# Root Surface Area of Permanent Mandibular Teeth in Patients with Anterior Open Bite Malocclusion: A CBCT Assessment

Theerapat Sirivan, Kachaphol Kuharattanachai, Dhirawat Jotikasthira and Kanich Tripuwabhrut*

Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University, Chiang Mai, 50200, Thailand
* Corresponding author. E-mail address: kanich.t@cmu.ac.th
Received: 24 April 2023; Revised: 27 July 2023; Accepted: 9 August 2023; Available online: 26 August 2023

**Abstract**

A previous study reported that the root surface areas (RSA) of the maxillary central and lateral incisors were substantially smaller in patients with anterior open bite malocclusion. However, the RSA of permanent mandibular teeth in patients with anterior open bite malocclusion has never been explored. The objective of this study was to investigate the RSA of permanent mandibular teeth in patients with anterior open bite malocclusion. Cone-beam computed tomography (CBCT) images of permanent mandibular teeth were selected from sixteen patients with anterior open bite malocclusion and sixteen patients with an anterior normal overbite. Mimics research software was used to construct three-dimensional tooth models from the CBCT images. 3-Matic Research software was employed to calculate the RSA. An independent t-test ($p < 0.05$) was used to compare the RSA of each tooth type. From the permanent mandibular central incisor toward the permanent mandibular second premolar, the means of RSA were significantly lower in the anterior open bite group than in the anterior normal overbite group. Anterior open bite malocclusion may affect the RSA in all permanent mandibular teeth except in permanent mandibular molars.

**Keywords:** Root surface area, Anterior open bite, Cone-beam computed tomography, Occlusal hypofunction, Orthodontic treatment

## Introduction

Previous studies provided interesting information about the anterior open bite. Anterior open bite is a type of malocclusion in which the anterior teeth have no incisal contact while the upper and lower posterior teeth are touching (Mizrahi, 1978). The prevalence of anterior open bite malocclusion depends on race and dental age and usually ranges between 1.5% and 11% (Lin, Huang, & Chen, 2013; Ng, Wong, & Hagg, 2008). An anterior open bite can be classified into three groups: dentoalveolar open bite, skeletal open bite, and a combination of both (Uribe, Janakiraman, & Nanda, 2015). It has also been reported that patients with an anterior open bite and a high mandibular plane angle tended to have lower root-per-crown ratios and shorter root lengths from incisors to premolars (Yun, Jeong, Pang, Kwon, & Jung, 2014).

Root surface area (RSA), the contact area between the dental root and surrounding bone, is an important factor in planning various dental treatment procedures, including orthodontic treatment. The RSA dimension depends on bone height and characteristics of the dental root, including tooth size, root length, root morphology, root trunk width, root diameter, and amount of roots (Gu et al., 2016; Pan et al., 2004). In previous studies, RSA was measured using the membrane measuring technique, the weighting conversion technique, the division planimetry technique, and the Three-dimensional (3D) laser scanning technique. The disadvantages of these methods include inaccuracy, imprecision, complicated measuring procedures, and the need for tooth extraction before RSA measurements (Hujoel, 1994). Numerous research projects are currently being conducted to develop more efficient and convenient methods for RSA measurement. CBCT can be used for RSA measurement to overcome the limitations of previous methods. By constructing 3D images with CBCT, RSA can be measured with high accuracy and without tooth extraction. Thus, the CBCT measuring technique is an appropriate method for calculating RSA in non-extraction teeth.

Recent studies showed that the RSAs of the permanent maxillary central and lateral incisors were significantly lower in patients with anterior open bite malocclusion than in those with the anterior normal overbite by the CBCT technique (Suteerapongpun, Sirabanchongkran, Wattanachai, Sriwilas, & Jotikasthira, 2017). However, no research has investigated the RSA of permanent mandibular teeth in patients with anterior open bite malocclusion. The purpose of this study was to evaluate and compare the RSA of permanent mandibular teeth in patients with anterior open bite malocclusion to patients with an anterior normal overbite.

## Methods and Materials

### Subjects and image acquisition

This study was approved by the Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University, Thailand (No. 52/2019).

To determine the minimal sample size required, a pilot study was performed. The sample size calculation was performed with G*Power (version 3.1.9.4, University of Kiel, Germany) software. Taking into account a power of 80% and a significance level of 5%, the final sample consisted of 14 individuals per group. The study subjects were Thai patients between 15 and 30 years old who had received orthodontic treatment and required pretreatment cone-beam computed tomography (CBCT) images for diagnosis and treatment plan at the Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University (Table 1). All patients had developed entire roots for all permanent mandibular teeth (excluding third molars) and had never received orthodontic treatment.

