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Effects of size and insertion angle of orthodontic mini-implants on skeletal anchorage

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Introduction: The primary aim of this in vitro study was to compare the insertion torque (IT) and anchorage force (AF) values of 4 different sizes of orthodontic mini-implants with 2 different angles. The second aim was to evaluate the relationship between IT and AF values under different diameter, length, and insertion angle variables. **Methods:** A total of 160 mini-implants, including 20 implants in each group, with 4 different sizes (1.6 × 8 mm, 1.6 × 10 mm, 2.0 × 8 mm, and 2.0 × 10 mm) at 2 different angles (70° and 90°), were inserted into bovine iliac bone segments. The IT and AF values leading to 1.5 mm deflection were compared. The correlations between IT and AF values under different variables were also analyzed. **Results:** The mini-implants with greater diameter and length showed greater IT and AF values (P <0.05). The IT and AF values of mini-implants inserted at 70° angle were significantly greater than those of mini-implants inserted at 90° angle (P <0.001). Significant correlations were found between IT and AF values in all variables. **Conclusions:** The diameter, length, and insertion angle of orthodontic mini-implants have significant effects on IT and AF values. Insertion angle and diameter of mini-implants are more effective than implant length on skeletal anchorage. Significant correlations are present between IT and AF values of mini-implants regardless of their diameters, lengths, and insertion angles. (Am J Orthod Dentofacial Orthop 2019;156:220-8)

Skeletal anchorage provided by orthodontic mini-implants is of great benefit owing to its predictability, minimal invasiveness, and low cost.[1,2] Considering the available insertion site, a number of different sizes of mini-implants are available. Clinically, the advantages of larger mini-implants are their ability to distribute the applied force over greater areas of bone with less bone stress. The advantages of longer mini-implants are that increased primary stability can be achieved.[3] Owing to the close relationship of neighboring teeth, the risk of root destruction should be considered in case of limited dimensions of alveolar bone.[4,5] Because of the availability of more appropriate bone for implant placement near the apical region of neighboring teeth, oblique insertion of orthodontic mini-implants were introduced to avoid root damage.[6-8] Another advantage of oblique insertion is that it increases the primary stability of the mini-implants.[9,10] In one study,[9] it was reported that highest insertion torque (IT) values were measured at angles between 60° and 70°. In another study,[10] it was reported that when miniscrews were loaded by pullout force, perpendicular inserted miniscrews (insertion angle of 90°) had the highest primary stability. On the other hand, when miniscrews were loaded by shear force, those with insertion angle of 45° had the highest primary stability values. Furthermore, some studies showed that insertion angle had no significant effect on miniscrew survival or stability.[11-13]

It is suggested that the primary stability of orthodontic mini-implants determines their reliabilities, as well as dental implants.[14-16] Thus, evaluation of the effectiveness of the parameters that have impact on the primary stability of the orthodontic mini-implants is crucial for successful anchorage. The success rates of

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orthodontic mini-implants were reported to be from 50% to 93%.[12,17-19] The feasible methods quantitatively assessing the primary stability of orthodontic mini-implants are insertion and removal torque values.[20] As shown in previous studies, the diameter, length, and insertion angle of orthodontic mini-implants have significant impacts on the primary stability and anchorage force (AF) values.[3,9,14,20,21] Thus, detailed evaluations of the parameters that have impact on the AF of the orthodontic mini-implants are crucial for clinical success. However, in most studies, diameter- or length-matched mini-implants were not used. Therefore, the actual and separate impacts of insertion angle, diameter, and length of mini-implants on primary stability and AF are lacking in the literature. Moreover, the relationship between IT and AF resistance of orthodontic mini-implants under different variables also remain limited.

The hypothesis of the present in vitro study was that the oblique insertion of 70° angle of orthodontic mini-implants has significant effect on primary stability and AF values with all assessed diameter and length variables. Considering the background described above, this study aimed to assess the impact of diameter, length, and insertion angle variables of orthodontic mini-implants on primary stability and skeletal anchorage. Thus, IT and AF values of 4 different sizes (1.6 × 8 mm, 1.6 × 10 mm, 2.0 × 8 mm, and 2.0 × 10 mm) of orthodontic mini-implants at 2 different angles (90° and 70°) were compared. And the second aim was to evaluate the correlation between IT and AF values under different diameter, length, and insertion angle variables.

