibular foramen, but we couldn't include them into one single multiple linear regression analysis, because they are all interdependent. For that reason, we chose only the skeletal variable showing the best correlation factor: the intermaxillary angle. We conducted a multiple linear regression analysis by using this previous variable (intermaxillary angle) in conjunction with age as the independent variable, and vertical position of the mandibular foramen as the dependent variable. A substantial 70 percent of the variation of the mandibular foramen's vertical position was explained by the available factors [r=0.830; Table 1(a)].

Table 1. MULTIPLE REGRESSION ANALYSIS USING AS DEPENDENT VARIABLE THE VERTICAL POSITION OF THE MANDIBULAR FORAMEN AND AS INDEPENDENT VARIABLES: THE PATIENTS AGE, THE INTERMAXILLARY ANGLE AND THE LOWER SOFT TISSUE RATIO (N=145)

(a) Patient's age and intermaxillary angle (R=0.83, P<.001), $Y=2.385+b_1 age+b_2 intermaxillary\ angle$

Independent variables	Coefficient B±(SD)	*P*-value
Age	0.58±0.06	<.001
Intermaxillary angle	-0.47±0.02	<.001

(b) Patient's age and lower anterior soft tissue ratio (R=0.84, P<.001), $Y=27.554+b_1 age+b_2 lower\ anterior\ soft\ tissue\ ratio$

Independent variables	Coefficient B±(SD)	*P*-value
Age	0.42±0.06	<.001
Lower anterior soft tissue ratio	-0.56±0.05	<.001

The second multiple regression analysis we conducted included the lower anterior soft tissue ratio variable (soft tissue variable) and age as the independent variable, and the mandibular foramen's vertical position as the dependent variable. We obtained a slightly better result, with more than 70 percent explaining the variability of the vertical position of the mandibular foramen [r=0.84; Table 1(b)].

In summary, the major part of the variation of the mandibular foramen's vertical position can be explained by the patient's age, intermaxillary angle, and lower anterior soft tissue ratio.

Correlation of the mandibular foramen's anteroposterior position to the patient's age and vertical facial morphology (Pearson's correlation). No statistically significant correlations were found between the anteroposterior location of the mandibular foramen and any of the tested variables.

Discussion

In this investigation, we were able to detect a statistically significant correlation between the mandibular foramen's vertical position and the age, intermaxillary angle, and lower anterior soft tissue ratio. It seems that both age and vertical facial morphology influence the distance of the mandibular foramen from the occlusal plane. The null hypothesis was rejected. On the other hand, the mandibular foramen's horizontal position was not found to be correlated with any of the variables under study.

The mandibular foramen's vertical position ranged from 3.1 mm below to 9.6 mm above the occlusal plane. These differences could be enough to be responsible for some unexpected cases of nerve block failure. In our sample, the mandibular foramen was observed to be below the occlusal plane level in younger patients and gradually located above it in older patients, reaching the occlusal plane level by the age of 8.5 years old. This agrees with previous findings,[22] particularly with the study by Hwang,[15] in which the foramen crossed the occlusal plane level by nine years old. Olsen[23] recommended injecting below the occlusal plane in patients with primary teeth and Benham suggested injecting[24] at that level or slightly below it. Other authors reported opposite findings, with the mandibular foramen at the level of the occlusal plane[25] or even below it.[1,26] Two factors could explain these differences with our results: (1) the technique used to locate the mandibular foramen; and (2) the origin of the patients. More specifically, the measurements in these last three cited studies were done directly on dry mandibles, which could induce some differences when studying structures located on radiographs. Furthermore, Mbajiorgu[25] and Mwaniki and Hassanali[26] studied African people, from Zimbabwe and Kenya, and Nicholson[1] worked on mandibles of East Indians. Only Caucasian patients were included in the present study, indicating that the location of the mandibular foramen could vary according to the ethnic group, as is the case for various other structures of the midface.

