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Original Article

Stability of two self-drilling Orthodontic Temporary Anchorage Devices (TAD) assessed by Histomorphometric Changes

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ABSTRACT

Aims: This work was aimed to evaluate bone density around two types of self-drilling orthodontic mini-screws in mongrel dogs. **Materials and methods**: two groups of TADs were inserted in the maxillae of six mongrel dogs. ***Group 1:*** six tapered self-drilling miniscrews, each of which was inserted in the right buccal side between the roots of the maxillary third premolar (P_3). ***Group 2:*** Six cylindrical self-drilling miniscrews, each of which was inserted in the right buccal side between the roots of the maxillary first molar (M^1). All of the TADs were inserted parallel to the occlusal plane. Occlusal radiographic views were taken at different time intervals: pre-insertion, just after insertion (T_0), after 4 weeks (T_1), after 8 weeks (T_2) and after 12 weeks (T_3). Using IDRISI Kilimanjaro computer software, the peri-implant area surrounding the apical one third of miniscrew was studied measuring the amount of grey shade. Bone density was measure in five areas (zone1 through zone 5) around the apical 1/3 of the TADs. Paired t- test was used to compare the measurements of the bone density pre-insertion of TADs between roots of M_1 and P_3, and the bone density post-insertion of TADs in the cylindrical and tapered TAD. The unpaired t-test was used to evaluate the difference in bone density of each zone around the tapered TAD and it correspondent zone around the cylindrical TAD. **Results**: the significance of the scheduled differences between means of bone density around group1 and group 2 were variable, indicating that the bone density depends on several factors. **Conclusion**: TAD design has an influence on the bone density. Cylindrical TADs have more bone density around than tapered TADs.

Key words: minisrews, TADs, minimplant, histomorfometeric changes, self-drilling.

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INTRODUCTION

Orthodontic skeletal anchorage such as mini-screws, palatal implants or mini-plates with screws has drawn considerable attention in the field of orthodontics [(1)]. Miniscrews or Temporary anchorage devices (TADs) have being severing as an alternative for conventional and complex means of anchorage ever since their invention [(1-3)]. These small but useful devices have several advantages including: less invasiveness, simple placement/removal procedures, feasibility of immediate loading, relatively reduced cost and improved orthodontic results. Hence patients become more compliant and orthodontists are more attracted to use them intensively nowadays [(4-7)]. The invention and devising of miniscrews had extended the orthodontic treatment scope, increased its efficiency, and decreased its limitations with less treatment time [(3)]. However few obstacles hindered their success that should be overcame, for instance the doubted stability which is variable among different patients and even among different orthodontists [2, 8-11]. In 2000, Melsen and Costa postulated that primary stability of TADs is the mechanical stability achieved immediately after insertion. Primary stability shows how much the screw is engaged or locked into the bone that would be manifested as a stable anchorage for the various clinical applications [12]. According to several authors [2, 13 and 14] primary stability and consequently success rates of TADs are influenced by quality and quantity of the host bone, surgical technique, and screw geometry.

Immediate loading and anchorage demands mandate stationary miniscrews, in other words, stability of the TADs is an issue that must be considered; the stability of mini-implants has been attributed to mechanical (device design and dimensions) and biological factors including the nature of the bone around the miniscrew particularly bone density [15]. This study was done to evaluate bone density related to two types of self-drilling orthodontic mini-screws in maxillae of mongrel dogs.

MATERIALS AND METHODS

Ethical approval was obtained from ethical committee for scientific research in the Sues canal university, Egypt.

The animals: 1-3 years old six healthy mongrel dogs were selected that had been properly fed and hosted in separate cages in the animal house of the University. All Dogs had their permanent teeth fully erupted.

The Materials: The sample consisted of 12 titanium alloy self-drilling mini-screws that divided into two groups. ***Group 1:*** six tapered self-drilling miniscrews [*](1.4mm neck diameter and 1.3mm diameter near the apex) (Figure 1.a). Parallel to the occlusal plane, each TADs of group 1 screws was inserted in the right buccal side between the roots of the maxillary third premolar (P_3); the threaded intra-bone part was 10mm long. ***Group 2:*** Six cylindrical self-drilling miniscrews[*] (1.4mm neck diameter, 1.4mm diameter near the apex) (Figure 1.b). Parallel to the occlusal plane, each of group 2 screws was inserted in the right buccal side between the roots of the maxillary first molar (M^1); the threaded intra-bone part was 10mm long.

