Craniofacial Height in Relation to Cross-Sectional Morphology of the Anterior Maxilla: An Anatomical Consideration in Implant Therapy

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Purpose: Patients who have a vertical growth pattern are more prone to complete alveolar bone growth later and run a higher risk for inhibition of growth and infraposition after implants have been placed. Moreover, it has been suggested for the same category of patients that craniofacial height may influence the alveolar bone morphology of the anterior maxilla during growth. Hence, it is important to identify such patients early when considering implant treatment in young patients. The purpose of this study was to investigate the height and width of the alveolar bone in the anterior maxilla in subjects with different craniofacial heights to assess if there is a relation between craniofacial height and the dimensions of the alveolar bone in the anterior part of the maxilla. Materials and Methods: Measurements on cephalograms and cone beam computed tomography (CBCT) images of the maxilla from 180 fully dentate subjects were analyzed and categorized into three angle groups based on the craniofacial height: low-, normal-, and high-angle groups. Measurements of the alveolar bone were taken interradicular, at six reference points distributed between the first premolar regions in the maxilla. The height and width of the alveolar bone were measured with a standardized technique at 3, 6, 9, and 12 mm from the top of the alveolar process. Results: Significant differences were found regarding the height of the alveolar bone in all the subgroups and regarding the width in the 9- and 12-mm subgroups, and between low-/normal- and low-/high-angle groups, where the high-angle group represented the thinnest alveolar bone. A significant difference was found between male and female patients concerning all dimensions of the alveolar bone. Conclusion: There is a relation between craniofacial height and the dimensions of the alveolar bone in the anterior part of the maxilla. Craniofacial height is an important factor to analyze when implant treatment is considered in the maxillary anterior region. This identification can preferably be carried out early in young patients who are still growing when various treatment options can still be considered. INT J ORAL MAXILLOFAC IMPLANTS 2020;35:386–394. doi: 10.11607/jomi.7776

Keywords: 3D, alveolar bone height, alveolar bone width, craniofacial height, growth, radiology

Patients with limited alveolar bone volume in the anterior maxilla will present a challenge when implant treatment is considered. Alveolar bone development and morphology have been associated with craniofacial height.1–3 The morphology of the alveolar process is mainly set during the craniofacial growth and tooth eruption. This development is highly dynamic from early childhood to the end of adolescence.4,5 By observing craniofacial height, individuals can be characterized in different vertical facial types. A feature that may disclose morphologic characteristics of the alveolar process is the dentoalveolar compensatory mechanism (DACM).6 For individuals with long vertical faces, the anterior teeth must continuously erupt in order to compensate for the vertical enlargement of the anterior face height during facial growth; hence, the alveolar process will be higher. In individuals with a short...
anterior face, the incisors erupt less during growth, resulting in a vertically shorter alveolar process.

The control of implant position, and hence the final esthetic outcome, requires an understanding of the morphologic structure and the dimensional dynamics of the alveolar process. The maxillary anterior region of the alveolar process is the most esthetically sensitive site, demanding higher attention, and elaborate preoperative planning should start as early as possible.

Several studies provide evidence of an association between vertical facial dimensions and morphologic features of the alveolar process. Sadek et al demonstrated that individuals with a high craniofacial height also have thinner alveolar bone anteriorly in the maxilla. Along with these findings, subjects with low craniofacial height also exhibit a larger alveolar bone width in the anterior region of the dentate maxilla. No significant difference was found for the posterior region of the maxilla.

Regarding alveolar bone height, in a study previously published by Klinge et al, the range of bone height in the midline area of the maxilla was between 11.6 mm (in subjects with low craniofacial height) and 28.4 mm (in subjects with high craniofacial height). A similar pattern but with proportionately higher differences was observed in the midline area of the mandible. Contradictive results were presented in another study, stating that there is no association between vertical facial height and alveolar bone height. Since the results differ among studies, further investigation implementing both alveolar bone height and width is of interest in order to establish evidence for the association of craniofacial height as a guideline for the prediction of alveolar bone dimensions.

Accordingly, the following criteria have been described to be associated with the morphology and volume of the alveolar bone: craniofacial vertical morphology, the form of the roots, and the inclination of the teeth. When a patient is predisposed to have a smaller volume of alveolar bone, the loss of bone due to normal bone remodeling after tooth loss will be of greater impact, resulting in a more challenging and complicated implant treatment. Based on previous research, it is hypothesized that there are differences in height and width of the alveolar bone in the anterior part of the maxilla between groups with different craniofacial heights and between males and females.