**Table 1** Gender and Age distribution by subject group

| Groups | N | Females | Males | Age (Years) | | |
|---|---|---|---|---|---|---|
| | | | | Minimum | Maximum | Mean |
| **Anterior open bite** | 16 | 10 | 6 | 16.67 | 29.42 | 22.23 ± 4.08 |
| **Anterior normal overbite** | 16 | 6 | 10 | 15.92 | 30.00 | 22.56 ± 3.72 |
| **Total** | 32 | 16 | 16 | 15.92 | 30.00 | 22.39 ± 3.84 |

All CBCT images of permanent mandibular teeth were captured with a GiANO (NewTom, Verona, Italy) CBCT unit at 90 kVp, 10 mA, a 0.15 mm voxel size, and an 11 cm x 8 cm field of view, and lateral cephalometric radiographs were taken using a GiANO (NewTom, Verona, Italy).

The lateral cephalometric radiographs were taken at maximum intercuspation with lip seal in the rest position and Frankfort horizontal plane according to the natural head position and were traced digitally using commercially available software (Dolphin imaging version 11.9, Dolphin Imaging & Management Solutions, Chatsworth, Calif). Patients were classified into two groups using the method described previously (Kuharattanachai et al., 2022; Suteerapongpun et al., 2017). Six cephalometric measurements were analyzed: (1) the sella-nasion (SN) to gonion-gnathion (GoGn) angle; (2) the SN to palatal plane (PP) angle; (3) the PP-GoMe angle; (4) the gonial angle; (5) the facial index; and (6) the ratio of posterior to anterior face height. When three or more measurements indicated an open vertical skeletal configuration, patients were classified as having an open vertical skeletal configuration. If four or more parameters demonstrated normal vertical skeletal configuration, subjects were classified as having normal vertical skeletal configuration. The anterior open bite group had an open vertical skeletal configuration and an anterior open bite. The normal overbite group had normal vertical skeletal configuration and anterior normal overbite. Exclusion criteria for both groups were the presence of craniofacial anomalies, signs of root resorption, severe periodontitis or periapical lesion in radiographs, embedded tooth, variation of tooth morphology or pathology, and systemic conditions.

**Measurement of the root surface area**

CBCT images of permanent mandibular teeth in patients with anterior open bite and anterior normal overbite in the digital imaging and communications in medicine (DICOM) file format were imported into Mimics Research version 15.01 and 3-Matic Research version 7.01 (Materialism, Leuven, Belgium) to calculate RSA (Figures 1 and 2) following the previously described method by Suteerapongpun et al. (2017). Images were properly aligned in the axial, coronal, and sagittal planes. New masks were created for the tooth. A mask of the areas of interest was created by predefining threshold values. The masks were then trimmed using the "crop mask tool" in all three dimensions. The specified tooth was segmented using the software's segmentation tool. Using the "multiple slice editing tool," templates were identified manually for the segmentation and separation of surrounding structures for each slice in each plane. The regions identified during the "multiple slice editing phase" were expanded during the "region growing phase" so that the tooth could be completely distinguished. When the "Calculate 3D" function was activated, 3D tooth models were finally generated (Figure 1). To separate the crown from the root, the cementoenamel junction was marked using the "Create curve" function. Using 3-Matic Research version 7.01 (Materialism, Leuven, Belgium), the crown and root surfaces of each tooth were calculated automatically. The final segmented image of the root surface area is shown in Figure 2.

All CBCT images were measured again after 4 weeks by the same examiner to assess intraobserver reliability.

**Statistical analysis**

The intraclass correlation coefficient (ICC) was employed to test the intra-examiner reliability. The mean and standard deviation of RSA were obtained using descriptive analysis. All data were subjected to the Shapiro-Wilk test to determine their normality. The independent t-test was implemented to compare the mean differences in RSA between the anterior open bite group and the anterior normal overbite group. The results were considered statistically significant at $p < 0.05$.

