The Effect of Force Application on the Stability of Mini-Screw in Different Insertion Angles (An in-vitro Study)

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Background and Objective: The stability of the mini-screw is an important factor for the success of orthodontic treatment using an absolute anchorage system. This study aims to evaluate the ideal insertion angle of a mini-implant in relation to force direction and to evaluate the maximum amount of force application at a specific angular configuration.

Method: In this experimental study 72 mini-screws were used, 36 of them were used for each shear and tensile force tests, eighteen samples were taken for the bone density D2 (nine for 60° angle, and nine for 90° angle), and 18 others were taken for the bone density D3 (nine for 60° angle, and nine for 90° angle). Guiding stents were fabricated for proper insertion angle, torque and speed were controlled by contra -angled handpiece. Shear and tensile force tests are done with the aid of a Universal Testing Machine.

Results: Mini-implants inserted at 90 angle over D2 density bone had higher stability when performing the tensile force test, while in the shear force test mini-implants placed at 60 angle were more stable when inserted on bony blocks with D3 density, however it was noted that the results were statistically not significant when compared with 60 insertion on blocks with D2 density.

Conclusion: To maintain a stable mini-implant during the orthodontic process, the ideal insertion angle is 90 when the force direction is vertical, tensile force, and its more appropriate to place the mini-implant at 60 angle when the direction of force is in a horizontal direction, shear force.

Key words: Mini-screw, Stability, Insertion Angle, Shear force, Tensile force.

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INTRODUCTION

Orthodontic anchorage can be defined as an apparatus used for the prevention of undesirable tooth movement.[1] Mini implant helps in better anchorage control and reduces side effects encountered with conventional anchorage systems, as they provide absolute anchorage.[2]

Stability is an important factor for the success of mini-implant and it can be divided into primary and secondary stabilities; primary stability depends on the mechanical engagement of mini-implant with the surrounding bone, which eventually may enhance immediate loading, while secondary stability is attained through bone resorption and formation a period after insertion, its affected by bone quality, quantity and design of mini-implant.[3] Mini-implants are usually made of titanium or stainless steel, both materials have satisfactory stability during the orthodontic process,[4] what matters is the diameter of the mini-screw, the large diameter has higher fracture resistance than the small diameter, regardless of the material of mini-screw fabrication, therefor a diameter of 2mm is selected for regions of the high force application.[5] Generally mini implants used in the orthodontic field should be of ideal length, diameter and angulation suiting the insertion site and biomechanics applied to the region, as increasing the diameter and length would increase the stress around the mini-implant, while reducing the angulation from 60° to 30° would reduce the stress.[6]

Orthodontic mini-implant failure hinders the overall treatment plan, therefore their stability and its measurement are the main concern of the clinician.[7] Surface roughness of the mini implant, the density of surrounding bone,[8] drilling method and the material of fabrication of the mini-screw have a noticeable role in its success, it's found that after multiple failures of pre-drilled titanium mini-implant a better choice is either self-drilling stainless steel mini implant or mini plates.[9] Other factors that affect the success rate are; length, the diameter of the screw and the amount of force application.[10] Mini-implant insertion site depends on; the type of movement and biomechanics needed for a particular treatment plan, such as; inter-radicular space, palatal, infrazygomatic, retromolar and buccal shelf regions. The mini-implants should be placed at an area with attached gingiva and high bone density whenever possible.[11] The insertion angle is an important factor to be considered during mini-implant insertion, a 90° angle is preferred for buccal side interradicular space, to prevent sinus perforation, while a 45° angle is satisfactory for infrazygomatic crest insertion.[12] Regarding the amount of force application mini-implants can endure more than 300g, however, less amount is required to make an ideal movement without harming teeth and surrounding structures, it is claimed that a 60° angle would offer satisfactory primary stability that would make immediate loading more successful.[13]

A precise mini implant position can be guaranteed through the use of guide extending over adjacent teeth with the aid of an intra-oral scanner and CBCT image,[14] however in other instants crown of the teeth can be used as an aid for determining the position min implant interdentally by taking interproximal radiographs,[15] since it is thought that the cement-enamel junction of tooth, that can be estimated through floss technique, is 1mm away from bone crest at interdental space.[16]

This study was performed to estimate the stability of mini-screw when its being inserted perpendicular to bone surface or at an angle, to avoid trauma to anatomical structures and increase contact to cortical bone, in different regions of upper and lower jaws and reduce the failure rate of the mini-screw during orthodontic practice to get efficient treatment plan.

