Comparison of molar intrusion efficiency and bone density by CT in patients with different vertical facial morphology

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SUMMARY The purpose of this study is to examine the relationship between molar intrusion efficiency and bone density in patients with different vertical facial morphology. Thirty-six female patients, with overerupted upper first molars, were divided into two groups according to mandibular plane angle (FH-MP): hyperdivergent, FH-MP > 30° (G1), hypodivergent, FH-MP < 22° (G2). Mini-screw implants with elastic chains were used to intrude upper first molars. Spiral CT was used to measure the intrusion degree of upper first molar and bone density, and molar intrusion efficiency was calculated as amount/duration (mm month⁻¹). In addition, each tooth was divided into three portions (cervical, furcation and apical) to measure the bone density. It was found in this study that treatment duration was 3·13 and 4·71 months in G1 and G2 and that the intrusion efficiency was 1·57 and 0·81 in G1 and G2 with significant difference (P < 0·05). There were significant differences in cervical, furcation and apical bone density between two groups (P < 0·05). The bone density was significantly reduced after molar intrusion. In addition, the bone density change was greater in G1 than in G2 (P < 0·05). It was concluded that molars were more easily to be intruded in hyperdivergent than in hypodivergent patients. The difference of bone density and bone density changes during intrusion may account for the variation of molar intrusion efficiency.

KEYWORDS: molar intrusion efficiency, bone density, computed tomography, vertical facial morphology, mandibular plane angle, bite force

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Introduction

Overeruption of maxillary molars usually results from early loss of antagonistic teeth. In addition, upper posterior dental height is greater in patients with anterior open bite than others (1). Molar intrusion with implants becomes a good solution for patients with overerupted maxillary molars and anterior open bite (2–5). There have been many researches concerning on molar intrusion with implant anchorage. The results indicate that significant true intrusion of molars could be obtained using implants as bony anchorage. However, the distance and time of molar intrusion are different in previous studies (6–8). Sherwood et al. (7) found that upper molar was intruded by 4·1 mm in 6·5 month, while they indicated in another study that molar was intruded 2 mm in 5·5 month. Furthermore, Park et al. (8) found molar intrusion rate was 0·5–1 mm per month. Therefore, molar intrusion efficiency varies in patients. However, little was known about the factors related to molar intrusion efficiency. It was suggested that bone structure and density have an influence on orthodontic tooth movement (9). Thus, it is inferred that molar intrusion efficiency is associated with bone quality including bone structure and density. However, no evidence shows definite relationship between bone density and molar intrusion efficiency.

Facial morphology could be divided into three categories vertically according to mandibular plane angle: short face, average face, and long face. There are soft and hard tissue differences among these individuals,
including anatomic feature of masticatory muscle, alveolar bone thickness and teeth inclination etc. The buccal and lingual cortical bone was thicker in short-faced individuals than in average and long-faced groups (10, 11). However, to our best knowledge, no conclusion could be drawn on the relationship between bone density and vertical facial morphology. In addition, it is unknown whether intrusion efficiency varies in patients with different vertical facial morphology.

Several non-invasive methods can be used to measure the alveolar bone density, including digital image analysis of microradiographs, dual energy X-ray absorptiometry and ultrasound (12–15). However, all of these approaches have inherent limitations, such as non-availability of three-dimensional information and the evaluation being only qualitative. The introduction of maxillofacial cone beam computed tomography (CBCT) has made 3D imaging more readily available for dental use. Though most CBCT devices showed a good overall correlation with CT numbers, large errors can be seen when using the grey values in a quantitative way. Computed tomography values (Hounsfield units: HU) and bone mineral density (BMDs) obtained by medical CT were used to assess the bone density of jaws. Within the range of CT values, the density of air was equal to −1000 HU, that of water was 0 HU and that of mandibular cancellous bone was from 500 to 850 HU in the posterior region and more than 850 HU in the anterior region. Therefore, medical CT was used to measure bone density in this study. The purpose of this study is to compare molar intrusion efficiency and bone density in patients with different vertical facial morphology, and explore the relationship of molar intrusion, bone density and facial morphology.