Hence, in an early stage of treatment planning of young still-growing patients, it is important to identify vertically growing patients with a risk of a thin alveolar phenotype, who are prone to developing excessive bone resorption after tooth loss in the esthetic zone of the anterior region of the maxilla. This factor may influence the choice of the most suitable treatment method, and in such cases, implant treatment may not always be the best choice of treatment. The purpose of this study was to investigate if there are any differences in height and width of the anterior region of the maxilla among subjects with different craniofacial heights and between males and females.

**MATERIALS AND METHODS**

The present observational study was conducted with the same material as previously reported by Klinge et al, utilizing pretreatment cone beam computed tomography (CBCT) scans and lateral cephalograms of 180 dentate subjects. This study was carried out in relation to the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD).

**Subjects**

The inclusion criteria was subjects referred to a clinic for a CBCT, between the years 2008 and 2013. Subjects with either missing permanent teeth other than third molars, periodontal disease diagnosed on the radiographs, major asymmetries of the jaws, or who had previously experienced orthodontic treatment were excluded. Cephalometric evaluation and subject classification into three categories were conducted as formerly described by Klinge et al. Only 60 scans from low-angle subjects were identified; this number was set as the limit for the number of scans to be consecutively included in the normal- and high-angle groups for equal comparison. The number of individuals included in each group was consequently set at 60 subjects, giving a total of 180 included scans.

**Radiography**

CBCT was performed, by one operator, using an i-Cat Cone Beam CT 17-19 (Imaging Sciences International). Field of view (FOV) was 16 × 13 cm, acquisition time was 8.9 seconds, with a voxel size of 0.3 mm, and exposure was set at 120 kVp and 18.54 mAs, with a total radiation dose of 458.6 mGy cm². Calibration of the i-Cat Cone Beam CT was performed according to the manufacturer’s requirements twice a year.

Lateral head images were generated from the CBCT scan using the i-Cat software program.

**Classification of Craniofacial Height**

Craniofacial height was determined cephalometrically using the Total Interactive Orthodontic Planning System (TIOPS) program. The radiography alignment and classification of craniofacial height have been described in detail previously. In brief, the subjects were categorized into three groups: high-, normal-, and low-angle individuals. A sample of morphologic differences between the
three groups and the typical anatomy of the dentoalveolar bone for the three groups, respectively, are shown in Fig 1. Before the measurements, adjustments for small deviations in the patient’s head position during exposure were corrected for by realigning the skull images in the axial, coronal, and sagittal planes, respectively (Fig 2).

Measurements of Alveolar Dimensions
A fully reconstructed three-dimensional image with sagittal, coronal, and axial slices was generated using iCATVision software.12

In the present study, the area of assessment was selected from the anterior maxilla in the midsection of the interradicular bone between the first premolar and the canine, between the canine and the lateral incisor, and between the lateral and central incisors, bilaterally (Fig 3).

The height and width of the alveolar bone was measured. The vertical measurement was determined by the long axis of the maxillary cross-sectional area. The height was assessed through the line drawn from the top of the alveolar process running perpendicular to the alveolar bone margin and ending at the nasion line as the upper limit (Fig 2c). Horizontally, the widths were measured perpendicular to the height measurement line at the levels of 3, 6, 9, and 12 mm (w1, w2, w3, and w4, respectively) measured from the top of the alveolar process (Fig 4).

All measurements of the alveolar bone height and width were performed, independently, by one of the authors (P.E.) who only had access to the decoded CBCT scans and was blinded to all other patient information. The operator underwent a trial/test session for calibration prior to the proper measurements. Measurement values were simultaneously recorded in a statistical spreadsheet by one of the other authors (A.K.).

Statistical Analysis
A one-way analysis of variance with Tukey post hoc test was used to compare the variables. A significance level of 5% was set in all comparisons. Statistical analysis was performed using IBM SPSS software (Version 22.0; IBM).

Ethical Considerations
The study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki (2008 version), approved by the Regional Ethical Review Board, Lund, Sweden (May 8, 2014, Dnr 2014/288), the Danish Health and Medicines Authority, Denmark (July 20, 2015, Sagsnr. 3-30-13-877/1), and the Danish Data Protection Agency, Denmark (July 7, 2015, J.nr. 2015-41-4117).