MATERIAL AND METHODS

This in vitro study was performed in the research laboratory of a faculty hospital. The study protocol was approved by the Ethics Committee of Çukurova University Faculty of Medicine (040414/25). All the orthodontic mini-implants were inserted in fresh segments of bovine iliac bone. The cortical bone thickness of bovine iliac bone ranges from 1 to 2 mm, which is similar to the cortical bone thickness of human maxilla and mandible. All of the bone segments were supplied from a certified company that uses animals without any disease. Standardized cube bone models with dimensions of 15 × 15 × 15 mm were prepared. The cortical bone thickness of the models was measured with the use of a fine-tip digital caliper. Each measurement was performed twice, and the average of the 2 measurements was recorded. These bone models were embedded in resin (Imicryl, London, U.K.) within a metal template. A total of 160 bone models were prepared for this study.

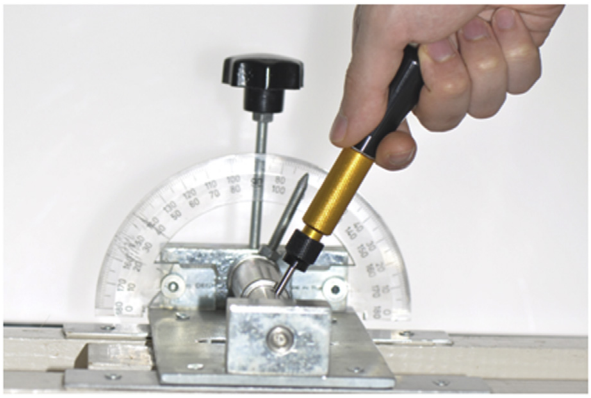

Fig 1. Insertion of an orthodontic mini-implant with the use of a screwdriver and a custom-made trestlework with goniometer to fix the bone models during insertion as well as to provide the desired insertion angle.

A total of 160 self-drilling mini-implants (Dual Top Screw; Jeil Medical Corp, Seoul, South Korea), including 20 implants in each group, with 4 different sizes (1.6 × 8 mm, 1.6 × 10 mm, 2.0 × 8 mm, 2.0 × 10 mm) at 2 different insertion angles (70° and 90°) were used in this study. All of the mini-implants were inserted by the same investigator. A custom-made trestlework with goniometer was fabricated to fix the bone models during implant insertion as well as to provide the desired insertion angle (Fig 1). The implants were manually inserted with the use of a handled screwdriver (Jeil Medical Corp) until the bone-to-collar distance of the implants reached 2 mm with the use of the trestlework. Then final screwing of 1 mm until the definite insertion depth (when bone-to-collar distance reaches 1 mm) was performed with the use of a digital torque-meter screwdriver (Checkline TSD 50). The final bone-to-collar distance of 1 mm was provided to simulate the gingival space in a clinical setting. Maximum IT values were recorded for all groups. One mini-implant was inserted into each bone model.

To mimic orthodontic force, each mini-implant was subjected to tangential force load parallel to the bone surface by with the use of a biomechanic testing machine (Testometric M500 25kN; Rochdale, Lancashire, U.K.). The crosshead speed was set at 0.05 mm/s. The central loading point was adjusted toward the head of mini-implant and deflection value was set as 1.5 mm, which represented movement that would result in clinical mini-implant mobility and potential failure.[14,22] AF values leading to 1.5 mm deflection were recorded. After tangential force application, each mini-implant was manually checked for mobility.