The anteroposterior position of the mandibular foramen ranged between half and two-thirds of the width of the ramus from its anterior border. The high variability of the mandibular foramen in the horizontal plane could partially account for inferior alveolar nerve block failure. But the location of the mandibular foramen on the anteroposterior plane is probably far less important than its location on the vertical plane. First of all, the ramus' width is far shorter than its height, which reduces the extent of the error. Moreover, it is easier to change the position of the needle's tip in the anteroposterior dimension just by moving it further posteriorly, but it is more difficult to change it in the vertical dimension.

The inferior alveolar nerve is considered a stable structure that does not undergo relocation or drift during growth.[27] In the present investigation, the distance of the mandibular foramen to the occlusal plane in patients who are young and/or have a high intermaxillary angle was shorter compared to patients who are older and/or have a low intermaxillary angle. It can be assumed that these finding can be attributed, at least partially, to the variation of the occlusal plane's position in respect to the ramus' vertical growth. Arat and Rübendüz[28] studied subjects with normal facial patterns in the early stage of pubertal growth; they found a substantial increase in the vertical alveolar dimensions, both in anterior and posterior alveolar heights, as well as an increase in the vertical dimension of the ramus.

Previous studies indicate that the functional capacity of the masticatory muscles is associated with the craniofacial morphology.[29,30] Hyperdivergent individuals are usually characterized by weak masticatory forces.[30] Reduced masticatory function was found to be related to overeruption of the molars and increase of the alveolar process height,[31] resulting in elevation of the occlusal plane in relation to the mandible's other structures. The same situation is seen in humans: long-face patients who have thinner muscles and low masticatory muscle activity show higher alveolar processes than short-face individuals. Higher alveolar processes bring the occlusal plane closer to the mandibular foramen and this morphological change could explain why the vertical distance of the foramen to the occlusal plane is smaller in long-face patients, given that they are characterized by a short ramus.[19]

The present study has shown that the distance of the mandibular foramen from the occlusal plane changes with age and according to the patient's vertical facial type. It seems that the current guidelines for an efficient inferior alveolar nerve block, which consider the distance of the mandibular foramen from the occlusal plane a constant, should be updated. A dentist knows the age of his patient and is able to distinguish a short-face from a long-face patient without taking a cephalometric radiograph. The current investigation was performed retrospectively on cross-sectional observations and, although its clinical implications are evident, its clinical applicability and validity need to be confirmed.

Conclusions

Based on this study's results, the following conclusions can be made:

1. The mandibular foramen lies at 3.1±2.6 mm above the occlusal plane, on average. Its position ranges from 3.1 mm below the occlusal plane to 9.6 mm above it.
    a. The distance of the mandibular foramen from the occlusal plane changes with age and depends on the patients' vertical facial morphology and whether it is measured on hard tissues (intermaxillary angle) or soft tissues (lower anterior soft tissue ratio).
    b. The smaller the lower anterior soft tissue ratio and the smaller the intermaxillary angle and the older a patient is, the higher the foramen is above the occlusal plane. In other words, in short-face and adult patients, the insertion of the needle should be made further from the occlusal plane than in long-face and younger patients.
    c. Consideration of the patient's age and facial type could provide the clinician with a better appreciation of the mandibular foramen position, which is a prerequisite to reduce inferior alveolar nerve block failure.
2. The mandibular foramen lies between half to two-thirds of the total width of the ramus measured from its anterior border. Its anteroposterior location is not correlated to any of the examined variables.