Methodology: Food was withheld one night before the operation. Each dog was pre-medicated with intramuscular injection of *chloropromazine hydrochloride* in a dose of 1 mg/Kg [**] 10-15 minutes prior to the induction of general anesthesia. General anesthesia was conducted with intravenous injection of thiopental sodium[***] 2.5% until the main reflexes were abolished [16]. Costume made acrylic guide stint was used to insure that TADs were inserted perpendicular to the cortical plate of the maxilla. This stint was L-shaped gadget and it was applied in such a way that the shorter rod was resting on and parallel to the occlusal table, and the longer rod was parallel to the gingiva corresponding to the insertion site of the bone. The stint had was holed with holes that are as large as the diameter as the tip of the screwdriver (Figure 2.a). Implantation of TADs was performed in clockwise insertion in accordance with manufacturer instruction (Figure 2.b).

After swabbing the area with Alcohol for disinfection, and application of infiltration local anesthesia, drill-free TADs were one-step inserted in the designated sites. Force was manually applied using palm and thumb grip until the penetration of bone, then pen grasp grip was used to rotate the miniscrew till it was completely inserted, with only the its head exposed in the oral cavity (Figure 3). Immediate, constant and continuous load was applied using 8mm long, heavy short Nickel Titanium coil spring[*]. It was ligated between the heads of the two types of TADs; the two heads were apart by a distance range of 20-26mm (Figure 4). The load lasted for 12 weeks period (Figure 7.b), and then TADs were removed by using a torque screwdriver[*] (Figure 3 and 4).

Bone density assessment:

For evaluation of bone density in the areas of insertion, occlusal radiographic views were taken at different time intervals: pre-insertion, just after insertion (T_0), after 4 weeks (T_1), after 8 weeks (T_2) and after 12 weeks (T_3). Each dog was positioned in a supine position to the table of the x-ray machine[*]. Radiographs were taken using an X-ray beam of 60kv-200ma. The distance between the cone and the table was fixed at about 55cm. The X-ray beam was centered using a light beam guide in the machine on the center of the film, and it was perpendicular to the occlusal plane (Figure 5). Using IDRISI Kilimanjaro computer software[*], the peri-implant area surrounding the apical one third of miniscrew was studied measuring the amount of grey color. By applying the digitize effect of the program, special dots could be

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[*] (NT15-8H) , Dentos, Daegu, Korea
[*] (LHD-B-TG), Dentos, Daegu, Korea
[*] Eureka, USA
[*] Clark's labs, Clark's university, USA

applied just over the thread interface of the TADs, and the area surrounding all the apical one third of the TADs. Then the program shades the selected area. Using this program, the area surrounding the implant in the digitized radiographs was divided into five zones with standardized width. The denso-metric analysis of five zones was measured in both groups.

The software analyzed the images through; image restoration, image enhancement and density measurements. Image restoration technique allows for both radiometric and geometric correction of images. The procedure was followed by image enhancement, and subtracting the implant from background image (surrounding bone). Finally, the density measurements were calibrated by quantifying the image on 256 grey-scales. Zero scale was given to the totally black regions (totally radiolucent), 256 for totally white (totally radiopaque) regions while values in between represented by shades of grey (Figure 6). This measurement was repeated five time for each set of test, then the mean value of the five readings were considered. After the 12 weeks, the mini-screws were removed in a counterclockwise direction using a torque Screwdriver (Figure 3).

Statistical analysis:

Statistical analysis was carried out using ***IBM SPSS statistics 22 ®. Mann-Whitney U test*** was run to compare the measurements of the bone density pre-insertion of TADs between roots of M_1 and P_3, and the bone density post-insertion of TADs in the cylindrical and tapered TAD. The test was used to evaluate the difference in bone density of each zone around the tapered TAD and it correspondent zone around the cylindrical TAD.

RESULTS

The descriptive data analyses including mean values and standard deviations and test of significance of bone density measurements at the different zones (1^{st} through 5^{th} zone) are listed in tables (2, 3, 4, 5 and 6).