Table I. Comparison of cortical bone thickness among groups ($P = 0.184$)

Group	n	Cortical bone thickness, mean ± SD (range)
1.6 × 8, 70°	20	1.52 ± 0.25 (1.19-1.88)
1.6 × 8, 90°	20	1.44 ± 0.24 (1.19-1.84)
1.6 × 10, 70°	20	1.39 ± 0.21 (1.11-1.87)
1.6 × 10, 90°	20	1.56 ± 0.23 (1.17-1.87)
2.0 × 8, 70°	20	1.46 ± 0.19 (1.19-1.89)
2.0 × 8, 90°	20	1.52 ± 0.21 (1.22-1.82)
2.0 × 10, 70°	20	1.47 ± 0.22 (1.19-1.85)
2.0 × 10, 90°	20	1.57 ± 0.22 (1.19-1.84)

Statistical analysis

For statistical analysis, SPSS 17.0 software was used (SPSS, Chicago, Ill). The statistical comparisons of mean values of cortical bone thickness, IT, and AF among groups were performed by means of 1-way analysis of variance. Bonferroni-corrected post hoc tests were used for multiple comparisons. Pearson correlation was used to test the correlations between IT and AF values of the study groups. The level of significance was set at $P < 0.05$.

RESULTS

A total of 160 bone samples were used in this study. The mean cortical bone thickness of the samples was 1.49 ± 0.23 mm (ranging from 1.11 to 1.89 mm). The mean cortical bone thicknesses of the samples were similar among the groups ($P = 0.184$; Table I). The lowest IT and AF values were observed in 1.6 × 8 mini-implants at 90° (10.20 ± 0.70 Ncm and 34.08 ± 3.62 N, respectively) and the highest values were observed in 2.0 × 10 mini-implants at 70° (17.62 ± 0.92 Ncm and 57.33 ± 5.96 N, respectively). In general, diameter and length increments and angle decrements resulted in higher IT and AF values.

When the dimension-matched mini-implants were compared, the implants at 70° showed significantly higher IT and AF values compared with those at 90° (all $P < 0.001$; Tables II and III; Figs 2 and 3). When the angle-matched mini-implants were compared, the implants with 2 mm diameter showed significantly higher IT and AF value compared with those with 1.6 mm diameter regardless of their length (all $P < 0.001$; Tables II and III).

Multiple comparisons of IT and AF values among groups are presented in Tables IV and V, respectively. The IT values of 1.6 × 8 mm mini-implants at 70° were similar to those of 2.0 × 8 mm mini-implants at 90° ($P = 1.000$; Table IV). The IT values of 1.6 × 10 mini-implants at 70° were similar to those of 2.0 × 10 mm mini-implants at 90° ($P = 1.000$; Table IV). Moreover, the AF values of 1.6 × 8 mm mini-implants at 90° were similar to those of 1.6 × 10 mm mini-implants at 90° ($P = 0.364$; Table V). The AF values of 1.6 × 8 mm mini-implants at 70° were similar to those of 1.6 × 10 mm mini-implants at 90° ($P = 0.813$; Table V). The AF values of 1.6 × 8 mm mini-implants at 70° were similar to those of 2.0 × 8 mm mini-implants at 90° ($P = 1.000$; Table V). The AF values of 1.6 × 10 mm mini-implants at 70° were similar to those of 2.0 × 8 mm mini-implants at 90° and 2.0 × 10 mm mini-implants at 90° (both $P = 1.000$; Table V). The AF values of 2.0 × 8 mm mini-implants at 90° were also similar to those of 2.0 × 10 mm mini-implants at 90° ($P = 0.068$; Table V). The AF values of 2.0 × 8 mm mini-implants at 70° were similar to those of 2.0 × 10 mm mini-implants at 90° ($P = 0.052$; Table V).

Detailed analysis of the results revealed that increments in mini-implant diameter of 0.4 mm resulted in 23.22%-29.02% increments of IT values. Increments in length of 2 mm resulted in 8.16%-14.90% increments of IT values. Oblique insertion at 70° resulted in 19.62%-27.45% increments of IT values compared with perpendicular insertion. In terms of skeletal anchorage, increments in diameter of 0.4 mm resulted in 25.61%27.30% increments of AF values. Increments in length of 2 mm resulted in 10.08%-12.05% increments of AF values. Oblique insertion at 70° resulted in 19.51%-21.32% increments of AF values.

Significant correlations were observed between IT and AF values of the mini-implants in all of the groups (Table VI).