References

1. Nicholson ML. A study of the position of the mandibular foramen in the adult human mandible. Anat Rec 1985;212: 110-2.
2. Jerolimov V, Kobler P, Keros J, Stanicić T, Bagić I. Foramen mandibulae as an indicator of successful conduction anesthesia. Coll Antropol 1998;22:169-77.
3. Afsar A, Haas DA, Rossouw PE, Wood RE. Radiographic localization of mandibular anesthesia landmarks. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;86:234-41.
4. Hayward J, Richardson ER, Malhotra SK. The mandibular foramen: Its anteroposterior position. Oral Surg Oral Med Oral Pathol 1977;44:837-43.
5. Narayana K, Vasudha S. Intraosseous course of the inferior alveolar (dental) nerve and its relative position in the mandible. Indian J Dent Res 2004;15:99-102.
6. Prado FB, Groppo FC, Volpato MC, Caria PH. Morphological changes in the position of the mandibular foramen in dentate and edentate Brazilian subjects. Clin Anat 2010;23:394-8.
7. Trost O, Salignon V, Cheynel N, Malka G, Trouilloud P. A simple method to locate mandibular foramen: Preliminary radiological study. Surg Radiol Anat 2010;32:927-31.
8. Wong MK, Jacobsen PL. Reasons for local anesthesia failures. J Am Dent Assoc 1992;123:69-73.
9. Keros J, Kobler P, Baucić I, Cabov T. Foramen mandibulae as an indicator of successful conduction anesthesia. Coll Antropol 2001;25:327-31.
10. Steiner RB, Thompson RD. Oral Surgery and Anesthesia. Philadelphia, Pa: Saunders; 1977.
11. Bennett CR. Monheim's Local Anesthesia and Pain Control in Dental Practice. 6th ed. St. Louis, Mo: Mosby; 1978.
12. Thoma KH. Oral Surgery. 3rd ed. St. Louis, Mo: Mosby; 1958.
13. Malamed SF. Handbook of Local Anesthesia. 5th ed. St. Louis, Mo: Mosby; 2004.
14. Pinkham JR. Local anesthesia and oral surgery in children. In: Pinkham JR, Casamassimo PS, Fields HW Jr, McTigue DJ, Nowak AJ, eds. Pediatric Dentistry: Infancy Through Adolescence. 4th ed. St. Louis, Mo: Elsevier-Saunders Co; 2005: 447-62.
15. Hwang TJ, Hsu SC, Huang QF, Guo MK. Age changes in location of mandibular foramen. Zhonghua Ya Yi Xue Hui Za Zhi 1990;9:98-103.
16. Movahhed T, Makarem A, Imanimogha M, Anbiaee N, Sarrafshir AR, Shakeri MT. Locating the mandibular foramen relative to the occlusal plane using panoramic radiography. J Appl Sci 2011;11:573-8.
17. Isaacson JR, Isaacson RJ, Speidel TM, Worms FW. Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. Angle Orthod 1971;41:219-29.
18. Fields H, Proffit R, Nixon W, Phillips C, Stanek E. Facial pattern differences in long-faced children and adults. Am J Orthod 1984;85:217-23.
19. Schendel S, Eisenfeld J, Bell W, Epker B, Mishelevich D. The long face syndrome: Vertical maxillary excess. Am J Orthod 1976;70:398-408.
20. Opdebeeck H, Bell WH. The short face syndrome. Am J Orthod 1978;73:499-511.
21. Houston WJ. Analyses of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.
22. Kanno CM, de Oliveira JA, Cannon M, Carvalho AA. The mandibular lingula's position in children as a reference to inferior alveolar nerve block. J Dent Child. 2005;72:56-60.
23. Olsen NH. Anesthesia for the child patient. J Am Dent Assoc 1956;53:548-55.
24. Benham NR. The cephalometric position of the mandibular foramen with age. J Dent Child 1976;43:233-7.
25. Mbajiorgu EF. A study of the position of the mandibular foramen in adult black Zimbabwean mandibles. Cent Afr J Med 2000;46:184-90.
26. Mwaniki DL, Hassanali J. The position of mandibular and mental foramina in Kenyan African mandibles. East Afr Med J 1992;69:210-3.
27. Björk A, Skieller V. Facial development and tooth eruption: An implant study at the age of puberty. Am J Orthod 1972;62:339-83.
28. Arat ZM, Rübendüz M. Changes in dentoalveolar and facial heights during early and late growth periods: A longitudinal study. Angle Orthod 2005;75:69-74.
29. Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. Acta Odontol Scand 1993;51:323-31.
30. Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. J Dent Res 1983;62:566-70.
31. Mavropoulos A, Odman A, Ammann P, Kiliaridis S. Rehabilitation of masticatory function improves the alveolar bone architecture of the mandible in adult rats. Bone 2010;47: 687-92.

