Abstract: This study investigated guidelines for placement of monocortical screws in the mandible, particularly the mandibular canal. In this study of 35 patients, we used cone-beam computed tomography to determine the distance from the alveolar crest to the superior border of the mandibular canal (DMC) and the shortest distance from the buccal and lingual cortex to the mandibular canal (attaining distance) in the areas between premolars (premolar area), between the second premolar and first molar (middle area), and between the first and second molars (molar area). The DMC values for these areas were 16.55, 18.94, and 16.58 mm, respectively, and were similar in adults and adolescents. When the attaining distance was 8 mm, the heights on the buccal and lingual sides of the areas were 9 and 16.6 mm, 13.7 and 14.7 mm, and 15.3 and 12 mm, respectively. Risk of proximity to the mandibular canal should be considered at above heights or greater when an orthodontic anchorage device (OAD) 8 mm in length is placed. Careful attention is needed for placements on lingual side in adolescents. By reducing the OAD length to 6 mm, placement safety increases in all areas except the premolar area, especially on the buccal side.

Keywords: mandibular canal; inferior alveolar nerve canal; cone-beam computed tomography (CBCT); orthodontic anchorage device (OAD).

Introduction

Damage to the mandibular canal can cause sensory paralysis of the lower teeth, gingiva, lip, and mental region (1,2), and special attention is therefore required during surgical procedures. Studies have investigated the location of the mandibular canal in order to provide guidelines for third molar surgery (3-5), dental implantation (6-10), orthognathic surgery (11,12), reduction of mandibular fractures (13).

A recent computed tomography (CT) study (4) classified the shape of the mandible at the third molar region in relation to buccal and lingual morphology and found differences in lingual cortical thickness and the distance between the root apex of the third molar and the mandibular canal. Hsu et al. (7) measured the distance between the buccal cortex and mandibular canal and reported that the distance at the first molar was significantly greater than that at the second premolar. Nagadia et al. (12) measured the distances from the mandibular canal to the buccal and lingual cortex and molars and reported the safest position and safe depth for a vertical buccal cut in sagittal split ramus osteotomy. For placement of monocortical screws to fix plates for mandibular fracture reduction, Levine et al. (11) measured the distances between the inferior alveolar nerve (IAN) canal and buccal cortex and between the alveolar crest and IAN.
canal in the first molar region. They concluded that the buc­colingual position of the IAN canal was associated with age and race.

Placement of orthodontic anchorage devices (OADs) is a surgical procedure performed frequently in the mandible, and a wide selection of sites is preferred for such placement. OADs can be classified into two types. In one type, the screw is placed in the superior region, such as at the attached gingiva area; in the other, the plate type includes a bone anchor that is fixed with screws in an inferior region, such as the root apical area (14-16). Levine et al. (11) concluded that measurement values for the IAN canal location should be considered when placing monocortical screws, to minimize the risk of IAN injury. This consideration also applies to fixtures inserted in various areas of the mandible, i.e., not only to dental implants but also to OADs.

Previous studies did not provide sufficient information on the location of the mandibular canal for placement of monocortical screws such as OADs, which can be inserted from every direction on the cortical bone surface. To develop guidelines for placement sites of monocortical screws, including OADs, in the mandible, we used cone-beam CT (CBCT) images to determine the depths of the mandibular canal and the shortest distance from the buccal and lingual cortex to the mandibular canal.

Materials and Methods

Participants
In total, 35 patients (13 males, 22 females; average age 22.7 ± 7.8 years; range 12.1-43.3 years) who visited the orthodontic department of Nihon University Dental Hospital participated in the study. All met the following criteria: 1) no history of orthodontic treatment, 2) no missing teeth, except third molars, 3) no history of mandibular skeletal deformity, and 4) no history of severe periodontal disease.

Participants were divided by age into an adolescent group (9 males, 6 females; average age 15.9 ± 2.7 years; range 12.1-19.4 years) and an adult group (3 men, 17 women; average age 27.8 ± 6.5 years; range 20.0-43.3 years).

This study was approved by the Ethical Committee of Nihon University School of Dentistry (EP2014-17). All patients received a sufficient explanation and consented to participate in this study.

Measurements
CBCT (3D Accuitomo, J. Morita, Kyoto, Japan) images were obtained from each participant for diagnostic purposes. The following parameters were used for CBCT imaging: field of view, 80 × 80 mm; voxel size, 0.125 mm³ in super-high-resolution mode; X-ray tube voltage, 80 kV; and current, 5.5 mA. A previous study (17) that used cross-sectional CBCT images for measurements defined the cross-sectional plane as the plane between a contact point (CP) and the middle point between the adjacent teeth at a depth of 10 mm from the CP.