RESULTS
Alveolar Bone Height
A significant difference was present between the low-, normal-, and high-angle groups in almost all evaluated sites, where high-angle subjects proved to have a greater alveolar bone height in comparison to normal- and low-angle subjects, and the normal-angle subjects had a greater alveolar bone height in comparison to low-angle subjects (Table 1). The only exception was...
Fig 2 Demonstration of alignment of all subjects according to three planes. (a) Axial: Alignment according to the vertical line passing through the nasal spine and the top of atlas. (b) Coronal: Aligning the skull in an upright position using a line passing the supraorbital rims, perpendicular to the vertical line. (c) Sagittal: Alignment according to the nasion line, horizontal line of the palatine roof/nasal floor, passing through the anterior and posterior nasal spine.

Fig 3 Demonstration of the location of the measured sites. MRP = maxillary right premolar; MRC = maxillary right canine; MRI = maxillary right lateral incisor; MLI = maxillary left lateral incisor; MLC = maxillary left canine; MLP = maxillary left premolar.

Fig 4 (a) The height (arrow) was measured from the crestal top to the white reference line. (b) The widths (arrows) were measured perpendicular to the center axis (here represented by the white line) at the heights 3, 6, 9, and 12 mm (w1, w2, w3, and w4, respectively).
the comparison between the normal- and high-angle groups on the left maxillary side, where no significance was seen (Table 2). The mean value recorded for alveolar bone height between the lateral and central incisors was 22.1 mm, which exceeded the posterior measurement between the premolar and canine of 19.5 mm.

An overall pattern of declining heights in a posterior direction was recognized. The minimum height recorded was 11.4 mm in the premolar region, and the maximum height recorded was 30.5 mm in the incisor region. All descriptive statistics including height and width are visualized in Tables 1 and 2.

### Table 1: Descriptive Statistics for Alveolar Bone Height and Width in Maxilla on Right Side (mm)

<table>
<thead>
<tr>
<th>Site</th>
<th>Low-angle group n = 60</th>
<th>Normal-angle group n = 60</th>
<th>High-angle group n = 60</th>
<th>Multiple comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min–Max</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>MLP</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>MRC</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MRI</td>
<td></td>
<td></td>
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</tbody>
</table>

### Table 2: Descriptive Statistics for Alveolar Bone Height and Width in Maxilla on Left Side (mm)

<table>
<thead>
<tr>
<th>Site</th>
<th>Low-angle group, n = 60</th>
<th>Normal-angle group, n = 60</th>
<th>High-angle group, n = 60</th>
<th>Multiple comparison</th>
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<td></td>
<td>Mean</td>
<td>Min–Max</td>
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</tr>
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<tr>
<td>MLC</td>
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<tr>
<td>MLI</td>
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</tbody>
</table>

**Note:** All descriptive statistics including height and width are visualized in Tables 1 and 2.
Alveolar Bone Width at 3 mm
The recorded width ranged from 4.3 to 11.5 mm. No significant differences were found between any of the angle groups at any site.

The mean value increased in the posterior direction, confirming a wider alveolar bone in the premolar area compared with the incisive area.

Alveolar Bone Width at 6 mm
The recorded width ranged from 4.2 to 11.9 mm. There were no significant differences found between the angle groups at any site.

The overall width was greater in the premolar area compared with the anterior region.

Alveolar Bone Width at 9 mm
The recorded width ranged from 3.3 to 15.7 mm. A significant difference was present between the low-angle group and both the high- and normal-angle groups in the incisor and premolar regions. Low-angle subjects were wider than the high-angle subjects in the premolar region on the right side and wider than both normal- and high-angle subjects in the incisor region bilaterally. No significant differences were found in the canine region.

The premolar region was significantly wider than the anterior region, and the anterior region was significantly wider than the canine region.

Alveolar Bone Width at 12 mm
The recorded width ranged from 3.1 to 17.6 mm. A significant difference was present between the low-, normal-, and high-angle groups in nearly all the regions. Low-angle subjects presented a wider alveolar bone compared with the high-angle group in all measured areas. The same relationship was shown between low- and normal-angle subjects, except for the premolar region. Furthermore, the mean value for the premolar region was greater than the anterior region, confirming a wider bone in the premolar region.