4. PUBLICATION ORIGINALE II (accept®pour publication)

Changes in the location of the human mandibular foramen as a function of growth and vertical facial type

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Abstract

In a previous cross-sectional investigation we showed that the mandibular foramen location depends on the age and the vertical facial pattern in growing individuals. The aim of the present longitudinal study was to explain how these factors influence the distance between the foramen and the occlusal plane. Knowing this distance is necessary for a successful inferior alveolar nerve block in clinical dentistry.

This distance, as well as another four cephalometric variables, were measured on both pre-treatment and 10-year post-treatment lateral cephalometric radiographs collected from 50 patients who underwent orthodontic treatment. The changes between these two sets of measurements were also calculated. A multiple regression analysis was performed using the pre-treatment age, the pre-treatment inter-maxillary angle, the change of the rotation of the occlusal plane and the change of the mandibular ramus height as independent variables, and the change of foramen-occlusal plane distance as dependent variable. The independent variables under study were found to account for more than half of the variability of the foramen-occlusal plane distance ($r=0.732$; $p<0.001$).

In very young individuals the mandibular foramen is located approximately at the level of the occlusal plane. With age it moves upwards relative to the occlusal plane and more so for those individuals with a low anterior facial height (short-face vertical facial type). These observations are, at least partially, explained by the differential growth of the various elements of the maxillo-mandibular complex and the change of the inclination of the occlusal plane.

Keywords : mandibular foramen, facial morphology, lateral cephalometric radiograph, growth, occlusal plane, inferior alveolar nerve block

Introduction

Knowing the exact location of the mandibular foramen is necessary for a successful inferior alveolar nerve block anesthesia. This anesthesia, one of the most commonly used in clinical dentistry, has a failure rate of approximately 10% (Wong & Jacobsen, 1992). It is obtained by inserting the needle at the inner surface of the ramus, parallel to the mandibular occlusal plane, at a level bisecting the fingernail (Steiner & Thompson, 1977; Bennett, 1978) or six to 10 mm (Thoma, 1958; Malamed, 2004). In a previous study (Epars et al. 2013), we measured the distance between the foramen and the occlusal plane in growing children in order to determine whether it was constant in every patient. It was found that it is not the case and that two main factors seem to influence this distance: 1) the age of the patient and 2) the vertical facial morphology. The distance between the foramen and the occlusal plane was significantly (positively) correlated to the patient's age: the older the growing individual the higher the foramen was relatively to the occlusal plane. This distance was also significantly (negatively) correlated with one of the skeletal variables depicting the vertical facial morphology: the inter-maxillary angle. This first cross-sectional study has raised a lot of questions concerning the mechanism behind these changes in the position of the foramen in relation to the occlusal plane.

The mandibular foramen is located at approximately the level of the occlusal plane in very young individuals. With growth, the increase of the alveolar height moves the occlusal plane away from the body of the mandible. As the occlusal plane is brought upwards in the ramus, one would expect that the foramen is located below the occlusal plane in older individuals. We found that exactly the opposite happens.

In order to explain this observation, we have formulated two hypotheses. The first one is that the foramen, through remodeling, is displaced upwards even more than the occlusal plane during growth. The second one is that the occlusal plane rotates during growth in a counter-clockwise fashion, which, purely geometrically, brings the mandibular foramen closer to it. We know that the inclination of the occlusal plane depends on the vertical facial growth pattern (Schendel & Bell, 1976; Opdebeeck et al. 1978). The aim of this longitudinal study was to investigate the observed changes in the location of the mandibular foramen as a function of growth and vertical facial types.

Material and methods

Material

In this retrospective longitudinal investigation we used the diagnostic records of growing patients who underwent orthodontic treatment in our university clinic. Those cases with complete pre-treatment and 10-year post-treatment records were first. Then the following exclusion criteria were applied:

a. radiographic records of insufficient quality,
b. patients with obvious asymmetry (more than 5mm at the lower border of the ramus), with syndromes or history of maxillofacial injury,
c. non-Caucasian patients (in order to have a more homogenous population sample),
d. patients older than 12 years old at the initial radiographic examination.

This investigation was submitted and received the approval of the Research Ethics Committee of the University of Geneva.