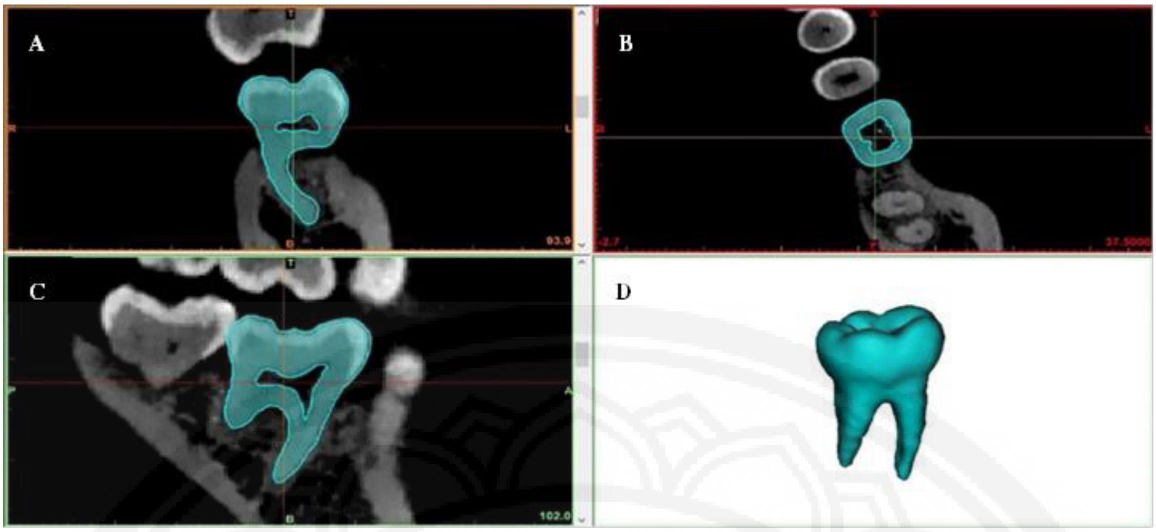


**Figure 1** Coronal view (A), axial view (B), and sagittal view (C) of a two-dimensional picture of the tooth boundaries acquired from the Mimics Research program version 15.01. They are used to generate a three-dimensional tooth model (D)

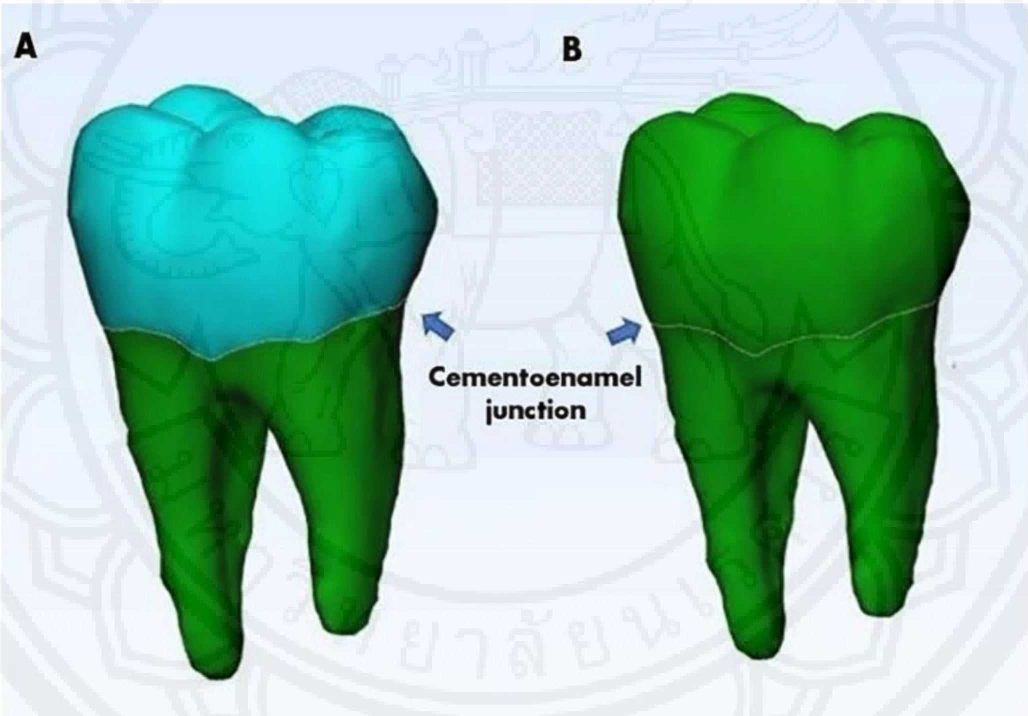


**Figure 2** To measure the root surface area, the cementoenamel junction is identified using a dental image extracted from the 3-Matic Research program version 7.01. The green region in (A) represents the root surface area, whereas the green region in (B) is the total surface area of the tooth (crown and root)