DISCUSSION

In this study, IT and AF values of 4 different sizes (including 2 of the same diameter matches and 2 of the same length: 1.6 × 8 mm, 1.6 × 10 mm, 2.0 × 8 mm, and 2.0 × 10 mm) of orthodontic mini-implants at 2 different angles (90° and 70°) were compared. Commonly used orthodontic mini-implants have diameters ranging from 1.4 to 1.8 mm.[18,23] In our routine clinical settings, mini-implants with diameter of 1.4 mm and 1.6 mm are frequently used for interradicular regions, and mini-implants with diameter of 2.0 mm are frequently preferred for zygomatic buttress and palatal regions. Because diameters of 1.4 mm and 1.6 mm are so close to each other, we used mini-implants with diameter of 1.6 mm and 2.0 mm in this study to observe the effects of diameter on IT and AF values more clearly. Another reason for choosing these diameters is to be able to discuss our results with the corresponding literature, as most of the previous studies on

Table II. Comparisons of insertion torque values (Ncm) of the study groups, mean ± SD (median, range)

		Angle		
Group	*n*	*70° (n = 20)*	*90° (n = 20)*	P
1.6 × 8	40	13.00 ± 0.92 (12.7, 11.8-14.4)	10.20 ± 0.70 (10.1, 9.0-11.8)	<0.001
1.6 × 10	40	14.30 ± 0.97 (14.0, 13.2-15.9)	11.72 ± 0.97 (11.9, 9.5-13.0)	<0.001
2.0 × 8	40	16.29 ± 0.95 (16.5, 13.8-17.9)	13.16 ± 0.77 (13.1, 11.5-14.4)	<0.001
2.0 × 10	40	17.62 ± 0.92 (17.4, 16.1-19.4)	14.73 ± 0.96 (14.9, 13.1-15.8)	<0.001
P		<0.001	<0.001	

Table III. Comparisons of anchorage force values (N) for mini-implants when deflection was 1.5 mm, mean ± SD (median, range)

		Angle		
Group	*n*	*70° (n = 20)*	*90° (n = 20)*	P
1.6 × 8	40	40.73 ± 4.41 (41.51, 33.85-45.82)	34.08 ± 3.62 (34.47, 26.45-38.12)	<0.001
1.6 × 10	40	45.64 ± 3.43 (45.73, 40.42-52.98)	37.62 ± 3.23 (37.64, 31.70-43.18)	<0.001
2.0 × 8	40	51.85 ± 5.03 (50.71, 46.47-62.83)	43.04 ± 4.21 (42.78, 34.62-49.47)	<0.001
2.0 × 10	40	57.33 ± 5.96 (56.46, 47.72-66.46)	47.38 ± 5.06 (47.82, 38.36-54.08)	<0.001
P	<0.001	<0.001		

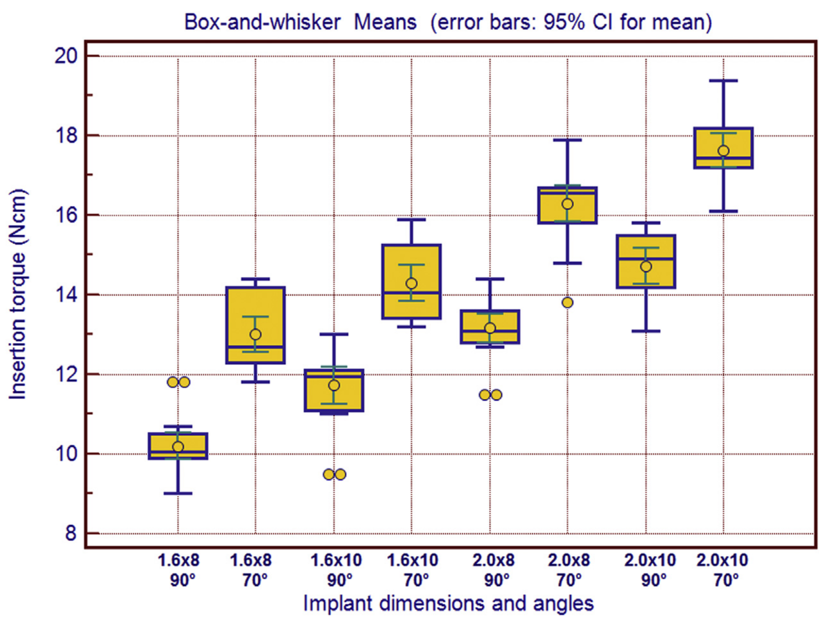

Fig 2. Box-and-whisker diagram showing the insertion torque values (Ncm) of orthodontic mini-implants with different dimensions and insertion angles.