All radiographs were taken with the same radiological equipment. The lateral cephalometric radiographs were taken using a Cranex3+ Ceph (Soredex, Tuusula, Finland) with Konika X-ray 24x30cm films (Konica Minolta Medical & Graphic Inc., Tokyo, Japan). For the panoramic radiographs, Scanora was used (Soredex, Tuusula, Finland) with Kodak X-ray 15x30cm films (Carestream Health Inc., Bagnolet, France). All radiographs were digitized (300 dpi, grayscale mode) using a flatbed scanner (Epson Expression 1600Pro; Seiko Epson Corp., Nagano, Japan) and stored in a jpeg format. The cephalometric radiographs were finally traced on screen using a cephalometric program (Viewbox3.0, DHal, Kifisia, Greece) and a custom-made analysis was created in order to measure sets of predefined variables.

Methods

In the context of this investigation, the mandibular foramen had to be located on the cephalometric radiographs. This was particularly difficult in some cases due to double structure superimposition and/or image blurring. In these cases, the foramen was first located on the corresponding panoramic radiograph and then transferred on the cephalometric one. This transfer from one type of radiograph to the other is possible since the proportional vertical position of the foramen does not change when measured on either the panoramic or the cephalometric radiograph, as it was previously shown in a study from the same authors (Epars et al. 2013).

In Figure 1 are shown all the cephalometric landmarks employed in order to calculate the location of the foramen as a function of its distance to the functional occlusal plane (*Foramen-occlusal plane distance, Mf-Mf'*) as well as the other variables under study. It had been previously found that the foramen-occlusal plane distance was not constant (Epars et al. 2013). Therefore, we selected four variables in order to explain the change of this distance: the age of the patient, the *Condyle-Gonion distance* (Co-Go), the *Inter-maxillary angle* (Ans-Pns // Go-Me) and the *Rotation of the occlusal plane* (S-N // occlusal plane). All these measurements were performed on both the initial and 10-year post-treatment radiographs and the differences between these two sets of measurements were calculated as well.