## Results

All subjects in both groups had a Class I skeletal pattern (ANB angle 0°-4°) (Table 2). In this study, of the 16 subjects in the anterior open bite group, 13 subjects had an open bite from canine to canine, and 3 subjects had an open bite from second premolar to second premolar. For RSA measurement, a high level of reproducibility in measurement was shown with a high intra-class correlation (r = 0.997) from the intra-examiner reliability test. The RSA in both groups was normally distributed and no statistically significant difference was observed between the right and left sides. For statistical analysis, the measurements from both sides were averaged.

**Table 2** Average of cephalometric measurements in the anterior open bite group and the anterior normal overbite group

| Cephalometric measurements | Norm | Anterior open bite | Anterior normal overbite |
|---|---|---|---|
| SN-GoGn (°) | 30.00 ± 5.60 | 38.47 ± 3.71 | 30.09 ± 3.50 |
| SN-PP (°) | 9.00 ± 3.00 | 0.88 ± 2.95 | -0.81 ± 3.77 |
| PP-GoMe (°) | 21.00 ± 5.30 | 33.13 ± 3.43 | 27.31 ± 3.92 |
| Gonial angle (°) | 118.00 ± 6.10 | 124.50 ± 4.58 | 122.41 ± 3.15 |
| UAFH/LAFH (%) | 81.00 ± 6.50 | 74.69 ± 2.99 | 81.44 ± 7.79 |
| PFH/AFH (%) | 65.00 ± 2.90 | 60.75 ± 2.68 | 66.41 ± 2.89 |
| ANB (°) | 2.00 ± 2.00 | 2.34 ± 1.29 | 2.41 ± 1.32 |
| U1-NA (°) | 22.00 ± 5.90 | 30.34 ± 5.58 | 30.56 ± 5.23 |
| L1-NB (°) | 30.00 ± 5.60 | 33.63 ± 7.55 | 31.03 ± 5.48 |

The means and standard deviations of the RSA of permanent mandibular teeth ranging from the mandibular central incisor to the mandibular second molar in the anterior open bite group were 130.32 ± 15.02, 151.92 ± 18.52, 223.58 ± 35.40, 188.89 ± 24.24, 181.85 ± 21.66, 368.84 ± 66.89, and 310.49 ± 52.23 $mm^2$, respectively. The means and standard deviations of the RSA of permanent mandibular teeth from the mandibular central incisor to the mandibular second molar in the anterior normal overbite group were 143.72 ± 17.41, 169.99 ± 22.44, 250.32 ± 38.26, 211.23 ± 33.20, 202.65 ± 29.43, 408.23 ± 58.00, and 344.18 ± 50.84 $mm^2$, respectively. Both groups demonstrated a similar trend, with the permanent mandibular first molar having the highest and the permanent mandibular central incisor having the lowest RSA, whereas the anterior open bite group's means of RSA for the permanent mandibular central incisor, permanent mandibular lateral incisor, permanent mandibular canine, permanent mandibular first premolar, and permanent mandibular second premolar were substantially lower than those of the anterior normal overbite group ($p < 0.05$) (Figure 3).

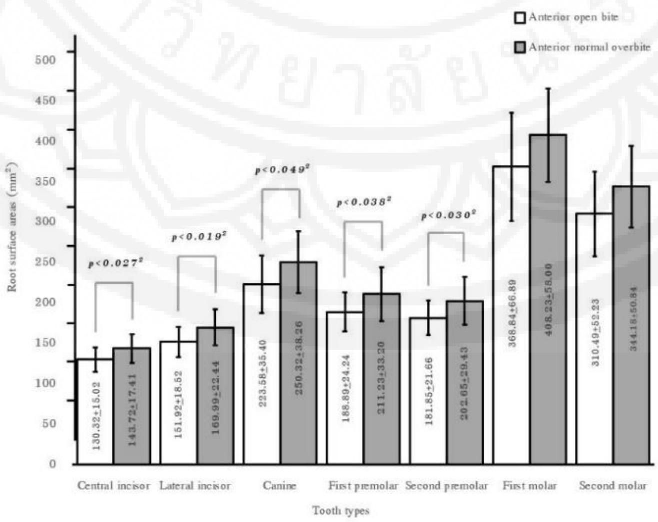


**Figure 3** The bar graph compares the root surface area of permanent mandibular teeth ([1]Differences between groups are derived from the root surface area of the anterior open bite group minus that of the anterior normal overbite group. [2]Significance levels: $p < 0.05$)

## Discussion

The RSA is one of the crucial considerations in planning various dental treatment procedures, including orthodontic treatment. The objective of this study was to analyze and compare the RSA in the permanent mandibular teeth of patients with anterior open bite malocclusion and anterior normal overbite, assessed using CBCT images.

