Evaluation of Optimal Sites for the Insertion of Orthodontic Mini-implants at Mandibular Symphysis Region Through Cone-beam Computed Tomography

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Abstract

Background: This study evaluates the overall bone thickness (OBT) and cortical bone thickness (CBT) of mandibular symphysis and to determine the optimal sites for the insertion of orthodontic mini-implants.

Methods: Cone-beam computed tomography (CBCT) images of 32 patients (18 males, 14 females), including 16 adults and 16 adolescents were included in this study. The sample was further categorized into three facial types: low angle, average angle, and high angle. OBT and CBT were measured at the mandibular symphysis region. All measurements were performed at six different heights (2 mm, 4 mm, 6 mm, 8 mm, 10 mm, and 12 mm from cementoenamel junction [CEJ]) and at seven different angles (0, 10, 20, 30, 40, 50, 60 degrees to the occlusal plane).

Results: Neither OBT nor CBT was influenced by age or sex, except for that CBT was significantly thicker in adults than in adolescents. OBT and CBT were significantly thicker in low-angle cases than in average- and high-angle cases. Both OBT and CBT were significantly influenced by insertion locations, insertion heights, insertion angles, and their interactions. CBT and OBT gained the greatest value at the location between two lower central incisors, and became greater with the increase of insertion height and insertion angle. Both recommended and optimal insertion sites were mapped.

Conclusions: Mandibular symphysis region was suitable for the placement of orthodontic mini-implants. The optimal insertion site was 6-10 mm apical to CEJ between two lower central incisors with an insertion angle being 0-60 degrees to the occlusal plane.

Background

Orthodontic mini-implants have been gaining wide popularity among orthodontists for the simplification of orthodontic biomechanics.[1] Various anatomic sites are available for the insertion of mini-implants, e.g., inter-radicular sites, palatal sites and infrazygomatic areas.[2–4] Of particular, anterior regions are frequently used for the insertion of mini-implants to intrude incisors.[5] Compared to maxillary anterior region, mini-implants are less frequently used at mandibular anterior region due to limited inter-radicular space, especially among mandibular crowding patients.[3] Yet, mini-implants at mandibular anterior region are clinically useful for lower incisor intrusion, intermaxillary fixation and molar protraction.[6]

Previous studies that focused on inter-radicular sites for mini-implants at mandibular region suggested that mandibular incisor regions were not feasible for the insertion of mini-implants.[3, 7] Fortunately, in contrast to inter-radicular regions, the quality and quantity of alveolar bone labial to mandibular incisor roots (mandibular symphysis region) are adequate to accommodate mini-implants without the risk of root damage. This renders the mandibular symphysis region a promising alternative for the insertion of mini-implants at the mandibular anterior region. However, to date, no study has investigated bone characteristics at the mandibular symphysis region for orthodontic mini-implants. Thus, our study aimed

to measure the bone thickness at mandibular symphysis region through CBCT, and to determine optimal sites for the insertion of mini-implants.

Methods

This study was conducted in accordance with the Declaration of Helsinki, and was approved by the Ethical Committee of West China Hospital of Stomatology, Sichuan University (WCHSIRB-2020-397).

Subjects

In total, 32 systematically healthy patients from West China Hospital of Stomatology, Sichuan University were enrolled and their CBCT images retrieved. The inclusion criteria consisted of patients with fully erupted incisors and no congenital or developmental craniofacial anomalies. The exclusion criteria included (1) missing teeth or dental implant in the anterior mandibular arch; (2) pathological lesions in the lower jaw; (3) blurred or unclear images; (4) medical history related to bone metabolism; (5) previous orthodontic treatment. The sample was further grouped by sex (18 males and 14 females), age (16 adolescents [ages 18–29] and 16 adults [ages 11–16]), and facial type (10 low-angle [MP-FH ≤ 22°], 11 average-angle [22°-29°] and 11 high-angle [≥ 29°]). Informed consent was obtained from patients or their parents for those under 18.

CBCT examinations

CBCT examinations were performed with a three-dimensional volume scanner (MCT-1, J Morita Mfg Corp, Kyoto,Kyoto-fu, Japan). Settings of the scanner were as follows: 85 kV, 5.0 mA; exposure time, 17.5 seconds; and voxel size, 0.2 mm.

Measurements

As displayed in Fig. 1A, seven anatomical locations were measured, i.e., 42, 42 − 41 (between right lateral incisor and central incisor), 41, 41 − 31, 31, 31–32 and 32 (corresponding to D, C, B, A, B’, C’, D’ respectively). At each location, measurements were performed at different heights (2 mm, 4 mm, 6 mm, 8 mm, 10 mm, and 12 mm from CEJ) and different angles (0, 10, 20, 30, 40, 50, 60 degrees to the occlusal plane) (Fig. 1B).