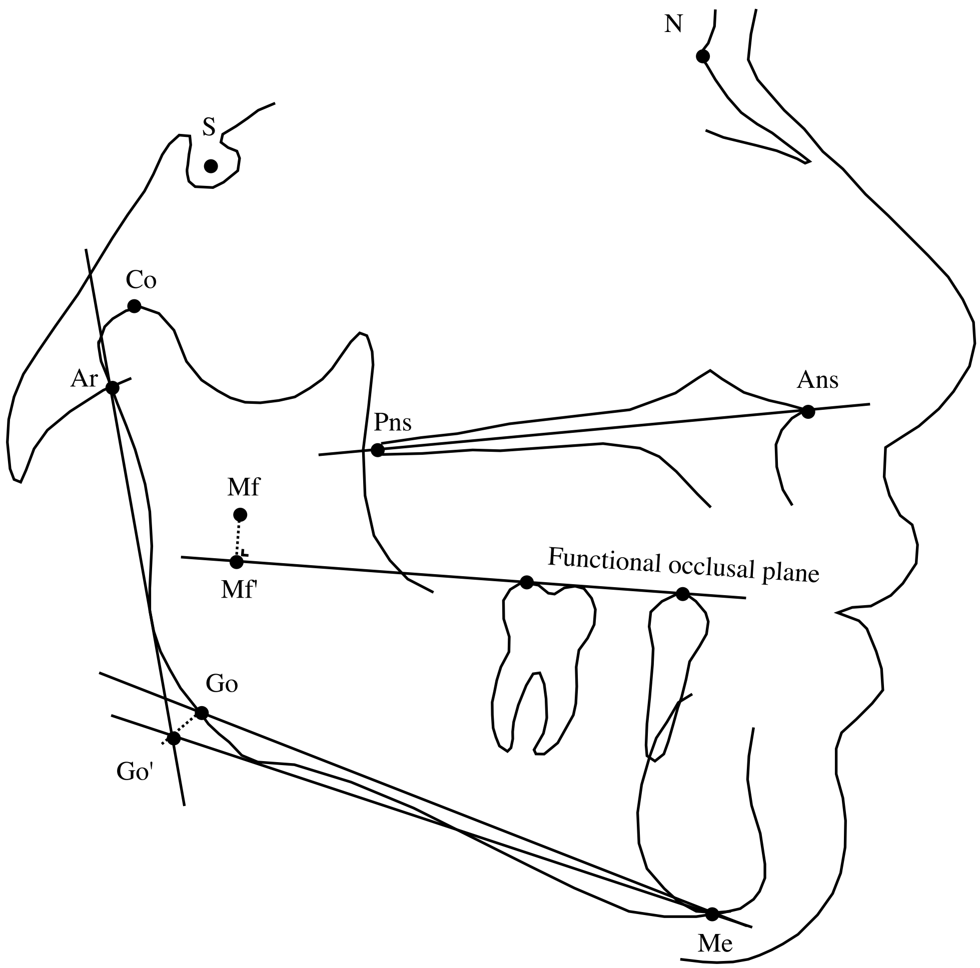

Fig. 1 Cephalometric landmarks used in the variables under study:
Ans (Anterior nasal spine), apex of the anterior nasal spine;
Pns (Posterior nasal spine), intersection point of soft palate, hard palate and pterygopalatinal fissure;
Ar (Articulare), radiographic intersection of the posterior margin of the ramus with the basion;
N (Nasion), anterior limit of the nasofrontal suture; *S (Sella),* center of sella turcica;
Co (Condyle), top of the condyle; *Me (Menton),* lowest point of the symphysis;
Go' (Gonion marked), intersection of the tangents to the mandible, through Ar and Me;
Go (Gonion), point on the contour of the mandible obtained by bisecting the angle Ar-Go'-Me;
Mf, mandibular foramen; *Mf',* projection of Mf on the occlusal plane.

Method's error and statistical analysis

The Shapiro-Wilk test revealed that all variables were normally distributed. Changes during the follow-up period were tested using a paired Student's t-test. A multiple regression analysis was performed using the pre-treatment age, the pre-treatment inter-maxillary angle, the change of the rotation of the occlusal plane and the change of the mandibular ramus height as independent variables, and the change of foramen-occlusal plane distance as dependent variable.

The significance level was set at $p<0.05$ (two-tailed). The Statistical Package for Social Sciences for Windows, version 20.0, (SPSS Inc., Chicago, USA) was used to perform all statistical evaluations.

In order to evaluate the systematic error of the vertical position of the foramen, the cephalometric radiographs of 15 subjects were randomly selected and analyzed 4 weeks later by the same operator (JFE). No differences were detected at a significance level of 0.05 ($p=0.21$, Pearson's correlation=0.99). Dahlberg's formula (Houston, 1983) was used to calculate the coefficient of reliability (*CR*), which was excellent (CR=0.996).

Results

Fifty patients (29 females and 21 males) fulfilled our inclusion criteria.

A. Descriptive statistics

1. Pre-treatment records

The average age before treatment was 9.5 ± 1.4 years (range 6.3 to 11.8 years). The foramen-occlusal plane distance was 2.9 ± 2.4mm (range -3.7 to 6.8 mm). A positive value means that the foramen is above the occlusal plane, whereas a negative value means that the foramen is below it. The Condyle-Gonion distance was 49.0 ± 4.6mm (range 37.7 to 59.2 mm). The mean inter-maxillary angle was 28.3

± 4.7° (range 14.0 to 37.9°) and the rotation of the occlusal plane was 20.0 ± 4.4° (range 10.2 to 28.8°).

2. 10-year post-treatment records

The average age was 24.2 ± 1.6 years (range 20.1 to 27.8). The foramen-occlusal plane distance was 5.5 ± 2.2mm (range 0.0 to 9.9mm). The Condyle-Gonion distance was 64.1 ± 7.4mm (range 47.7 to 81.5mm). The mean inter-maxillary angle was 24.6 ± 6.0° (range 13.2 to 35.7°) and the rotation of the occlusal plane was 17.4 ± 5.3° (range 8.3 to 28.5°).

B. Changes during the follow-up period

1. Paired t-test

We tested the changes during the follow-up period with a Student's t-test for each variable under study. There was a significant difference ($p<0.001$) for each of them (Table 1).