Material and method

An experimental study design was applied for the present study and it was conducted in Erbil city which is the capital of Kurdistan regional government - Iraq, the study was conducted during the period between November of 2021 to September of 2022.

1. Materials

Mini implants

In this study 72 mini-implants (Optimus Ortho system from Osteonic company, Korean) hole headed, 9mm in length and 1.6mm in diameter were used, taking in consideration the sample size of previous studies.

Bone specimens

Two different density bone blocks from (Sawbones company, Malmo, Sweden) were used; the first group had D2 (0.49g/cm3) density cancellous bone no. 1522-04, while the second group D3 (0.32 g/cm3) density cancellous bone no. 1522-03, all blocks were laminated with a layer of cortical bone no. 1522-16 (0.64 g/cm3), 2mm in thickness. The blocks were 42mm in height, to resemble a 2mm thick cortical layer of human jaws and a 40mm cancellous layer, 100mm long and 50mm wide. These dimensions were found to be more suitable to be used with Universal Testing Machine.

Stent

Two stents were fabricated similar to implant surgical stents, to guide the mini-implants to be inserted in a pre-selected insertion angle, the first stent had six guiding holes, which led the mini-implants to be inserted at a 90° angle, while the second stent with 6 holes provided a 60° insertion angle. The first three holes at the end of the block were used to perform the shear test and the middle three for performing the tensile force test (Figure 1).

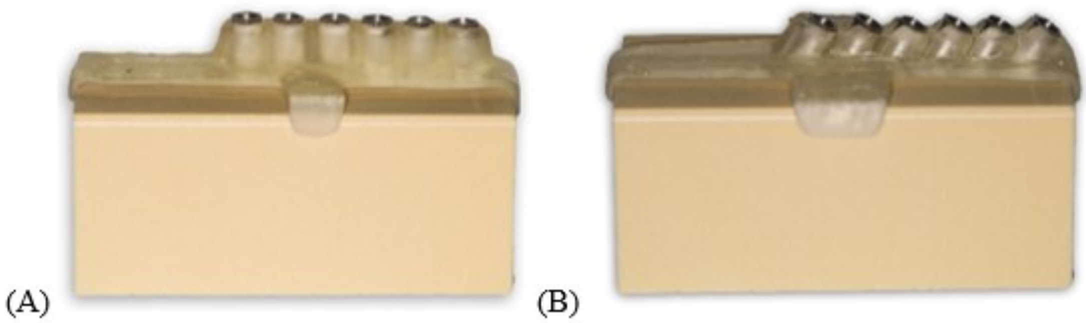

Figure 1: Guiding stent (A) 90̊ insertion angle (B) 60̊ insertion angle.

Drilling device

Mini-implants were inserted with a pre-determined insertion torque and speed with the aid of a contra-angle handpiece, (C-SAILOR PRO Dental implant system) was used for purpose of the study. The insertion torque was fixed to 15 Ncm, since a maximum insertion torque of 18- 24 Ncm is thought to be enough to prevent damage to the surrounding tissue,[17] and a speed of 200rpm, as some articles stated that the best insertion speed is 100-200rpm to reduce temperature generated during drilling.[18]

Metal holder

Two metal holders were custom-made for the purpose of the study, they helped in holding the artificial bony block fixed in place during the experimental procedure. The first holder was used to hold the bony specimen in a vertical direction to apply shear force, while the second was fabricated to hold the specimen in a horizontal direction for applying pull-out (tensile force). The holders were fabricated in a manner that could slide with a sliding jig when needed and fixed at a specific distance, since multiple mini-screws were inserted on the same bony specimen.