Previously, RSA measurement was performed using the two-dimensional assessment technique, providing a high probability of measurement error, such as distortion of measuring materials, dimensional change in the tooth models, destruction of tooth structures, inability of the horizontal sectioning to conform to the curve of the cementoenamel junction and the need for tooth extraction before RSA measurement (Mowry, Ching, Orjansen, Cobb, Friesen, MacNeill, & Rapley, 2002; Tasanapanont, Apisariyakul, Tanapan Wattanachaii, Sriwilas, Midtbø, & Jotikasthira, 2017). Several recent studies have shown that CBCT images provide a high level of accuracy to overcome the inaccuracies described above for tooth segmentation and RSA calculation (Suteerapongpun et al., 2017; Suteerapongpun, Sirabanchongkran, Wattanachai, Sriwilas, & Jotikasthira, 2018; Tasanapanont et al., 2017). Voxel size is another crucial aspect of CBCT images that must be carefully chosen because it will affect the X-ray imaging quality. For the accuracy of this study, a voxel size of 0.15 mm was chosen (Sang, Hu, Lu, Wu, Li, & Tang, 2016).

The subjects in this study were adult patients with Class I skeletal relationships, aged between 15 and 30 years old (Table 1), and with no dental root anomalies. All permanent mandibular teeth are supposed to have completed roots by the time a person is 15 years old, except for the third molars (Priya et al., 2015; Studen-Pavlovich & Vieira, 2019). An epidemiological study among individuals between the ages of 31 and 44 revealed a high prevalence of periodontal diseases (Mamasoliyevna, 2023). Therefore, the age range for the subject recruitment in this study was 15 to 30 years old. Furthermore, to avoid dental root anomalies, subjects with craniofacial anomalies (Hypoparathyroidism, Down syndrome, Turner syndromes, etc.), head and neck irradiation or chemotherapy of childhood malignancies during tooth development, previous orthodontic treatment, dental trauma, severe periodontitis, embedded tooth, and periapical lesion on radiograph were excluded.

Root morphology is one of the factors that affect RSA measurement. Concerning the influence of variation in root morphology among individuals, the root morphology should be the same in each tooth type, from the permanent mandibular central incisor to the permanent mandibular second premolar, except for the permanent mandibular first molar and second molar. The permanent mandibular first molar in the open bite group had three 3-rooted and twenty-nine 2-rooted, but five 3-rooted and twenty-seven 2-rooted in the normal overbite group, respectively. According to Gu et al. (2016), the root variation of the permanent mandibular first molar was variable, they found two root types: 3-rooted and 2-rooted. The RSAs of these two were not different because of the small size of the extra root in the 3-rooted one. For the permanent mandibular second molar, there were twelve C-shaped roots and twenty 2-rooted roots in both groups. Gu et al. (2016) also show a more than 20% decrease in the mean RSA of C-shaped mandibular second molars in comparison with that of typical 2-rooted molars. Therefore, it can be postulated that the root morphology might not influence the comparison of RSA in both groups of subjects.

Normal occlusal loading is a key factor in maintaining the health of periodontal tissues. It has been suggested that functional occlusion is essential for the normal developmental response of dental roots, alveolar bone, and supporting structures (Hayashi, Hayashi, & Kawata, 2016; Motokawa et al., 2013). It was reported that occlusal hypofunction may cause abnormal root shape, decreased dental root volume, increased pulp cavity volume (Kuharattanachai et al., 2022), atrophic changes in the alveolar bone proper and periodontal ligament, such as periodontal space narrowing, collagen fiber disorientation (Kaneko, Ohashi, Soma, & Yanagishita, 2001), and vascular constriction (Sringkarnboriboon, Matsumoto, & Soma, 2003). So it can affect the point of force application in orthodontic tooth movement due to changes in the location of the center of resistance (Kuharattanachai, Rangsri, Jotikasthira, Khemaleelakul, & Tripuwabhrut, 2022). Long and narrow roots and external root resorption were observed in occlusal hypofunction conditions during tooth movement in rats (Motokawa et al., 2013; Sringkarnboriboon et al., 2003).