Differences Between Males and Females
A significant difference was present between males and females in both height and width in all sites. Males were proven to have an alveolar bone that is both higher and wider in the anterior part of the maxilla on all measured regions and levels (3, 6, 9, and 12 mm). The average differences based on mean values for all regions were as follows: height, 1.5 mm; w1, 0.6 mm; w2, 1.1 mm; w3, 1.5 mm; and w4, 1.4 mm (Tables 3 and 4).

DISCUSSION
The results of the present study suggest that craniofacial height is important for the development of horizontal and vertical bone dimensions of the alveolar process in the anterior region of the maxilla. This may be of value to identify at-risk patients in which implant treatment may...
be less suitable due to a nondesirable growth pattern and, as a consequence, alveolar bone deficiency.

The majority of the absence of permanent teeth in the anterior region of the maxilla in children and adolescent patients is caused by traumatic dental injuries or agenesis. In growing patients, implant treatment is contraindicated until growth is completed. However, the planning of final treatment, including tooth replacement, starts already when the patient is still growing. Many factors have to be considered to replace a lost tooth in the anterior maxilla, and treatment planning shall always be related to the patient’s growth status and dental situation. Orthodontic space closure, prosthetic rehabilitation, or autotransplantation may, in some cases, be better alternatives to implant treatment, while in other cases, implant treatment is a better choice.

Malmgren and Malmgren reported a difference in infraposition of ankylosed roots between the two types of vertical and horizontal growers, where individuals prone to more vertical growth showed the highest risk of alveolar process growth and are regarded as patients at risk for infraposition. Such patients also have an increased risk for infraposition of implants, and for this reason, may not be suitable for implant treatment. There is value in identifying such patients early in the treatment planning. It has been suggested that cephalometric radiographs are important for evaluating the direction of growth of the jaws since there is a difference between horizontal and vertical growers.

The results of the present study indicate that patients with a long vertical face are also more prone to a thinner alveolar phenotype. When planning such cases, an assessment of which facial type the patient belongs to can be a valuable tool to find the high-angle cases that are patients at risk for bone deficiency and accentuated vertical growth, where implant treatment may be less suitable. Moreover, it is also important to identify the subjects with low facial height who seem to be more stable and more suitable for dental implant treatment. Detecting/identifying this in an early stage of treatment planning is considered highly relevant and favorable from a patient perspective. The purpose of this study was to investigate if there are any differences in height and width of the alveolar bone anteriorly in the maxilla, between subjects with different craniofacial heights, based on CBCT images. There are similar studies where this relationship has been investigated; however, the majority are focused on mandibular dimensions as well as the thickness of the cortical buccal bone. Various results regarding alveolar bone height in relation to craniofacial height have been demonstrated. In a study conducted by Gracco et al, no statistically significant differences among craniofacial heights were found. However, a majority of studies have in fact obtained similar results to the findings of the present study. Sadek et al found that the high-angle group had the largest anterior dentoalveolar height in the maxilla and the mandible. The same results were confirmed by Kuitert et al. These findings

### Table 4: Difference Between Sexes When Comparing Measurements of Alveolar Bone Height and Width (mm) on Left Side

<table>
<thead>
<tr>
<th>Site</th>
<th>Male n = 60</th>
<th>Female n = 120</th>
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<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>20.5</td>
<td>14.0–25.7</td>
<td>2.8</td>
</tr>
<tr>
<td>w1</td>
<td>8.5</td>
<td>5.6–11.5</td>
<td>1.2</td>
</tr>
<tr>
<td>w2</td>
<td>9.5</td>
<td>7.1–11.9</td>
<td>1.1</td>
</tr>
<tr>
<td>w3</td>
<td>9.8</td>
<td>7.4–12.2</td>
<td>1.2</td>
</tr>
<tr>
<td>w4</td>
<td>10.1</td>
<td>7.1–14.0</td>
<td>1.7</td>
</tr>
<tr>
<td>MLC</td>
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<td></td>
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<tr>
<td>h</td>
<td>22.2</td>
<td>11.5–28.0</td>
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</tr>
<tr>
<td>w1</td>
<td>7.0</td>
<td>4.7–8.5</td>
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<tr>
<td>w2</td>
<td>8.0</td>
<td>5.8–9.7</td>
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<tr>
<td>w3</td>
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<td>5.4–11.7</td>
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<tr>
<td>w4</td>
<td>8.9</td>
<td>5.0–14.5</td>
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<tr>
<td>MLI</td>
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<tr>
<td>h</td>
<td>23.1</td>
<td>13.4–29.6</td>
<td>3.0</td>
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<td>6.7</td>
<td>5.1–8.9</td>
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<td>8.5</td>
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<td>w4</td>
<td>9.4</td>
<td>5.1–14.5</td>
<td>1.7</td>
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MLP = maxillary left premolar, MLC = maxillary left canine, MLI = maxillary left lateral incisor; mean = mean value, min-max = minimum and maximum value; SD = standard deviation; n = number of subjects. Alveolar bone height (h); width (w) at the heights 3, 6, 9, and 12 mm from the crestal top (w1, w2, w3, and w4, respectively). *Significant at P < .05.
agree with the theory that the DACM is closely connected to the vertical growth of the face. In contrast to Sadek et al., the findings of the present study suggest a difference in the first premolar area as well, which might be of interest regarding the extent of DACM, suggesting that it might also influence the alveolar height more posterior in the maxilla area.