Both overall bone thickness (OBT) and cortical bone thickness (CBT) were examined. OBT was defined as the distance between the labial and lingual edge of the bone or between the labial edge and the lamina dura when dental root was met (Fig. 1B). CBT was interpreted as the distance between the external and internal aspect of the labial cortex (Fig. 1B). The measurements were conducted by using INFINITT PACS (INFINITT Healthcare Co., Ltd, Seoul, Korea).

After two weeks’ interval, twenty percent of the sample were randomly selected for repeated measurement by the same investigator to test the intra-observer reliability.

Statistical analyses

The intraclass correlation coefficient (ICC) test and paired t test were used to analyze the intra-observer reliability. The comparison of left and right sides was performed by using paired-t test.

Analysis of variance (ANOVA) was applied to investigate the influence of the following variables on OBT and CBT, including insertion location, facial type, sex, age, insertion height and insertion angle. Further comparisons among different insertion locations or among different facial types were performed by Tukey post-hoc test. Two-way ANOVA was used to compare OBT and CBT among different insertion heights and insertion angles.

All data were analyzed by SPSS 25.0 and GraphPad Prism 8.3.0, and a p value less than 0.05 was considered as statistical significance.

Results

Intra-observer reliability

Paired-t test revealed that the data were similar between the repeated measurements ($p > 0.05$). Moreover, the ICC test showed that the intra-observer reliability was good ($r = 0.92$).

Differences between left and right sides

As displayed in Fig. 1A, a total of seven locations were examined. We compared both OBT and CBT between left and right sides, and found no significant difference between the two sides ($p > 0.05$ for both OBT and CBT). Thus, we combined the data of the two sides and a total of four locations (location A, B, C, and D) were examined for further analysis (Fig. 1C).

Comparisons of OBT and CBT among different facial types

As displayed in Fig. 2, OBT was significantly thicker in the low-angle cases than in average- and high-angle cases at the insertion height of 12 mm at location A ($p < 0.05$). Moreover, similar results were found for CBT at location A and B (both $p < 0.05$) (Fig. 3).

The influences of sex and age on measurements

As shown in Table 1, for OBT, no significant difference was found between sexes or between the two age groups (both $p > 0.05$). CBT was significantly higher among adults than among adolescents ($p = 0.001$), while did not differ between sexes ($p > 0.05$).

Table 1
Variance analysis of influence of gender and age on cortical bone thickness and overall bone thickness

	Gender		P	Age		P
	Males	Females		Adolescents	Adults	
	Mean(mm)±SD	Mean(mm)±SD		Mean(mm)± SD	Mean(mm)±SD	
CBT	1.35 ± 1.06	1.33 ± 0.90	0.271	1.31 ± 0.89	1.38 ± 1.09	0.001*
OBT	7.65 ± 6.93	7.57 ± 6.28	0.393	7.56 ± 6.76	7.67 ± 6.55	0.272

Comparisons of OBT and CBT at different insertion locations

For OBT, Tukey's post-hoc test found that it was significantly different among the four insertion locations ($p < 0.001$) (Fig. 4a). OBT was the greatest at location A, with the order of thickness being A > C > B > D.

Similar results were found for CBT, except for no difference between location A and location C. The order of thickness was A = C > B > D ($p < 0.001$, Fig. 4b).

Moreover, three-way ANOVA test found that both OBT and CBT were influenced by insertion location ($p<0.001$), insertion height ($p<0.001$), insertion angle ($p<0.001$) and their interactions ($p<0.001$). Specifically, as depicted in Fig. 5, OBT was similar among the four insertion locations at the insertion height of 12 mm, while significantly different among them at insertion heights less than 12 mm ($p < 0.001$). Moreover, except for the insertion height of 2 mm, OBT increased with an increase in insertion angle for all insertion locations. Similar results were found for CBT (Fig. 6).

Comparisons of OBT and CBT among different insertion heights and insertion angles

Two-way ANOVA test revealed that, at each insertion location, both CBT and OBT were significantly influenced by different insertion heights, insertion angles and their interactions (all $p < 0.001$). As displayed in Fig. 7A, OBT increased with an increase in insertion height and insertion angle (except for the height of 2 mm). Similar results were found for CBT (Fig. 7B).

Recommended and optimal insertion sites

As shown in Fig. 7, recommended insertion sites were identified as the areas where OBT was greater than 5 mm and CBT was 1–2 mm. Then, both recommended and optimal insertion sites were mapped from both the frontal and sagittal views in Fig. 8.