the same topic compared those diameters.[9,14,15,20,22] In one previous study,[9] it was reported that maximum IT values were recorded when orthodontic mini-implants were inserted at angles between 60° and 70°. Similarly, Xu et al[24] concluded that miniscrews with insertion angles of 50°-70° had higher osseointegration. Albogha et al[25] indicated that 60°-70° insertion angles showed highest stability of anchorage with lowest principal strain according to finite element analysis. Because the previous studies[9,24,25] indicate that the highest anchorage values were observed at insertion angles of 50°-70°, in the present study, 90° and 70° were chosen as insertion angles (perpendicular versus oblique) to evaluate effectiveness of oblique insertion

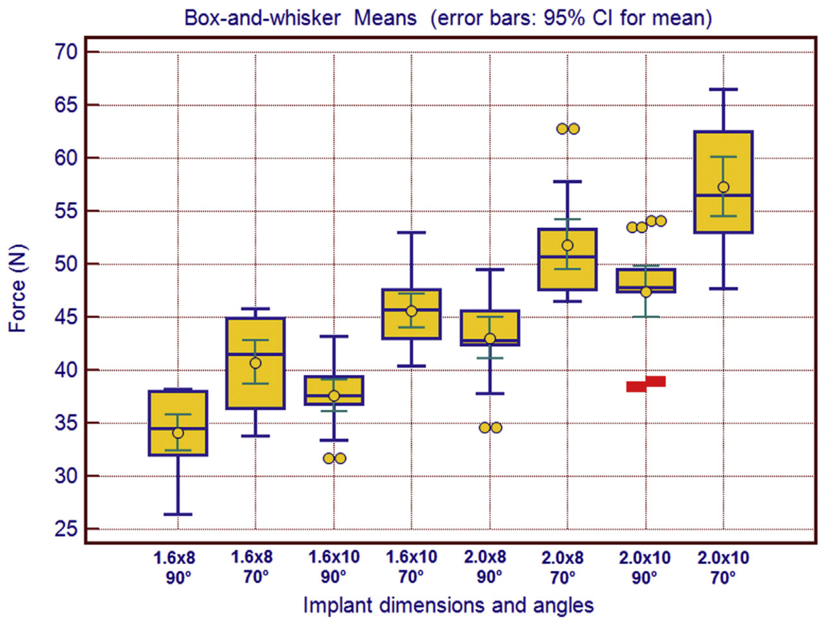

Fig 3. Box-and-whisker diagram showing the anchorage force values (N) of orthodontic mini-implants with different dimensions and insertion angles.

from the standpoint of different diameter and length variables of orthodontic mini-implants.

It is well known from dental implantology literature that primary stability of the implants determines their survival rate and reliability.[14-16] Various methods for determining primary stability of implants have been tested: histologic assessment, radiodensitometric examination, assessment of insertion or removal torque, and percussion testing.[16,17,20,26] Because orthodontic mini-implants are much smaller than dental implants, the feasible methods quantitatively assessing the primary stability are insertion and removal torque values.[20] In a recent clinical study, it was concluded that Periotest value, IT value, and cortical bone thickness could serve as index of initial stability for predicting anchorage success of mini-implants.[17] Therefore, in the present study, we assessed IT values to evaluate the primary stability of the mini-implants.

Our study showed that increments in diameter and length as well as oblique insertion angle resulted in higher IT and AF values. Detailed analysis of our results revealed that diameter and insertion angle are more important than length of orthodontic mini-implants in terms of IT and AF values. Although high IT values might be associated with high primary stability, it is well known that excessive IT is related to increased subsequent bone compression, microdamage, and implant failure.[27,28] Watanabe et al[17] used mini-implants 1.4 × 6 mm in size and reported that failed mini-implants had significantly higher IT values (10.7 ± 1.9 Ncm) than successful ones (8.5 ± 2.1 Ncm). A previous survey revealed that ~10% of orthodontists experienced mini-implant fracture during clinical practice.[29] In a recent study, orthodontic mini-implant failure was stated as 14.2%.[17] It was reported that IT values higher than 10 Ncm cause increased failure rates for mini-implants with a diameter of 1.6 mm.[15] In another study, it was discussed that limitation of IT to a maximum value of 200 Nmm was recommendable because IT values >230 Nmm cause implant fractures.[20] In our study, the IT values ranged from 9.0 to 15.9 Ncm for mini-implants with a diameter of 1.6 mm, and from 11.5 to 19.4 Ncm for mini-implants with a diameter of 2.0 mm. Though we did not observe any screw fracture in the present study, combined effects of the corresponding parameters (increments in diameter and length and oblique insertion angle) that increase the IT values of mini-implants should be considered carefully, especially in regions with thick cortical bone and high bone density.