Testing machine

A universal testing machine was used for testing shear and tensile forces. During the tensile force test, the blocks were held horizontally and the test was performed by a Universal testing machine (Terco MT 3037), while for the shear test they were held vertically and a Universal testing machine (Gunt WP300) was used to perform the test (Figure 2).

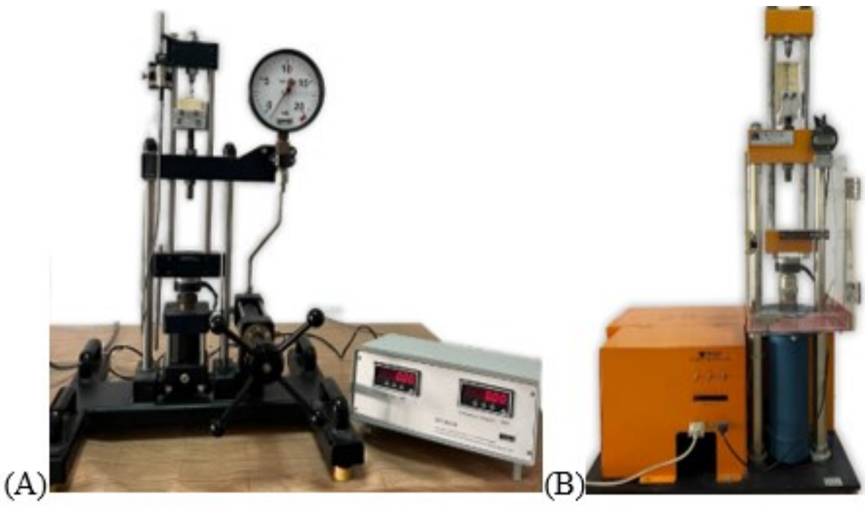

Figure 2: Universal Testing machine testing A: Tensile force test B: Shear force test.

Method

The first step was stent fabrication, where a followable composite was placed on predetermined positions of mini-screw after taking a CBCT image by (CBCT Newtom HR) machine, (NNT Software CBCT Version 14) was used to process the image, later (Realguide Software Version 5) was used for selection insertion site by placing virtual mini-implants on the position of previously cured followable composite perpendicular to the bone surface at 90̊ and angled at 60̊ angle. (Figure 3).

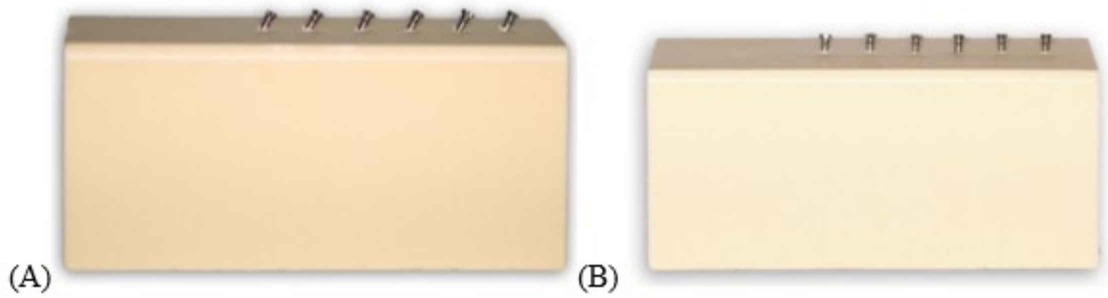

Figure 3: (A) Mini-implants placed at 60̊ angle (B) Mini-implant placed at 90̊ over the artificial bone surface.

Motor-driven handpiece was used to insert the mini-screws on bony blocks for better standardization by maintaining torque to 15Ncm and the speed to 200rpm.