Anterior open bite is a malocclusion in which the anterior teeth have no incisal contact while the upper and lower posterior teeth are in contact (Mizrahi, 1978). Uehara, Maeda, Tomonari, and Miyawaki (2013) compared the root length of individuals with an anterior open bite to those with an anterior normal overbite group. They reported that the anterior open bite tends to develop short dental roots from the incisors to the premolars in the maxillary and mandibular teeth. In addition, they described that the occlusal hypofunction and atrophic changes in the periodontal ligament could influence root length. However, they stated the limitations of panoramic radiographs and suggested further research using CBCT. On CBCT images, Arriola-Guillen Arriola-Guillén, Valera-Montoya, Rodríguez-Cárdenas, Ruíz-Mora, Castillo, and Janson (2020) discovered that there was no significant difference in the root length of maxillary incisors between subjects with and without an anterior open bite group; however, there were significant differences in the root length of mandibular lateral incisors, indicating that individuals with an anterior open bite have longer root lengths than the normal overbite groups. Furthermore, it is important to note that length and area measurements are distinct. A narrower and longer root may contain a smaller area, while a wider and shorter root may contain a larger area. Consequently, area and length measurements must be independently and carefully evaluated. However, these results of this identify only the root length and do not evaluate the RSA.

Suteerapongpun et al. (2017) compared the RSA of permanent maxillary teeth in anterior open bite and anterior normal overbite groups using CBCT images. They reported that the RSA of the permanent maxillary central and lateral incisors were smaller in the open bite group. However, no research has been conducted on the RSA of permanent mandibular teeth in individuals with an anterior open bite. The findings of the current study indicate that the RSA from the permanent mandibular central incisor to the permanent mandibular second premolar in the anterior open bite group was substantially lower than those for the anterior normal overbite group. The results might be explained by the effect of occlusal hypofunction, which is characterized by loss of occlusal contact and weak occlusal force. In addition to occlusal hypofunction, low tongue posture (Artese, Drummond, Nascimento, & Artese, 2011; Selvi, Shanmugham, & Kannan, 2019) may account for the lower RSA in the anterior open bite group. Teeth and alveolar bone are subjected to opposing forces and pressure resulting from muscle function. The intrinsic forces of the lips and tongue at rest provide the balance necessary to position the teeth. The continuous light forces of the tongue during oral function are considered more significant than the intermittent forces (Chakraborty, Chandra, Tandon, Azam, & Rastogi, 2020). The pressure exerted on the lingual surface of the lower anterior teeth, as demonstrated by their proclination (Table 2), may be attributable to low tongue rest posture. Previous research has shown that root resorption occurs when tongue pressure on a tooth exceeds the physiologic limit (Harris & Butler, 1992; Shetty, Ameena, Y, & Madhur, 2021). This situation may occur during or after root formation.

Following previous research, anterior open bite malocclusion might play a significant role in the development of tooth morphology and periodontal structures. This condition when identified at an early age; interceptive orthodontic treatment can prevent the consequences of occlusal hypofunction and is useful for orthodontic treatment. Furthermore, orthodontic force must be carefully applied to correct the anterior open bite to prevent excessive root resorption during treatment.

## Conclusion and Suggestions

In summary, subjects with anterior open bite malocclusion exhibited lower RSA in the permanent mandibular central incisor, lateral incisor, canine, and first and second premolar. However, there were no statistically significant differences between the groups of permanent mandibular molars.

## Acknowledgements

This work was supported by the Research Fund for Postgraduate Students of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand, and the Royal College of Dental Surgeons of Thailand. The authors would like to express their appreciation to the Department of Radiology, Faculty of Medicine, Siriraj Hospital, Mahidol University, for their advice and assistance with simulation software during this study. Additionally, we would like to express our heartfelt gratitude to Dr. Thanapat Sastraruji of Chiang Mai University's Faculty of Dentistry for his statistical consultation. We also wish to thank Mr. Roy I. Morien of the Naresuan University Graduate School for his editing of the grammar, syntax and general English expression in this manuscript.