Fig. 1 Tomographic cross-sections were defined by the interalveolar septa between the first and second premolars (A), the second premolar and first molar (B), and the first and second molars (C), after fixing a plane passing from a contact point (CP) to the middle of root surfaces of the adjacent teeth at a depth of 10 mm from the CP.
arch at each area) images cross-sectioned by the three slice planes and the One Volume Viewer 3D imaging program (ver. 1.6.1.13, J. Morita, Kyoto, Japan), we measured the depths of the mandibular canal (DMC: perpendicular distance relative to the reference plane fixed to the superior border of the mandibular canal) was measured. (b) When the region of measurement was just above the mental foramen, the superior margin of the foramen was considered the superior border of the mandibular canal.

Fig. 2 (a) The depth of the mandibular canal (DMC: the perpendicular distance relative to a reference plane fixed to the tips of the buccal and lingual cusps from the alveolar crest to the superior border of the mandibular canal) was measured. (b) When the region of measurement was just above the mental foramen, the superior margin of the foramen was considered the superior border of the mandibular canal.

Fig. 3 The attaining distance (AD) from the bone surface to the mandibular canal surface was measured at 1-mm intervals for heights of 1-25 mm. The figure shows the procedure for measurement of ADs for section B.

A total of 210 tomographic images were used in this study: 35 images each from both sides of the three slice planes (sections A, B, and C). Areas that deviated from the field of view of the CBCT images were excluded from the analysis. All measurements were performed by one examiner (Y.U.).

**Statistical analysis**

To determine measurement error, we randomly selected CBCT images from 10 participants and re-measured the DMC and AD approximately 1 month after (T2) the initial measurements (T1). The Pearson correlation coefficient was used to evaluate differences between these measurements (T1–T2). The two-tailed *t*-test was used to assess the significance of differences between groups in relation to age. All statistical analyses were performed using SPSS software (ver. 16.0 for Windows, SPSS Japan, Tokyo, Japan). *P* values < 0.05 were considered to indicate statistical significance.

**Results**

The reliability test (T1–T2) showed a significant correlation (*P* < 0.01; *r* = 0.91-0.99), thereby confirming the reliability of the measurements.

Table 1 shows the mean DMC values. The values for the three sections (A, B, and C) were 16.55 ± 2.95, 18.94 ± 2.28, and 16.58 ± 1.88 mm, respectively. The mean DMC values, according to age, are shown in Table 2. There was no statistically significant difference between the adolescents and adults.

The mean AD values are shown in Fig. 4. When the AD was 8 mm on the buccal and lingual sides, the heights were 9.0 and 16.6 mm, respectively, for section A, 13.7 and 14.7 mm for section B, and 15.3 and 12.0 mm for section C.

AD values for the two age groups are shown in Fig. 5A-C. On section A, the AD values on the lingual side at heights of 1-7 mm were significantly greater for the adults than for the adolescents (*P* < 0.01-0.05, Fig. 5A). On section B, the AD values on the buccal side at heights of 20-24 mm were significantly greater for the adolescents than for the adults (*P* < 0.05), whereas the values on the lingual side at heights of 2-8, 17, and 18 mm were significantly greater for the adults than for the adolescents (*P* < 0.05, Fig. 5B). For section C, on the lingual side, AD values at heights of 1-16 mm were significantly greater for the adults than for the adolescents (*P* < 0.01-0.05); however, at heights of 23-25 mm, AD values were significantly greater for the adolescents than for the adults (*P* < 0.05, Fig. 5C).

**Discussion**

In orthodontic treatment, the use of widely selectable sites for OAD placement is preferred in order to adapt to various cases. OAD placement sites in the mandible have tended to be mainly on the buccal side because of placement difficulties and anatomical features, and in consideration of risks related to proximity to the mandib-
ular canal and tongue irritation (18). A few studies have reported placement of OADs on the lingual side of the mandible (19,20). In such cases, the orthodontist must determine whether the local anatomical features, such as the mandibular canal, permit placement. However, there is no relevant information on OADs that can be inserted from any direction on the cortical bone surface, including the lingual side of the mandible.

The present study used CBCT imaging to measure the shortest distance between the mandibular canal and the surface of the mandible at various heights. Several previous studies of OAD placement sites used CT images (21-25), and a cadaveric study confirmed the accuracy of such images (6). However, CT imaging, including CBCT, is regarded as an invasive examination because of the radiation exposure involved. Therefore, we used CBCT images that had already been obtained from orthodontic patients for diagnostic purposes.

Levine et al. (11) investigated the distance between the IAN canal and the alveolar crest at the position of the first molar in adults and reported a mean distance of 17.4 ± 3.0 mm. In the present study, the mean DMC values at sections B (middle area) and C (molar area) in adults were 19.33 ± 2.5 mm and 16.89 ± 2.07 mm, respectively (Table 2). These values are similar to the mean distance reported previously (11).