The cortical bone thickness, implant design, and implant site preparation protocol have strong impacts on the primary stability and clinical performance of mini-implants.[20,22,30] Bovine iliac bone was used as a model in the present study. The cortical bone thickness of bovine iliac bone ranges from 1 to 2 mm (mean 1.49 mm) and is similar to that of the human jawbones, which were reported as 1.62 mm for the maxilla and 2.13 mm for the mandible in a human

Table IV. Multiple comparisons of insertion torque values (Ncm) among study groups

Group 1	Group 2	Mean diff	SE	95% CI	P
1.6 × 8, 90°	1.6 × 8, 70°	−2.80	0.19	−3.48 to −2.12	<0.001
	1.6 × 10, 90°	−1.52	0.21	−2.30 to −0.74	<0.001
	1.6 × 10, 70°	−4.10	0.33	−5.30 to −2.90	<0.001
	2.0 × 8, 90°	−2.96	0.22	−3.72 to −2.18	<0.001
	2.0 × 8, 70°	−6.09	0.31	−7.23 to −4.95	<0.001
	2.0 × 10, 90°	−4.53	0.29	−5.57 to −3.48	<0.001
	2.0 × 10, 70°	−7.42	0.25	−8.32 to −6.52	<0.001
1.6 × 8, 70°	1.6 × 10, 90°	1.28	0.24	0.42 to 2.14	<0.001
	1.6 × 10, 70°	−1.30	0.32	−2.46 to −0.14	0.018
	2.0 × 8, 90°	−0.16	0.23	−1.00 to 0.68	1.000*
	2.0 × 8, 70°	−3.29	0.29	−4.34 to −2.24	<0.001
	2.0 × 10, 90°	−1.73	0.37	−3.09 to −3.37	0.005
	2.0 × 10, 70°	−4.62	0.35	−5.87 to −3.37	<0.001
1.6 × 10, 90°	1.6 × 10, 70°	−2.58	0.31	−3.69 to −1.46	<0.001
	2.0 × 8, 90°	−1.44	0.23	−2.29 to −0.59	<0.001
	2.0 × 8, 70°	−4.57	0.35	−5.83 to −3.31	<0.001
	2.0 × 10, 90°	−3.01	0.32	−4.19 to −1.83	<0.001
	2.0 × 10, 70°	−5.90	0.31	−7.03 to −4.77	<0.001
1.6 × 10, 70°	2.0 × 8, 90°	1.14	0.26	0.19 to 2.09	0.009
	2.0 × 8, 70°	−1.99	0.27	−2.98 to −0.99	<0.001
	2.0 × 10, 90°	−0.43	0.28	−1.44 to 0.58	1.000*
	2.0 × 10, 70°	−3.32	0.30	−4.39 to −2.25	<0.001
2.0 × 8, 90°	2.0 × 8, 70°	−3.13	0.30	−4.21 to −2.05	<0.001
	2.0 × 10, 90°	−1.57	0.28	−2.58 to −0.56	<0.001
	2.0 × 10, 70°	−4.46	0.23	−5.29 to −3.63	<0.001
2.0 × 8, 70°	2.0 × 10, 90°	1.56	0.27	0.57 to 2.54	<0.001
	2.0 × 10, 70°	−1.33	0.31	−2.45 to −0.21	0.010
2.0 × 10, 90°	2.0 × 10, 70°	−2.89	0.27	−3.88 to −1.90	<0.001

*P >0.05 (not statistically significant).