## References

Arriola-Guillén, L. E., Valera-Montoya, I. S., Rodríguez-Cárdenas, Y. A., Ruíz-Mora, G. A., Castillo, A. A.-D., & Janson, G. (2020). Incisor root length in individuals with and without anterior open bite: a comparative CBCT study. *Dental Press Journal of Orthodontics, 25*, 23e21-23e27. https://doi.org/10.1590/2177-6709.25.4.23.e1-7.onl

Artese, A., Drummond, S., Nascimento, J. M. d., & Artese, F. (2011). Criteria for diagnosing and treating anterior open bite with stability. *Dental Press Journal of Orthodontics, 16*, 136-161. https://doi.org/10.1590/S2176-94512011000300016

Chakraborty, P., Chandra, P., Tandon, R., Azam, A., & Rastogi, R. (2020). Evaluation of Tongue Force on Mandibular Incisor in Various Malocclusions. *Journal of Oral & Dental Health, 4*, 7-11. http://doi.org/10.33140/jodh.04.02.02

Gu, Y., Tang, Y., Zhu, Q., & Feng, X. (2016). Measurement of root surface area of permanent teeth with root variations in a Chinese population—A micro-CT analysis. *Archives of Oral Biology, 63*, 75-81. https://doi.org/10.1016/j.archoralbio.2015.12.001

Harris, E. F., & Butler, M. L. (1992). Patterns of incisor root resorption before and after orthodontic correction in cases with anterior open bites. *American Journal of Orthodontics and Dentofacial Orthopedics*, *101*, 112-119. https://doi.org/10.1016/0889-5406(92)70002-R

Hayashi, A., Hayashi, H., & Kawata, T. (2016). Prevention of root resorption in hypofunctional teeth by occlusal function recovery. *The Angle Orthodontist*, *86*, 214-220. https://doi.org/10.2319/012215-47.1

Hujoel, P. P. (1994). A meta-analysis of normal ranges for root surface areas of the permanent dentition. *Journal of clinical periodontology*, *21*, 225-229. https://doi.org/10.1111/j.1600-051X.1994.tb00310.x

Kaneko, S., Ohashi, K., Soma, K., & Yanagishita, M. (2001). Occlusal hypofunction causes changes of proteoglycan content in the rat periodontal ligament. *Journal of periodontal research*, *36*, 9-17. https://doi.org/10.1034/j.1600-0765.2001.00607.x

Kuharattanachai, K., Jotikasthira, D., Sirabanchongkran, S., Srisuwan, T., Rangsri, W., & Tripuwabhrut, K. (2022). Three-dimensional volumetric evaluation of dental pulp cavity/tooth ratio in anterior open bite malocclusion using cone beam computed tomography. *Clinical Oral Investigations*, *26*, 1997-2004. http://doi.org/10.1007/s00784-021-04179-x

Kuharattanachai, K., Rangsri, W., Jotikasthira, D., Khemaleelakul, W., & Tripuwabhrut, K. (2022). Does pulp cavity affect the center of resistance in three-dimensional tooth model? A finite element method study. *Clinical Oral Investigations*, *26*, 6177-6186. http://doi.org/10.1007/s00784-022-04567-x

Lin, L.-H., Huang, G.-W., & Chen, C.-S. (2013). Etiology and Treatment Modalities of Anterior Open Bite Malocclusion. *Journal of Experimental & Clinical Medicine*, *5*, 1-4. https://doi.org/10.1016/j.jecm.2013.01.004

Mamasoliyevna, D. S. (2023). Modern aspects of etiology and pathogenesis periodontal diseases. *International Scientific Research Journal*, *4*, 141-151. https://doi.org/10.17605/OSF.IO/DXW8K

Mizrahi, E. (1978). A Review of Anterior Open Bite. *British Journal of Orthodontics*, *5*, 21-27. https://doi.org/10.1179/bjo.5.1.21

Motokawa, M., Terao, A., Karadeniz, E. I., Kaku, M., Kawata, T., Matsuda, Y., . . . Tanne, K. (2013). Effects of long-term occlusal hypofunction and its recovery on the morphogenesis of molar roots and the periodontium in rats. *The Angle Orthodontist*, *83*, 597-604. https://doi.org/10.2319/081812-661.1

Mowry, J. K., Ching, M. G., Orjansen, M. D., Cobb, C. M., Friesen, L. R., MacNeill, S. R., & Rapley, W. (2002). Root Surface Area of the Mandibular Cuspid and Bicuspids. *Journal of Periodontology*, *73*, 1095-1100. https://doi.org/10.1902/jop.2002.73.10.1095

Ng, C. S. T., Wong, W. K. R., & Hagg, U. (2008). Orthodontic treatment of anterior open bite. *International Journal of Paediatric Dentistry*, *18*, 78-83. https://doi.org/10.1111/j.1365-263X.2007.00877.x