In the present study, the method to study dentate subjects was chosen to enable the evaluation of the effect of the genetic component of growth solely without being affected by factors related to areas where teeth already have been lost. In such areas, it is known that atrophy due to trauma and inhibition of growth of the alveolar bone will take place and affect growth locally.

The width of the alveolar process was measured at the heights of 3 (w1), 6 (w2), 9 (w3), and 12 (w4) mm from the top of the alveolar process, while most implants are preferably placed within this range in the bone. Multiple comparison between the alveolar bone width at levels w1 and w2 and craniofacial height revealed no statistical significance at the measured sites. However, statistical significance was shown at levels w3 and w4 at a majority of the measured sites. Gracco et al. revealed no statistical significance at the measured sites. The results of Gracco et al also correspond to the measurements of the present study at w1 and w2 and found no significant difference in the height of 15 mm. These results demonstrate that the major relationship between facial height and alveolar bone measures is located in the region least exposed to the bone resorption pattern observed after tooth loss.

Similar to the results of the present study, Sadek et al. found that the high-angle group had significantly thinner alveolar bone anteriorly in the maxilla compared with the low-angle group. This was the case at both mid-root-level and at the level of the root-apex. In contrast to the significant difference at w4 in the premolar site in the present study, they found no statistical difference posterior to the canine.

The multiple comparison between sexes proved that there is a significant difference at all sites. Hence, alveolar bone height and width of the males are greater overall. From a statistical perspective, this aspect is interesting since it could be stated that males are more suited for implant treatment based on their anatomical conditions. However, this probably has no clinical relevance because this study reveals average values of height and width for both sexes that are sufficient to place implants, but in the extreme cases of high angles, one can envision that the possibility for immediate implant treatment in women is less likely than men, due to deficiency in the alveolar bone volume.

Implant treatment might not be the first choice of treatment in patients with a high-angle facial type because these individuals also tend to display more gingiva and also may be inclined to have a prolonged, continued eruption due to the DACM compensating for the vertical face height. However, taking into account that the width at w3 and w4 (9 to 12 mm from the top of the process) of the alveolar bone is significantly thinner in the high-angle subjects, it would be interesting to study if bone augmentation procedures were more frequently needed in high-angle subjects when replacing congenital missing lateral implants in a young adult, compared to subjects with a normal or low craniofacial height.

In summary, it is suggested that assessing craniofacial vertical height is of clinical importance to identify at-risk cases where implant treatment may be less suitable. By doing such an analysis before growth is completed, other treatment options, such as orthodontic space closure, autotransplantation, and prosthetic solutions may be chosen instead of implant treatment.

CONCLUSIONS

This study claims a statistically significant difference in height and width of the alveolar process in major aspects associated with the craniofacial height and sex. Evidence has been presented that individuals with a high-angle facial type are more prone to a thinner alveolar bone in the anterior part of the maxilla compared to subjects with a low-angle facial type.

Already in adolescence, a clinical examination could reveal the vertical craniofacial morphology and, there by, give the clinician an indication of which treatment option to choose in the cases of tooth loss or agenesis in the anterior part of the maxilla.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Yohei Jinno, Department of Oral and Maxillofacial Surgery and Oral Medicine, Faculty of Odontology, Malmö University, for data analysis. The authors reported no conflicts of interest related to this study.

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