Materials and methods

Patient selection and molar intrusion

The present research has been conducted in full accordance with ethical principles including the World Medical Association Declaration of Helsinki. This study was independently reviewed and approved by local ethical committee of Zhejiang University (Hangzhou, China). Written consent of each subject was also obtained. A total of 40 consecutively finished female adult patients (ages, 20–42 years; mean ± s.d., 28.93 ± 7.55) from 2008 to 2012 with overerupted upper first molars were selected in this study. They were divided into two groups according to mandibular plane angle: hyperdivergent, FH-MP>30° (G1), hypodivergent, FH-MP<22° (G2), every group has 20 patients. The inclusion criteria were as follows: no patients <18 years old to minimise the effects of growth; no bone metabolic disease; no previous orthodontic treatment; no active periodontal disease at the beginning of treatment; no metal crowns, dental bridges and dental implants to avoid beam-hardening effect; all female patients to minimise the effects of sex differences. Mini-screw implants were placed under local anaesthesia in buccal region between first and second molars and palatal region between second premolar and first molar (Fig. 1). Sufficient distance was left between root apex and mini-screw implants to avoid interference with the intended intrusive tooth movement. After initial healing of soft tissue around mini-screw implants in 2 weeks, intrusion force of 100 g was applied with elastic chains (Fig. 1). The duration of molar intrusion was recorded. We found mini-screw implants loosened in two hyperdivergent patients and two hypodivergent patients. The four patients were excluded from this study; thus, 36 patients were included and every group had 18 patients. Eighteen hyperdivergent and 18 hypodivergent adult female patients without molar intrusion were selected as control groups.

Bone density measurement by CT

Before CT scanning, the patients were placed in a lying position with the head horizontally positioned. A multislice unit* was used, and helical scanning was performed using a tube voltage of 120 kV and a tube current of 200 mA. The occlusal plane of each patient was set perpendicular to the floor base using ear rods. Computed tomography images of 40 patients were obtained before and after molar intrusion using the same condition. Once collected, the CT raw data were converted into DICOM format. This DICOM formatted data was exported into Mimics 10.01 software† to analyse and to determine bone density by grey scale value (HU). Prior to measuring bone density, 3D

*GE Yokogama Medical System, Tokyo, Japan.
†Materialise, Leuven, Belgium.
model was resliced to obtain new CT slices of teeth that were perpendicular to the longitudinal axes of teeth using the ‘reslice’ function in the software program. The slice number was set as 3 (Fig. 2). Bone density around the teeth was assessed at three levels: cervical, furcation and apical portions (Fig. 3). The cervical portion was set as parallel to alveolar crest. The furcation portion was set as 1 mm above the root furcation, and the apical portion was set as parallel to buccal root apex. Before measuring bone density, the following steps (Fig. 4) were executed: (i) segmenting the area of tooth from the CT image using threshold value of cementum; (ii) expanding by one voxel to include PDL using the morphology operation; (iii) expanding by a further three voxel to include surrounding bone using the morphology operation; (iv) subtracting tooth and PDL from tooth, PDL and surrounding bone. The volumes of the areas and their density values are also demonstrated (Fig. 4).

Molar intrusion efficiency measurement

The axial images of CT were imported into Mimics 10.01 software1. A 3D virtual model was created. Using axial, coronal and sagittal views, the midsagittal plane of the model was oriented vertically, the transporionic line was oriented horizontally and the Frankfort horizontal plane (FH plane) was oriented horizontally. The measurement of molar position (DB-FH: distal buccal cusp-FH plane and MB-FH: mesial buccal cusp-FH plane) was shown in Fig. 5. The amount of molar intrusion was calculated as the difference of (DB-FH+MB-FH)/2 before and after intrusion, and the intrusion efficiency was calculated as amount/duration (mm month\(^{-1}\)).

Measurement reliability

For the evaluation of the intra-examiner error, the grey scale value and pre-treatment molar position measurement procedure were repeated by the same person 4 weeks later. The method error was calculated from the equation: \(S_x = \sqrt{\sum D^2/2N}\), where \(S_x\) is the error of the measurement, \(D\) is the difference between duplicated measurements and \(N\) is the number of double measurements (16). The errors of the measurements were 0.11 mm and 29.35 Hu, respectively. The reliability coefficients were 0.91 and 0.88, respectively.

Statistical analysis

All statistical analyses were performed using SPSS software packages (SPSS for windows XP, version 13.0\(^2\)). The mean and s.d. for each value were determined. Independent and paired \(t\)-tests were used to determine the statistical significance of the value in two groups. The statistical significance was determined at 0.05 levels of confidence.

Results

Comparison of molar intrusion efficiency in hyperdivergent and hypodivergent patients

The maxillary first molars were successfully intruded in all the patients according to their clinical needs. Mean molar intrusion was 4.57 and 3.64 mm in G1 and G2 with no significant difference (\(P > 0.05\)). Mean treatment duration was 3.13 and 4.71 months in G1 and G2 with significant difference (Table 1) (\(P < 0.05\)). In addition, the intrusion efficiency was 1.57 and 0.81 mm in G1 and G2 with significant difference (\(P < 0.05\)), which means upper molars was more easily intruded in hyperdivergent patients than in hypodivergent patients.