Table 1. Changes in the variables under study during the 10-years follow-up period (paired t-test):

Variable	Mean	Std dev	Confidence interval (95%)		*P* value
			Superior	Inferior	
Foramen-Occlusal plane distance (mm)	2.61	3.23	1.69	3.52	< 0.001
Gonion-Condyle distance (mm)	15.00	6.05	13.28	16.72	< 0.001
Inter-maxillary angle (°)	-3.29	3.63	-4.32	-2.25	< 0.001
Rotation of the occlusal plane (°)	-2.64	3.77	-3.71	-1.57	< 0.001

2. Changes of the foramen-occlusal plane distance:

We investigated if the sex of the patient had an influence on the change of the foramen-occlusal plane distance during the follow-up period: it had none ($p=0.513$).

We conducted a multiple linear regression analysis by using the initial age, the initial inter-maxillary angle, the change in the rotation of the occlusal plane and the change in Condyle-Gonion distance as independent variables, and the change of foramen-occlusal plane distance as dependent variable. The independent variables under study were found to account for more than half of the variability of the foramen-occlusal plane distance ($r=0.732$; $p<0.001$) (Table 2).

Table 2. Multiple regression analysis using as dependent variable the change of foramen-occlusal plane distance (R = 0.732, p < 0.001) and as independent variables the initial age, the initial inter-maxillary angle, the rotation of the occlusal plane and the change of the Condyle-Gonion distance (n=50, df =49)

$Y = 10.630 + b_1$initial age $+ b_2$initial inter-maxillary angle $+ b_3$rotation of the occlusal plane $+ b_4$change in Condyle-Gonion distance

Independent variables	Coefficient β	Standard Error	*P* value
Initial age	-0.337	0.244	= 0.003
Initial inter-maxillary angle	-0.218	0.073	= 0.048
Rotation of the occlusal plane	-0.410	0.091	< 0.001
Change of the Condyle-Gonion distance	0.301	0.059	= 0.009

Discussion

In this investigation we found that the foramen-occlusal plane distance increases with growth. This change was influenced by the vertical facial growth pattern. In short-face individuals this distance increases even more. Four cephalometric variables were found to partially explain these changes and a multiple regression analysis model was proposed.

We found that the foramen-occlusal plane distance was 2.9 ± 2.4mm (range -3.7 to 6.8mm) on average before the orthodontic treatment and 5.5 ± 2.2mm (range 0.0 to 9.9mm) 10-years after the end of the treatment. The change of this distance was correlated to the initial age of the patients. Hwang et al. (1990) also described an increase of the foramen-occlusal plane distance with age, but without relating this change to any growth pattern. He assessed that the foramen was crossing the occlusal plane level by the age of 9 and that it was moving upward from the occlusal plane since then. To our knowledge, no other longitudinal study has been done about the change of the foramen-occlusal plane distance and the factors contributing to it.

The vertical facial growth pattern is cephalometrically evaluated commonly by the angle formed by the maxillary and the mandibular planes (inter-maxillary angle). In long-face individuals this angle is increased, while in short-face ones it is decreased. These two opposite vertical facial types depend mainly of the structures located below the palatal plane (Isaacson et al. 1971; Fields et al. 1984) and the position of the palatal plane itself may have an influence on the facial type. In the present study the pre-treatment inter-maxillary angle was correlated to the foramen-occlusal plane distance.

The change of the foramen-occlusal plane distance during the follow-up period was also correlated to the rotation of the occlusal plane and the change of the Condyle-Gonion distance. In the short-face growth pattern the occlusal plane rotates anteriorly, while in the long-face one it rotates posteriorly during growth. The Condyle-Gonion distance increases more during growth in short-face than in long-face individuals. The craniofacial morphology was found to be related to the functional capacity of the masticatory muscles (Kiliaridis et al. 1993). Rats fed with soft diet develop a reduced masticatory function, which lead to increase of the alveolar process height and over-eruption of the molars (Mavropoulos et al. 2010). The same situation is seen in humans: long-face patients have thinner muscles and are usually characterized by reduced muscular activity; their bone is consequently less stimulated (Proffit & Fields, 1983). Their ramus is shorter, the goniac angle is larger and the occlusal plane is steeper (Odegaard, 1970; Fields et al. 1984); the alveolar bone processes are also higher with an over-eruption of the teeth (Schendel et al. 1976). These changes directly affect the occlusal plane: its location and its relation to the bony mandibular structures are modified. In these long-face patients, the over-eruption of the teeth moves the occlusal plane upward in the ramus. Moreover, a steeper occlusal plane is the result of an increased rotation of the occlusal plane. The anterior part of the occlusal plane is moving away from the cranial base whereas the distal part is coming closer to the cranial base. These upwards movements bring the occlusal plane closer to the mandibular foramen and this could explain why the foramen-occlusal plane distance is decreased in long-face patients.