Discussion

Anterior orthodontic mini-implants have been well validated for the effective correction of deep bite.[5] However, due to limited inter-radicular space in mandibular anterior region, especially among patients with anterior crowding, the clinical application of mini-implants for the intrusion of mandibular incisors was impeded.[3] Fortunately, it is suggested that extra-alveolar mini-implants that are inserted outside dental roots may expand the clinical applications of mini-implants.[8] Mandibular symphysis is a complex articulation formed by the fusion of left and right halves of mandible.[9] As fusion progresses, mandibular symphysis grows anteriorly and laterally, resulting in an adequate bony projection anterior to incisor roots.[10] This renders mandibular symphysis an excellent candidate for extra-alveolar orthodontic mini-implants placement that could be used for the intrusion of mandibular anterior teeth.

Our recent study (not yet published) found that mandible is more susceptible to asymmetry as compared to cranial bone and maxillae. Thus, we tested whether bone thickness was similar between the left and the right sides. Our results revealed that both OBT and CBT did not differ between two sides. This suggests that the insertion techniques are similar for left and right sides, yet practitioners' laterality should be considered.

It has been well documented that the thickness of alveolar bone was significantly influenced by different facial types[11, 12]. Consistently, we found that both OBT and CBT were significantly thicker in the low-angle cases than in average- and high-angle cases. This finding is in line with Hoang et al.[13] but disagrees with Sadek et al.[12], which could be attributed to different insertion heights were measured. Specifically, Hoang et al. measured the OBT at the apical level while Sadek et al. measured CBT at the height of 4 mm and 7 mm that were not apical enough. Thus, we suggest that OBT and CBT differed among different facial types only at the apical level.

Sex and age factors play important roles in the development of bone thickness and a previous study revealed that bone thickness was influenced by both sex and age factors.[4] However, we found that both OBT and CBT were similar between males and females, which could be attributed to different regions that were investigated. Interestingly, although OBT was similar between adults and adolescents, CBT was significantly greater among adults than adolescents, which is consistent with the study by Cassetta et al.[14] These findings suggest that overall bone thickness in the mandibular symphysis region may not while cortex may grow among adolescents.

Our results revealed that both OBT and CBT were thickest at location A while thinnest at location D. As is mentioned above, mandibular symphysis is formed by the fusion of two halves of a mandible and grows laterally as fusion progresses.[10] This median-to-lateral growth pattern explains why OBT and CBT were thickest at location A while thinnest at location D. Interestingly, we found that the OBT was different among the four locations (A > C > B > D) below 10 mm while similar beyond 12 mm, which could be attributed to the influence of dental roots. Specifically, location A and C were inter-dental areas while dental roots were in location B and D, rendering OBT greater at location A and C than at location B and D. In contrast, dental roots were not in the way of mini-implant insertion beyond 12 mm for all the four sites,

thus OBT was similar among the four locations beyond 12 mm. Likewise, similar results were found for CBT. CBT was thinner at root areas (B and D) than at inter-dental areas (A and C). This could be attributed to the fact that alveolar bone was expanded and cortex thinned while teeth erupt, resulting in a thinner or even no cortex around dental roots, which is supported by the phenomenon that alveolar bone defects labial to dental roots were highly prevalent among general population.[15, 16]

In clinical practice, in case of inadequate bone quality and/or quantity, it is prudent to place orthodontic mini-implants more apically and with certain angulations.[17, 18] For example, it is advised to place a mini-implant with an angle of 60–70 degrees to the occlusal plane at the infrazygomatic region to avoid root damage.[19] Due to limited inter-radicular space of the mandibular anterior areas, it is very likely that root damage is encountered during the insertion of mini-implants at this area.[20] Thus, to avoid potential root damage at this area, inserting mini-implants more apically with angulations is recommended. This could be explained by the following two factors. Firstly, dental roots become smaller and inter-radicular space is larger at a more apical level. Secondly, alveolar bone buccal to dental roots becomes thicker with larger insertion angulation. This is supported by our results that both OBT and CBT increased with an increase in insertion height and insertion angle. Thus, we suggest that orthodontic mini-implants could be placed apically with certain angulation at the mandibular anterior area, in order to avoid root damage.