\(^1\)SPSS, Chicago, IL, USA.
Pre-treatment and post-treatment bone density in hyperdivergent and hypodivergent patients

The pre-treatment and post-treatment bone density of three portions including cervical, furcation and apical were calculated (Table 2). There were significant differences in cervical, furcation, apical bone density of pre-treatment and post-treatment between G1 and G2 ($P < 0.05$). Bone density is lower in hyperdivergent patients than in hypodivergent patients, which means bone density is associated with vertical facial morphology.

Bone density change in hyperdivergent and hypodivergent patients

The bone density of three portions was significantly reduced after intrusion both in G1 and G2 ($P < 0.05$). Significant difference was found in the bone density change between patients with molar intrusion and without molar intrusion (Table 3) ($P < 0.05$). In addition, the reduction of bone density was greater in G1 than in G2 (Table 2) ($P < 0.05$), which means bone density change is also associated with vertical facial morphology.

Fig. 2. Prior to measuring bone density, 3D model was resliced to obtain new CT slices of teeth that were perpendicular to the longitudinal axes of teeth using the `reslice` function in the software program. The slice number was set as 3.

Fig. 3. The bone density was assessed at three levels: cervical, furcation and apical portions. The cervical portion was set as parallel to alveolar crest. The furcation portion was set as 1 mm above the root furcation, and apical portion was set as parallel to buccal root apex.
It is observed in this study, absolute molar intrusion, ranged from 2 to 6 mm, could be achieved by mini-screw implants. There was no significant difference in the amount of molar intrusion among patients of different vertical morphology. However, significant difference was found in duration and efficiency of molar intrusion between hyperdivergent and hypodivergent patients. To the best of our knowledge, there was no study concerning on the factors affecting molar intrusion efficiency. Previous study has found that complex relationship exists between structures of the mandibular body and facial types (11). However, no research has been studying the relationship between facial type and bone density. Therefore, the purpose of this study is to explore the relationship of molar intrusion efficiency, bone density and facial type.

Clinical application of CBCT in the field of dento-maxillofacial radiology is gaining importance and

**Fig. 4.** The bone density measurement. (a) segmenting the area of the tooth from the CT image using the threshold value of the cementum; (b) expanding by one voxel to include the PDL using the morphology operation; (c) expanding by a further three voxel to include the surrounding bone using the morphology operation; (d) subtracting the tooth and PDL from the tooth, PDL and surrounding bone. The volumes of the areas and their density values are also demonstrated.

**Fig. 5.** The measurement of molar position. The measurement of molar position was defined as DB-FH: distal buccal cusp-FH plane and MB-FH: mesial buccal cusp-FH plane. (a) The frontal view of molar position measurement. (b) The lateral view of molar position measurement.
spreading widely. However, CBCT data have a larger amount of scattered X-rays than conventional spiral CT. This may enhance the noise in reconstructed images and thus affect the low contrast detectability (17). Because of scatter and artefacts, HU values in CBCT are not valid, and therefore, the method of correlating BMD to HU values from CBCT is not ideal. Moreover, the scatter and artefacts in CBCT get worse around inhomogenous tissues with reduced HU values up to 200 HU (18), which confirms that the HU in CBCT is not a valid method for bone density assessment. Therefore, medical CT was used to measure bone density in this study.

Bone density of cervical, furcation and apical parts of upper first molars was lower in hyperdivergent patients than in hypodivergent patients. The results provide evidence that bone density is associated with vertical facial type. Furthermore, it was found in this study that molar intrusion efficiency was greater in hyperdivergent than in hypodivergent patients, which is consistent with the results of bone density. There were no differences of age, sex and orthodontic force in the two groups, which might affect orthodontic tooth movement (19, 20). Therefore, it is indicated that the difference of bone density account for the distinct molar intrusion efficiency. What is the cause of difference of bone density in patients with various vertical skeletal facial type? Tsunori et al. (21) found that complex relationship exists between the structure of mandible body and facial type. The buccal and lingual cortical bone was thicker in short-faced individuals than in average and long-faced groups. Furthermore, the mandible is short, wide, strong and square in short-face pattern. The difference of mandible shape and structure may result from the bite force or masticatory function caused by masticatory muscle. Kubotga measured bone mineral content in the first molar of mandible using dental radiographs and reported that the density was higher in molars with a stronger bite force (22). Van Limborgh classified the

### Table 1. The amount, duration and efficiency of molar intrusion

<table>
<thead>
<tr>
<th>Sample numbers</th>
<th>Hyperdivergent</th>
<th>Hypodivergent</th>
<th>P</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusion (mm)</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>18 patients per group</td>
<td>4.57</td>
<td>0.98</td>
<td>3.64</td>
<td>1.25</td>
</tr>
<tr>
<td>Duration (month)</td>
<td>3.13</td>
<td>0.90</td>
<td>4.71</td>
<td>1.50</td>
</tr>
<tr>
<td>Efficiency (mm month⁻¹)</td>
<td>1.57</td>
<td>0.51</td>
<td>0.81</td>
<td>0.21</td>
</tr>
</tbody>
</table>

NS, not significance.