Pan, J.-H., Chen, S.-K., Lin, C.-H., Leu, L.-C., Chen, C.-M., & Jeng, J.-Y. (2004). Estimation of single-root surface area from true thickness data and from thickness derived from digital dental radiography. *Dentomaxillofacial Radiology*, *33*, 312-317. https://doi.org/10.1259/dmfr/19746488

Priya, S. P., Higuchi, A., Fanas, S. A., Ling, M. P., Neela, V. K., Sunil, P. M., . . . Kumar, S. (2015). Odontogenic epithelial stem cells: Hidden sources. *Laboratory Investigation, 95*, 1344-1352. https://doi.org/10.1038/labinvest.2015.108

Sang, Y.-H., Hu, H.-C., Lu, S.-H., Wu, Y.-W., Li, W.-R., & Tang, Z.-H. (2016). Accuracy Assessment of Three-dimensional Surface Reconstructions of In vivo Teeth from Cone-beam Computed Tomography. *Chinese Medical Journal, 129*, 1464-1470. http://doi.org/10.4103/0366-6999.183430

Selvi, A. K., Shanmugham, K. G., & Kannan, M. S. (2019). A Review on Role of Tongue in Malocclusion. *Indian Journal of Public Health Research & Development, 10*, 1067-1074. https://doi.org/10.37506/v10%2Fi12%2F2019%2Fijphrd%2F192272

Shetty, S. K., Ameena, B., Y, M. K., & Madhur, V. K. (2021). Root Resorption with Tads. *Scholars Journal of Dental Sciences, 7*, 247-251. https://doi.org/10.36347/sjds.2021.v08i07.012

Sringkarnboriboon, S., Matsumoto, Y., & Soma, K. (2003). Root Resorption Related to Hypofunctional Periodontium in Experimental Tooth Movement. *Journal of Dental Research, 82*, 486-490. https://doi.org/10.1177/154405910308200616

Studen-Pavlovich, D., & Vieira, A. M. (2019). The Dynamics of Change. In A. J. Nowak (Ed.), *Pediatric Dentistry: Infancy through Adolescence* (6th ed., pp. 555-561). https://doi.org/10.1016/B978-0-323-60826-8.00037-7

Suteerapongpun, P., Sirabanchongkran, S., Wattanachai, T., Sriwilas, P., & Jotikasthira, D. (2017). Root surface areas of maxillary permanent teeth in anterior normal overbite and anterior open bite assessed using cone-beam computed tomography. *Imaging Science in Dentistry, 47*, 241-246. https://doi.org/10.5624/isd.2017.47.4.241

Suteerapongpun, P., Sirabanchongkran, S., Wattanachai, T., Sriwilas, P., & Jotikasthira, D. (2018). Root Surface Areas of Maxillary Permanent Teeth in a Group of Thai Patients Exhibiting Anterior Open Bite Using Cone-Beam Computed Tomography. *Chiang Mai Dental Journal, 39*, 69-76. Retrieved from https://he01.tci-thaijo.org/index.php/cmdj/article/view/195876

Tasanapanont, J., Apisariyakul, J., Tanapan Wattanachaii, T., Sriwilas, P., Midtbø, M., & Jotikasthira, D. (2017). Comparison of 2 root surface area measurement methods: 3-dimensional laser scanning and cone-beam computed tomography. *Imaging Science in Dentistry, 47*, 117-122. https://doi.org/10.5624/isd.2017.47.2.117

Uehara, S., Maeda, A., Tomonari, H., & Miyawaki, S. (2013). Relationships between the root-crown ratio and the loss of occlusal contact and high mandibular plane angle in patients with open bite. *The Angle Orthodontist, 83*, 36-42. https://doi.org/10.2319/042412-341.1

Uribe, F. A., Janakiraman, N., & Nanda, R. (2015). Esthetics and biomechanics in orthodontics. In. R. Nanda (Series Ed.), *Management of Open-Bite Malocclusion* (2nd ed., pp. 147-179). https://doi.org/10.1016/B978-1-4557-5085-6.00009-6

Yun, H.-J., Jeong, J.-S., Pang, N.-S., Kwon, I.-K., & Jung, B.-Y. (2014). Radiographic assessment of clinical root-crown ratios of permanent teeth in a healthy Korean population. *The journal of advanced prosthodontics, 6*, 171-176. https://doi.org/10.4047/jap.2014.6.3.171