The stability of orthodontic mini-implants is influenced by several factors[21–23]. Of particular, insertion depth and cortical thickness are of vital importance[24, 25]. A great body of evidence reveals that mini-implants are stable with adequate insertion depth and appropriate cortical thickness[26, 27]. It is well-documented that mini-implants are stable if the insertion depth is greater than 5 mm [28]. Interestingly, theoretically speaking, mini-implants could be more stable with greater cortical thickness. However, cortical fracture may happen during the insertion of mini-implant if cortical thickness is greater than 2 mm, rendering a cortical thickness of 1–2 mm to be appropriate for the insertion of mini-implants[29]. Thus, we mapped the yellow areas with the following requirements: OBT was greater than 5 mm and CBT was 1–2 mm (Fig. 8A). In the yellow area, there is a trade-off relationship between insertion height and insertion angle. Specifically, insertion angle should be larger if the insertion height is lower, e.g., insertion angulation was 45–60 degrees at the height of 4–6 mm while 0–60 degrees at the height of 12 mm. However, soft tissue inflammation is very likely if the insertion is too apical. On the other hand, mini-implant slippage is more likely if the insertion angle is too large. Thus, clinicians should choose not-too-apical insertion site in the yellow area where soft tissue inflammation and slippage of mini-implants are less likely to happen.

As mentioned above, the two halves of mandible that fuse at the median plane form a bony projection, rendering the location A the best insertion site at the mandibular symphysis region. As depicted in Fig. 8A and B, we suggest that the optimal insertion site is 6–10 mm apical to CEJ between the two central incisors with an insertion angulation of 0–60 degrees.

Conclusion

1. Mandibular symphysis is suitable for the insertion of orthodontic mini-implants, with the best insertion location being between two central incisors.
2. A mapping of recommended and optimal insertion sites with recommended insertion heights and insertion angles is suggested.
3. The optimal insertion site is 6–10 mm apical to CEJ between two central incisors with an insertion angle of 0°-60°.

Abbreviations

CBCT: Cone-beam computed tomography

OBT: Overall bone thickness

CBT: Cortical bone thickness

MP-FH: Frankfort plane to mandibular plane angle

CEJ: Cementoenamel junction

ANOVA: Analysis of variance

ICC: Intraclass correlation coefficient

Declarations

Ethics approval and consent to participate

This study was approved by the Ethical Committee of West China Hospital of Stomatology, Sichuan University (NO. WCHSIRB-2020-397).

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SZ was a major contributor to the study conception, design, and the first draft of the manuscript. XW and LL completed sample selection and data collection. LW performed data analysis. ZW and XY conducted result visualization. HLgave guidance throughout the course of the study. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Schematic diagram of measuring method. A. Seven insertion locations, A: the section bisecting the distance between two lower central incisors; B: labial to the middle of right central incisor; C: the section bisecting the distance between the right central and lateral incisors; D: labial to the middle of right lateral incisor; B’, C’, D’ represent the contralateral sites of B, C, D respectively. B. Measurements of overall bone thickness (OBT) and cortical bone thickness (CBT) at different insertion heights and angles. C. Four insertion locations after left- and right-side data were combined.

Figure 2

Comparisons of OBT among different facial types at each location. *, $p< 0.05$.

Figure 3

Comparisons of CBT among different facial types at each location. *, $p< 0.05$.

Figure 4

Comparisons of OBT and CBT among investigated locations. (a). Comparison of OBT among four insertion locations. *, $p< 0.05$. (b) Comparison of CBT among four insertion locations. ns, $p>0.05$.

Figure 5

Comparison of the overall bone thickness (OBT) among four insertion locations at each insertion height. *, $p < 0.05$, statistical significance among four sites.

Figure 6

Comparison of the cortical bone thickness (CBT) among four insertion locations at each insertion height. *, $p < 0.05$, statistical significance among four sites.

Figure 7

Comparison of OBT and CBT at different insertion heights and angles. A, Overall bone thickness (OBT). The horizontal dotted lines are drawn at thickness of 5 mm. The colored regions indicated the recommended height levels and insertion angles for mini-implants placement. B, Cortical bone thickness (CBT). Thickness of 1 mm and 2 mm are marked with horizontal dotted lines.

Figure 8

Recommended sites with appropriate insertion angles for mini-implants at the mandibular symphysis region. A, Frontal view. The yellow areas are feasible for mini-implants placement where OBT is greater than 5 mm and CBT is 1-2 mm. Different insertion angles are recommended for different subregions. The recommended insertion angle is 45-60 degrees for the yellow areas occlusal to the green line, 20-60 degrees for the yellow areas between the green and black line, and 0-60 degrees for the yellow areas apical to the black line. The oval green area is optimal for mini-implants placement, where OBT and CBT were the thickest with insertion height less than 10 mm for the prevention of soft tissue irritation. B, Lateral view of the optimal site and virtually placed mini-implants in the optional range of insertion angles.