*P < 0.05.

### Table 2. Bone density (HU) of pre-treatment and post-treatment and the bone density change of two groups

<table>
<thead>
<tr>
<th>Sample numbers</th>
<th>Hyperdivergent</th>
<th>Hypodivergent</th>
<th>P</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>367.55</td>
<td>51.24</td>
<td>500.40</td>
<td>56.54</td>
</tr>
<tr>
<td>Furcation</td>
<td>503.16</td>
<td>56.42</td>
<td>626.53</td>
<td>48.17</td>
</tr>
<tr>
<td>Apical</td>
<td>262.45</td>
<td>33.69</td>
<td>337.70</td>
<td>43.84</td>
</tr>
<tr>
<td>Post-treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>299.58</td>
<td>52.44</td>
<td>453.10</td>
<td>55.29</td>
</tr>
<tr>
<td>Furcation</td>
<td>431.33</td>
<td>58.71</td>
<td>582.99</td>
<td>57.95</td>
</tr>
<tr>
<td>Apical</td>
<td>214.45</td>
<td>33.04</td>
<td>284.95</td>
<td>46.31</td>
</tr>
<tr>
<td>Change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>67.98</td>
<td>8.88</td>
<td>47.30</td>
<td>6.92</td>
</tr>
<tr>
<td>Furcation</td>
<td>71.83</td>
<td>12.63</td>
<td>43.54</td>
<td>10.56</td>
</tr>
<tr>
<td>Apical</td>
<td>48.00</td>
<td>8.10</td>
<td>52.75</td>
<td>14.10</td>
</tr>
</tbody>
</table>

NS, not significance.

*P < 0.05.
various factors involved in the growth and development of bones into genetic factors and showed that they interact (23). Jawbones receive physical stimulation from biting and chewing throughout life. Mechanical stress applied to bone influences bone volume and structure by controlling bone remodeling, and it is generally agreed that application of mechanical stress to bone is necessary to maintain bone volume and structure. Sato et al. (24) found that bone density in cancellous bone was reduced by 38\% in the root apex and 16\% on the lingual side as a result of lost masticatory function. Therefore, the different bite force caused by masticatory muscle may account for the variance of bone density in patients with distinct vertical facial type.

Some studies have focused on the bone response to orthodontic tooth movement in animals and found bone fraction and mineral density are reduced during tooth movement using histomorphometric methods. Hus et al. (25) found in a clinical study that bone density around teeth reduced significantly after application of orthodontic forces 7 months. In this study, we found that bone density was reduced in the cervical, furcation and apical region of upper first molar after intrusion movement. The intrusion force was transferred from teeth to periodontal ligament and alveolar bones, and many layers of networked reaction were involved in the transduction of mechanical force into molecular events (signal transduction) and orthodontic tooth movement (26). Orthodontic tooth movement is associated with bone remodelling, which consists of bone resorption and apposition, induced by osteoclasts and osteoblasts. It was found in this study that bone density were greatly reduced in hyperdivergent patients, which was most likely due to the differences in periodontal ligament and bone cell populations, genomes, and protein expression patterns. Furthermore, bone metabolism may be faster in hyperdivergent patients than in hypodivergent patients, and the difference of activity and number of osteoclasts may account for the variation in bone density change (27). This could also account for the difference of molar intrusion efficiency in hyperdivergent patients and hypodivergent patients.

Some limitation of this study should be considered. First, the bone density measurement was only limited in upper first molar. The further study will explore the bone density of entire region of jawbone including maxilla and mandible. Second, only 20 patients were included in every group; thus, further study will expand the patient samples and male patients will be included.

Conclusions

Absolute molar intrusion could be achieved by mini-screw implant in patients with different mandibular plane angle. The molars were more easily to intrude in hyperdivergent than in hypodivergent patients. The difference of bone density and bone density change during intrusion may account for the variation of molar intrusion efficiency. The bite force caused by masticatory muscle may account for the difference of molar intrusion efficiency in hyperdivergent patients and hypodivergent patients.

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Disclosure

No conflict of interests declared.

References


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