<u>Zone (1) bone density measurements:</u>

At the time of insertion (T_{01}) the mean bone density around tapered group was 126.54 ±40.40, and it was 157.67 ± 26.35 around cylindrical group, revealing a significant difference (p=0.038). After one month of insertion (T_{11}), there was insignificant difference (p = 0.581) between the mean value of bone density related to tapered TADs (111.07±60.06), and that around cylindrical TADs (116.20±67.70). After two months from insertion (T_{21}), the results revealed significant difference (p=0.016) where the mean of bone density related to tapered group was 139.09±63.30 and in relation to cylindrical group, it was 161.39±64.41. The results revealed insignificant difference (p=0.098) at 3^{rd} month after insertion (T_{31}), the mean bone density was 190.74±33.21 around tapered group, and it was 201.38±28.45 in relation to the cylindrical group (Table 2).

<u>Zone (2) bone density measurements:</u>

At the time of insertion (T_{02}) the mean bone density around tapered group was 124.55±40.72, and it was 156.06±26.86 around cylindrical group, revealing a significant difference (p=0. 0.036). After one month of insertion (T_{12}), there was insignificant difference (p=0.572) between the mean value of bone density related to tapered TADs (109.81±60.19), and that around cylindrical TADs (115.13±68.24). After two months from insertion (T_{22}), the results revealed significant difference (p=0.019) where the mean of bone density related to tapered group was 136.62±63.48, and in relation to cylindrical group was 160.26±64.64. The results revealed insignificant difference (p=0.104) at 3^{rd} month after insertion (T_{32}), the mean bone density was 189.85±33.49 around tapered group, and it was 200.70±28.35 in relation to cylindrical group (Table 3).

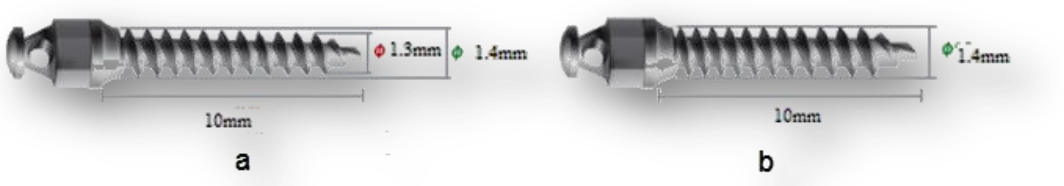

Figure 1: Photograph showing Tapered (a) and Cylindrical (b) mini-screws

Figure 2: (a) guiding stint (b) application of the guiding stint in TADs insertion

Figure 3: Torque screwdriver used for insertion and removal of TADs

Figure 4: Pen-grasp TADs tightening

Figure 5 : TADs before loading, and after loading

Figure 6: X-ray beam is perpendicular to occlusal plane

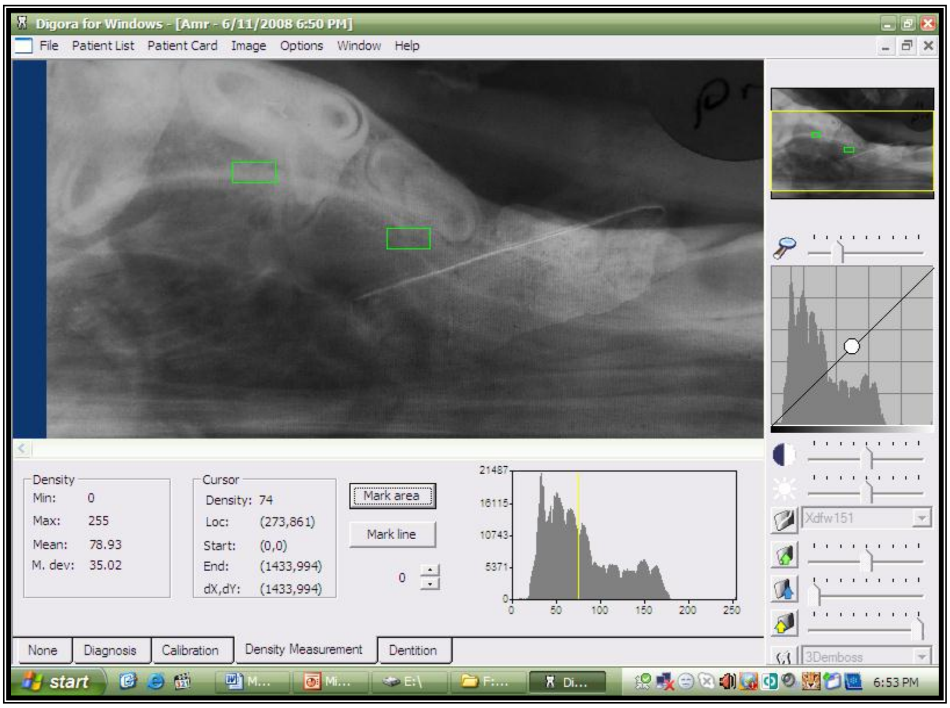

Figure 7: Photograph showing the area of interest for pre-insertion bone density measurements