The heights on the buccal and lingual sides when the AD was 8 mm, a common OAD length (26), were 9 and 16.6 mm, respectively, in the premolar area, 13.7 and 14.7 mm in the middle, and 15.3 and 12 mm in the molar areas (Fig. 4). Thus, in regions inferior to and near these heights, the risk of proximity to the mandibular canal must be considered because an AD value less than 8 mm might be indicated. The differences in the heights of the buccal and lingual sides of the premolar area are attributable to the location of the mental foramen, which is commonly located between or below the premolars (27,28). In the molar area, this difference might be due to both the running course of the mandibular canal and the specific bone shapes, which are affected by lingual concavity. In terms of proximity to the mandibular canal in the premolar area, as compared with the buccal side, the lingual side is considered the safer placement site, even in the inferior region. In the molar area, the height when the AD was 8 mm on the lingual side was less than that on the buccal side. This placement condition on the lingual side is associated with the risk of proximity to the mandibular canal and with placement difficulties (18). Thus, the inferior and distal regions, such as the molar area on the lingual side, are probably unsuitable sites for OAD placement.

A comparison of AD between age groups showed that the significant differences when AD was more than 8 mm on the lingual side (Fig. 5A-C, $P < 0.01-0.05$) could be ignored when placing an 8-mm OAD. In the middle area, the AD values of adults were significantly lower than those of adolescents at heights of 20-24 mm on the buccal side ($P < 0.05$, Fig. 5B). The age difference in AD values in this region appears to reflect the increase in height of the alveolar process of the mandible during growth, which might affect the depth of the mandibular canal (29). In the molar area, the AD values were significantly

| Table 1 Depth of the mandibular canal (DMC) |
|----------------|----------------|----------------|
| DMC            | 4-5            | 5-6            | 6-7            |
|                | Mean SD Min Max| Mean SD Min Max| Mean SD Min Max|
| 4-5: premolar area (between first and second premolars), 5-6: middle area (between second premolar and first molar), 6-7: molar area (between first and second molars). |
| 16.55 2.95 10.29 22.23 | 18.94 2.28 11.76 23.36 | 16.58 1.88 11.94 20.64 |
| n               | Age Mean       | Age Mean       |
| 70              | 22.70          | 22.70          |
| 7.82            | 22.70          | 22.50          |
| 7.82            |                | 7.84           |
| 4-5: premolar area (between first and second premolars), 5-6: middle area (between second premolar and first molar), 6-7: molar area (between first and second molars). |

| Table 2 Depth of the mandibular canal (DMC), by age group |
|----------------|----------------|----------------|
| DMC            | Adolescents   | Adults         |
|                | Mean SD       | Mean SD        |
| 4-5: premolar area (between first and second premolars), 5-6: middle area (between second premolar and first molar), 6-7: molar area (between first and second molars). |
| 15.81 2.68 17.11 3.02 | 18.42 1.83 19.33 2.50 | 16.18 1.52 16.89 2.07 |
| n               | Age Mean       | Age Mean       |
| 30              | 15.94          | 15.94          |
| 40              | 27.78          | 27.78          |
| 2.69            | 15.94          | 15.94          |
| 6.46            | 6.46           | 6.46           |
| 6.61            |                |                |
| 4-5: premolar area (between first and second premolars), 5-6: middle area (between second premolar and first molar), 6-7: molar area (between first and second molars). |
lower for the adolescents than for the adults at heights of 11-16 mm on the lingual side ($P < 0.01-0.05$, Fig. 5C). This difference was likely related to vertical growth in the alveolar process (29). Thus, further attention should be given to heights of 11 mm or more when an 8-mm OAD is placed on the lingual side of the molar area in adolescents.

With a 2-mm reduction in OAD length (from 8 to 6 mm), the heights on the buccal and lingual sides when AD was 6 mm were 11.2 and 19.8 mm, respectively, in the premolar area and 18.5 and 16.8 mm in the middle area. In the molar area, this height on the lingual side was 13.8 mm. The height on the buccal side could not be determined because the AD value was always greater than 6 mm (Fig. 4). Thus, the placement area that was considered to avoid proximity to the mandibular canal increased when the screw length was reduced by 2 mm. In particular, a large increase in this placement area was found in regions from the second premolar to the second molar on the buccal side.

The present results and relevant clinical implications are summarized below: 1. The mean DMC values in the premolar, middle, and molar areas were 16.55, 18.94, and 16.58 mm, respectively; 2. On the lingual side, the AD tended to be shorter in adolescents than in adults. This suggests that OADs require greater care when placed on the lingual side in adolescents; 3. When 8-mm OADs are placed, the risk of proximity to the mandibular canal on the buccal and lingual sides should be considered at heights ≥9 and ≥16.6 mm, respectively, in the premolar area, ≥13.7 and ≥14.7 mm in the middle area, and ≥15.3 and ≥12 mm in the molar area; 4. By reducing OAD length from 8 to 6 mm, the available placement areas to avoid proximity to the mandibular canal increased at all measurement sites. In particular, heights greater than 18.5 mm in the middle area and all heights in the molar area on the buccal side were considered safer for placement.
Conflict of interest
All authors have no conflict of interest to declare.

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