Table V. Multiple comparisons of anchorage force values (N) among study groups

Group 1	Group 2	Mean diff	SE	95% CI	P
1.6 × 8, 90°	1.6 × 8, 70°	−6.65	1.41	−11.13 to −2.17	<0.001
	1.6 × 10, 90°	−3.54	1.41	−8.03 to 0.94	0.364*
	1.6 × 10, 70°	−11.56	1.41	−16.04 to −7.08	<0.001
	2.0 × 8, 90°	−8.96	1.41	−13.44 to −4.48	<0.001
	2.0 × 8, 70°	−17.77	1.41	−22.25 to −13.29	<0.001
	2.0 × 10, 90°	−13.31	1.41	−17.79 to −8.82	<0.001
	2.0 × 10, 70°	−23.25	1.41	−27.74 to −18.77	<0.001
1.6 × 8, 70°	1.6 × 10, 90°	3.11	1.41	−1.38 to 7.59	0.813*
	1.6 × 10, 70°	−4.81	1.41	−9.39 to −0.43	0.018
	2.0 × 8, 90°	−2.31	1.41	−6.79 to 2.17	1.000*
	2.0 × 8, 70°	−11.12	1.41	−15.60 to −6.64	<0.001
	2.0 × 10, 90°	−6.65	1.41	−11.14 to −2.17	<0.001
	2.0 × 10, 70°	−16.60	1.41	−21.08 to −12.12	<0.001
1.6 × 10, 90°	1.6 × 10, 70°	−8.02	1.41	−12.50 to −3.53	<0.001
	2.0 × 8, 90°	−5.42	1.41	−9.89 to −0.93	0.005
	2.0 × 8, 70°	−14.23	1.41	−18.71 to −9.74	<0.001
	2.0 × 10, 90°	−9.76	1.41	−14.25 to −5.28	<0.001
	2.0 × 10, 70°	−19.71	1.41	−24.19 to −15.22	<0.001
1.6 × 10, 70°	2.0 × 8, 90°	2.60	1.41	−1.88 to 7.08	1.000*
	2.0 × 8, 70°	−6.21	1.41	−10.69 to −1.72	0.001
	2.0 × 10, 90°	−1.74	1.41	−6.23 to 2.74	1.000*
	2.0 × 10, 70°	−11.69	1.41	−16.17 to −7.21	<0.001
2.0 × 8, 90°	2.0 × 8, 70°	−8.81	1.41	−13.29 to −4.33	<0.001
	2.0 × 10, 90°	−4.35	1.41	−8.83 to 0.14	0.068*
	2.0 × 10, 70°	−14.29	1.41	−18.78 to −9.81	<0.001
2.0 × 8, 70°	2.0 × 10, 90°	4.46	1.41	−0.02 to 8.95	0.052*
	2.0 × 10, 70°	−5.48	1.41	−9.97 to −0.99	0.004
2.0 × 10, 90°	2.0 × 10, 70°	−9.95	1.41	−14.43 to −5.46	<0.001

*P >0.05 (not statistically significant).

Table VI. Correlations between insertion torque and anchorage force values of the study groups, *r* (*P*)

Group	n	70° (n = 20)	90° (n = 20)
1.6 × 8	40	0.868 (<0.001)	0.864 (<0.001)
1.6 × 10	40	0.611 (0.004)	0.837 (<0.001)
2.0 × 8	40	0.855 (<0.001)	0.836 (<0.001)
2.0 × 10	40	0.757 (<0.001)	0.733 (<0.001)

r, Pearson correlation coefficient.

cadaver study.[14] Thus, this bone model may successfully mimic clinical conditions. Anyway, the recorded IT values were similar to clinically measured values.[30] In the present in vitro study, the mean cortical bone thicknesses of bone samples were similar among the groups ($P = 0.184$). Moreover, the same implant design and standardized site preparation protocol were used, so the differences of IT and AF values may be attributed to the dimensions (diameter and length) and insertion angles of the mini-implants.