The artificial bone blocks were held by custom-made metal frames and mounted on Universal Testing Machine, one time vertically to perform a shear force test and the second time horizontally for a tensile force test. A drop of pick force measurement due to; a bend, pull-out of mini-screw, or fracture of peri-implant bone fragments was

Statistical analysis

The data were analyzed using the Statistical Package for Social Sciences (SPSS, version 26). Descriptive statistic was used to show the mean and standard deviation. While Shapiro Wilco test showed that shear test results were not normally distributed while tensile force test results were normally distributed. For non-parametric variables, Mann Whitney test was used, while for Parametric variables, an independent sample t-test was used for finding the differences between the mean ranks of different density bones D2 and D3, on different angular insertions 90̊ and 60˚. Two-way ANOVA was used to evaluate the effect of insertion angle, bone density and their interaction of both on test results. A p value of ≤ 0.05 was considered as statistically significant.

Results

The normality test revealed that shear force test data was not-normally distributed, while tensile force data was normally distributed.

Eighteen samples were taken for the bone density D2 (nine for 60° angle, and nine for 90° angle), and eighteen samples were taken for the bone density D3 (nine for 60° angle, and nine for 90° angle), these were for each of the shear force, and the tensile force (Table 1). During the tensile test 5 mini-implants were completely pulled out of the socket, the rest were partially pulled and caused the force to drop down suddenly. While during the shear test 6 mini-screws caused a fracture in the cortical layer, 5 were completely pulled out and the rest were partially out of the bony socket.

A/ Shear force

Maximum shear force ranged between 230N to 270N when the insertion angle was 60̊ whether the bone density was D2 or D3, however, the highest mean value was (254.44N±14.24) when the mini-implant was inserted at 60̊ angle on a block of D3 density and the highest median value was 250N when the insertion angle was 60̊ in both D2 and D3 density bone blocks. While the lowest shear force ranged between 90N to 230N when the mini-implant was inserted at a 90̊ angle on a block of D2 density, and the lowest mean value was (146.67N± 44.44) when the insertion angle was 90˚ on a D3 density block, regarding the lowest median was (130N) when the insertion angle was 90̊ in both D2 and D3 density bone blocks.

B/ Tensile force

Maximum tensile force ranged between 340N to 270N when the insertion angle was 90̊ on the D2 density bony block, and the highest mean value was 308.89N± 24.21 N at the same insertion conditions. While the lowest tensile force ranged between 100N to 130N when the mini-implant was inserted at a 60̊ angle on a block of D3 density, and the lowest mean value was 133.33N±17.32 under the same insertion conditions.

Table 1. Descriptive statistics of the shear force and tensile force by bone type and angle degree.

	Shear force (Newton)				**Tensile force (Newton)**			
	Bone/ angle	**Bone/ angle**	**Bone/ angle**	**Bone/ angle**	**Bone/ angle**	**Bone/ angle**	**Bone/ angle**	**Bone/ angle**
	D2/60	**D2/90**	**D3/60**	**D3/90**	**D2/60**	**D2/90**	**D3/60**	**D3/90**
N	9	9	9	9	9	9	9	9
Mean	247.78	152.22	254.44	146.67	194.44	308.89	133.33	215.56
SD	12.02	47.90	14.24	44.44	22.97	24.21	17.32	18.78
Median	250.00	130.00	250.00	130.00	190.00	310.00	130.00	210.00
Minimum	230.00	90.00	230.00	100.00	160.00	270.00	100.00	190.00
Maximum	270.00	230.00	270.00	230.00	230.00	340.00	160.00	250.00

There was no significant difference in the shear force between D2 and D3 bone densities, whether the angle was 60° ($p = 0.297$), or 90° ($p = 0.931$) testing the mean ranks by Mann-Whitney. Regarding the mean tensile force, when the angle was 60°, it was significantly ($p < 0.001$) higher in D2 bone density (194.44 N) than in D3 bone density (133.33 N). And when the angle was 90°, the mean tensile force in D2 (308.89 N) was significantly ($p < 0.001$) higher than that of D3 (215.56 N), tested by unpaired t-test (Table 2).

Table 2. Comparing shear force and tensile force of D2 and D3 bone types, on 60- and 90-degree angles.