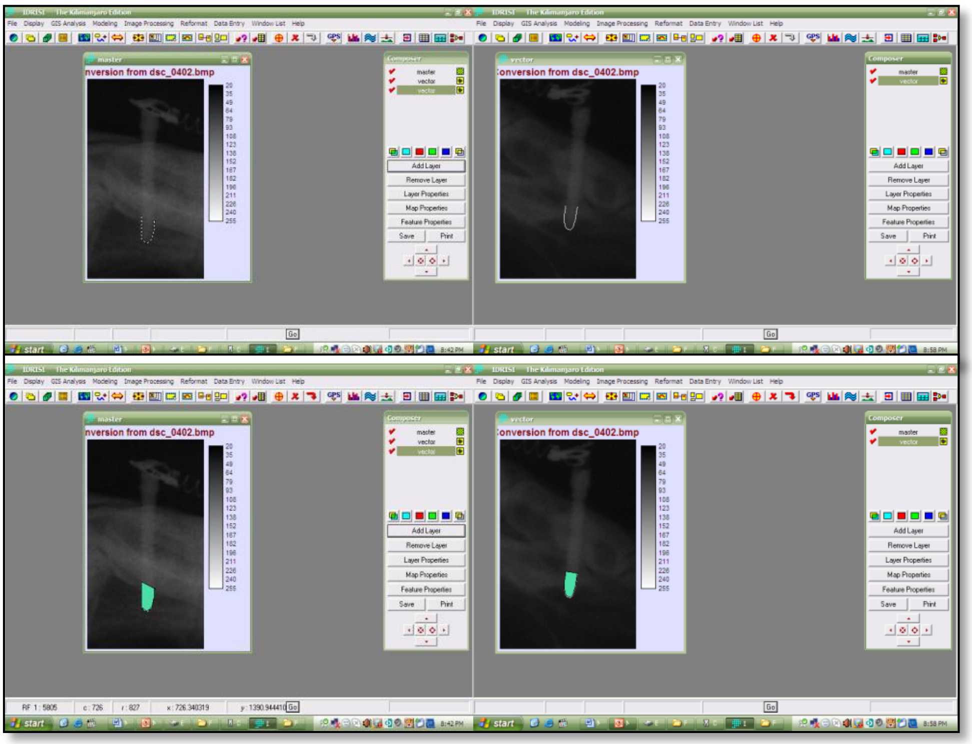

Figure 8: Measurements of bone density

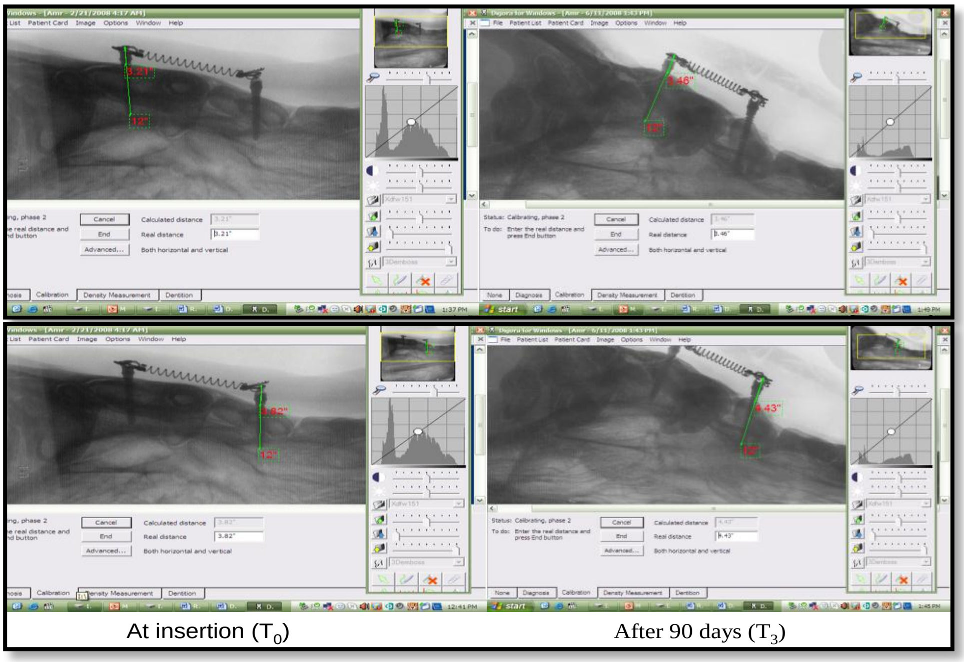

Figure 9: Measurements of extruded part of the miniscrew at insertion time (T_0) and after 12 weeks post-insertion (T_3)