The results of the present study revealed that larger-diameter mini-implants provided increased IT and AF values. These results were consistent with previous studies.[3,9,13] The highest IT and AF values were observed when the mini-implants were inserted at a slightly oblique angle (70° insertion angle) in the present study. This result is thought to be due to the longer distance through cortical bone when the mini-implants were inserted in an oblique direction. In a previous study, Wilmes et al[9] analyzed the effects of 7 different insertion angles (from 30° to 90°) of orthodontic mini-implants on IT values and found that the highest IT values were measured at angles from 60° to 70°. Meira et al[31] reported that mini-implants with 45° insertion angles had significantly higher IT compared with those with 90° insertion angles. Araghbidikashani et al[10] reported that increased primary stability values were achieved with oblique insertion (from 90° to 45°) when miniscrews were loaded by shear force, and with 90° insertion when pullout force was applied. Their results were consistent with ours. Although oblique insertion of orthodontic mini-implants has favorable effects in terms of IT and primary stability, it also has some drawbacks: Oblique insertion creates a greater lever arm which may subsequently cause screw failure.[32] Therefore, the mutual effects of diameter, length, and insertion angle of mini-implants should be considered carefully in clinical setting. The pairwise comparison results of the present study revealed the detailed mutual effects of the assessed diameter, length, and angle variables of mini-implants (Tables IV and V). These data may guide clinicians while choosing optimum combination of mini-implant dimension and insertion angle to achieve proper primary stability and clinical performance.

To our knowledge, this in vitro study is the first investigation evaluating the combined effects of 4 different sizes (2 diameter-matched and 2 length-matched sizes) and 2 different insertion angles of orthodontic mini-implants on primary stability and skeletal anchorage. In a previous study,[9] the primary stability of orthodontic mini-implants with 2 different sizes (1.6 × 8 mm and 2.0 × 10 mm) and 7 different angles was evaluated. However, the 2 different sizes had different diameters and lengths, so the authors could not evaluate the effects of diameter and length separately. In another study, Morarend et al[3] evaluated the effects of small-diameter (1.5 × 15 mm) and large-diameter (2.5 × 17 mm) orthodontic mini-screws on skeletal anchorage. However, in that study, because the mini-screws also had different lengths besides diameters, the results could not solely be attributed to the diameter.

The present study revealed significant correlations between IT and AF values of the mini-implants in all groups. The mini-implants with higher IT values showed higher AF values in all the diameter, length, and insertion angle variables. In a human cadaver study, McManus et al[14] reported significant correlation between maximum placement torque and resistance to movement when all screws were considered together. When miniscrews placed in the maxilla were considered separately, the authors found significant relationship between maximum placement torque and resistance to movement. However, the authors reported that this relationship was not observed for mandibular miniscrews. It is understood that the significant correlations between IT and AF values are present in all angle, diameter, and length variables but not in all bone quality variables. It seems that in dense bone regions, mini-implants reach similar AF values regardless of their IT values.

Owing to the in vitro nature of the present study, we could not examine the loading-related biologic changes in the present study. However, because the primary stability and anchorage potential of orthodontic mini-implants are thought to result from mechanical interlock, a waiting period for osseointegration before orthodontic loading is unnecessary.[3,33] Thus, in vitro studies of orthodontic mini-implants may closely mimic their immediate loading response in situ after placement.

The findings of the present study revealed that greater diameter and length, and 70° insertion angle, of orthodontic mini-implants lead to significantly greater primary stability and AF resistance which may be advantageous in regions with reduced bone quality as well as in cases with more AF is needed. In another in vitro study, da Cunha et al[34] observed that mechanical performance of mini-implants differed depending on the bone quality of the insertion site. Those authors concluded that certain geometric parameters may be set considering the bone quality of the designated insertion site.[34] In cases with limited bone space between 2 adjacent teeth, the clinician should use small-diameter mini-implants to minimize the risk of root destruction. In such cases, longer mini-implants or oblique insertion seems to be favorable to achieve higher IT and AF values while minimizing the risk of root perforation.

The results of the present study confirmed our hypothesis and showed that the oblique insertion angle of 70° had a significant effect on primary stability and AF values in all assessed diameter and length variables.

CONCLUSIONS

Depending on the insertion site, the clinician should choose an optimum combination of mini-implant dimensions and insertion angle to achieve proper primary stability and clinical performance. Insertion angle and diameter of mini-implants are more effective than mini-implant length on skeletal anchorage. Significant correlations are present between IT and AF values of mini-implants regardless of their diameters, lengths, and insertion angles.

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