One should be cautious extrapolating the results found in this study to the whole population. Our sample is comprised exclusively of individuals who received an orthodontic treatment. One could argue that the relationship between the foramen and the occlusal plane was influenced by the orthodontic treatment itself. Although orthodontic appliances can cause moderate changes of the occlusal plane cant, Van der Linden (2008) showed that this was only temporary and that the occlusal plane returned eventually to its initial situation. Our sample consisted exclusively of Caucasian individuals. This was found preferable in order to have a more homogeneous population sample. It is possible, since many structures of the lower face vary according to the ethnic group, that our result do not apply to non-Caucasian individuals.

Conclusions

1. The mandibular foramen is located at approximately the level of the occlusal plane in very young individuals. It then moves upwards relative to the occlusal plane during growth.

2. The vertical facial growth pattern influences this phenomenon. In short-face individuals the distance of the foramen to the occlusal plane is bigger than in long-face ones.

3. These observations are, at least partially, explained by the differential growth of the various elements of the maxillo-mandibular complex and the change of the inclination of the occlusal plane.

References

Bennett CR. Monheim's local anesthesia and pain control in dental practice. 6th ed. Saint Louis, Mo: Mosby; 1978.

Epars JF, Mavropoulos A, Kiliaridis S. Influence of age and vertical facial type on the location of the mandibular foramen. Pediatr Dent. 2013 Jul-Aug;35(4):369-73

Fields H, Proffit R, Nixon W, Phillips C, Stanek E. Facial pattern differences in long-faced children and adults. Am J Orthod. 1984 Mar;85(3):217-23.

Houston WJ. Analyses of errors in orthodontic measurements. Am J Orthod. 1983;83 (5):382-90.

Hwang TJ, Hsu SC, Huang QF, Guo MK. [Age changes in location of mandibular foramen]. Zhonghua Ya Yi Xue Hui Za Zhi 1990;9 (3):98-103.

Isaacson JR, Isaacson RJ, Speidel TM, Worms FW. Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. Angle Orthod. 1971;41 (3):219-29.

Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. Acta Odontol Scand. 1993 Oct;51(5):323-31.

Malamed SF. Handbook of Local Anesthesia. 5th ed. St. Louis, Mo: Mosby; 2004.

Mavropoulos A, Odman A, Ammann P, Kiliaridis S. Rehabilitation of masticatory function improves the alveolar bone architecture of the mandible in adult rats. Bone. 2010 Sep;47(3):687-92.

Odegaard J. Mandibular rotation studies with the aid of metal implants. Am J Orthod. 1970 Nov;58(5):448-54.

Opdebeeck H, Bell WH. The short face syndrome. Am J Orthod. 1978;73 (5):499-511.

Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. J Dent Res. 1983

May;62(5):566-70.

Schendel S, Eisenfeld J, Bell W, Epker B, Mishelevich D. The long face syndrom: vertical maxillary excess. Am J Orthod. 1976;70 (4):398-408.

Steiner RB, Thompson RD. Oral surgery and anesthesia. Philadelphia : Saunders; 1977.

Thoma KH. Oral surgery, 3rd ed. St Louis, Mo: Mosby; 1958.

Van der Linden FP. Sheldon Friel memorial lecture 2007: myths and legends in orthodontics. Eur J Orthod. 2008 Oct;30(5):449-68.

Wong MK, Jacobsen PL. Reasons for local anesthesia failures. J Am Dent Assoc. 1992 Jan;123(1):69-73.

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