		D2		D3		
	Angle	**Mean**	**(SD)**	**Mean**	**(SD)**	**P**
Shear force (Newton)	60º	247.78	(12.02)	254.44	(14.24)	0.297*
Tensile force (Newton)	60º	194.44	(22.97)	133.33	(17.32)	< 0.001†
Shear force (Newton)	90º	152.22	(47.90)	146.67	(44.44)	0.931*
Tensile force (Newton)	90º	308.89	(24.21)	215.56	(18.78)	< 0.001†

*By Mann-Whitney test comparing mean ranks. †By unpaired t-test comparing means.

When both factors (bone density, and angle of insertion) are considered together, still the angle of insertion is the only factor that affects the shear strength ($p < 0.001$), while tensile force is affected significantly by each of the bone density and angle of insertion ($p < 0.001$), but it is affected little more by the angle of insertion (partial Eta squared = 0.860) than by the bone density (partial Eta squared = 0.792), despite that there was little effect of the interaction between bone density and angle of insertion (Eta = 0.142) (Table 5).not available

Discussion

Primary stability is essential for immediate loading mini-implants,[19] mechanical interlocking of mini-implant with surrounding bone is important for obtaining it.[20] Some factors are determinants for stability, such as; the length of the exposed part of the mini-implant, its angulation, the direction of force application [21], the thickness of the cortical layer and density the of cancellous bone.[22]

A- Shear force

The high mean of shear force is measured when the mini-implant was inserted at 60˚ (254N±14) on the D3 density block, while the lowest was recorded by 90˚ insertion angle (146N±44) on the D3 density block. These results agreed with the study of Araghbidikashani,[23] which stated that angular insertion of mini-screw would bear more force when loaded by shear force than perpendicular insertion, although the results of our study were slightly higher, this can be explained by the saw action phenomenon that was observed, as the mini-screw in some instances travelled and cut the surrounding bone in direction of force application before recording failure point. These results agree with the study of Pickard[24] which noted that after losing primary stability the mini-implant can sustain load, however, the side effects are mostly seen at the peri-implant bony structure, especially when there is the engagement of the apical part of the screw with cortical bone at the lingual side. The type of failure in the 60˚ insertion angle is concentrated on the bone-implant interface, resulting in bone fragment fractures, or saw action to the adjacent bony surface, the results were consistent with the study of Watanabe,[25] which found that the torque at the peri-implant region is higher when high force is applied not parallel to the line of mini-screw insertion, therefor it iss stated that mini-implant can sustain load under orthodontic force even if they have lost primary stability. [19,26]

Besides mini-implant angular orientation, bone density and property of cortical surface play a crucial role in its stability.[24,27] It was noted that a 60˚ angular insertion on the D3 bony block during the shear test had slightly higher stability than the same angular insertion on the D2 block.

This phenomenon can be explained by Möhlhenrich,[28] who found that implant angulation in high-density bone reduced stability, whereas that in low-density caused no effect on stability with increasing implant size.

B- Tensile force

The highest mean of pull-out force was recorded by 90̊ insertion angle (308N±24) on the D2 density block, while the lowest was measured by 60̊ insertion angle (133N±17) on the D3 density block, these results are very close to the results of Araghbidikashani,[23] however; the later tested different angular insertions on bony specimens with similar densities. It's found that posterior regions of the jaws have thicker bone density so they can withstand higher degrees of pull-out force (388N±23) while anterior regions can withstand a lower mean range of (134N±24).[29]

The results of our study revealed that both the insertion angle of the mini-implant and the density of bone act on tensile force results, however, the angle of insertion have a greater impact, while the interaction of both factors has a lower effect on stability during the pull-out test. Möhlhenrich[28] stated that placing an implant at an angle on high-density bone would lower the stability, however; when bone density is low changing the angulation wouldn't have a remarkable effect.[28]

Conclusion

Mini-screw is more resistant to pull-out force when it's inserted perpendicular to the surface of a bone at 90̊ angle, while it will withstand more shear force when it's inserted at 60̊ angle.

The stability of the mini-implant is higher when the direction of force application is parallel to the line of mini-implant insertion.

Mini-screw inserted at 90̊ is more stable in high-density bone, on the other hand, bone density does not have a remarkable effect on stability when the mini-implant is inserted at 60̊ angle.

Conflicts of interest

The author reported no conflict of interest.

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