Zone (3) bone density measurements:

At the time of insertion (T_{03}) the mean bone density around tapered group was 123.83±40.73, and it was 155.45±26.70 around cylindrical group, revealing a significant difference (p=0. 0.035). After one month of insertion (T_{13}), there was insignificant difference (p=0.566) between the mean value of bone density related to tapered TADs (109.42±60.30), and that around cylindrical TADs (114.74±68.02). After two months from insertion (T_{23}), the results revealed significant difference (p=0.017) where the mean of bone density related to tapered group was 135.88±63.61, and in relation cylindrical group was 159.75±64.63. The results revealed insignificant difference (p=0.108) at 3rd month after insertion (T_{33}), the mean bone density was 189.23±33.54 around tapered group, and it was 200.39±28.24 in relation to cylindrical group (Table 4).

Zone (4) bone density measurements:

At the time of insertion (T_{04}) the mean bone density around tapered group was 123.36±40.65, and it was 155.71±25.92 around cylindrical group, revealing a significant difference (p=0.0.033). After one month of insertion (T_{14}), there was insignificant difference (p=0.560) between the mean value of bone density related to tapered TADs (108.96±60.52), and that around cylindrical TADs (114.32±67.96). After two months from insertion (T_{24}), the results revealed significant difference (p=0.016) where the mean of bone density related to tapered group was 135.50±63.67, and in relation cylindrical group was 159.33±64.47. The results revealed insignificant difference (p=0.108) at 3rd month after insertion (T_{34}), the mean bone density was 188.88±33.70 around tapered group, and it was 200.36±28.17 in relation to cylindrical group (Table 5).

Zone (5) bone density measurements:

At the time of insertion (T_{05}) the mean bone density around tapered group was 123.11±40.43, and it was 155.18±26.20 around cylindrical group, revealing a significant difference (p=0.0.032). After one month of insertion (T_{15}), there was insignificant difference (p=0.557) between the mean value of bone density related to tapered TADs (108.73±60.59), and that around cylindrical TADs (114.05±67.93). After two months from insertion (T_{25}), the results revealed significant difference (p=0.014) where the mean of bone density related to tapered group was 133.64±65.29, and in relation cylindrical group was 158.91±64.30. The results revealed insignificant difference (p=0.106) at 3rd month after insertion (T_{35}), the mean bone density was 188.55±33.72 around tapered group, and it was 200.32±28.07 in relation to cylindrical group (Table 6).

Table 1: The descriptive analysis data of first molars (M_1) and third premolar (P_3) bone density just before insertion.

Area	M_1		P_3		p
Time	Mean	±S.D.	Mean	±S.D.	
Pre insertion	136.167	39.746	114.000	40.254	0.088 NS

P = Probability for the effect of bone area
NS = Insignificant (P>0.05)
M_1 = The roots of first permanent molar
P_3 = The roots of third premolar

Table 2: Descriptive analysis data and significance of bone density measurements at 1st zone .

Screw	Tapered		Cylindrical		p
Time	Mean	±S.D.	Mean	±S.D.	
T_{01}	126.54	40.40	157.67	26.35	0.038*
T_{11}	111.07	60.06	116.20	67.70	0.581NS
T_{21}	139.09	63.30	161.39	64.41	0.016*
T_{31}	190.74	33.21	201.38	28.45	0.098NS

* = Significant at p≤0.05
T_{01} = Bone density measurement for 1st zone at time of insertion
T_{11} = Bone density measurement for 1st zone after 1 month
T_{21} = Bone density measurement for 1st zone after 2 month
T_{31} = Bone density measurement for 1st zone after 3 month

Table 3: The descriptive analysis data of bone density measurements at 2nd zone.

Screw	Tapered		Cylindrical		p
Time	Mean	±S.D.	Mean	±S.D.	
T_{02}	124.55	40.72	156.06	26.86	0.036*
T_{12}	109.81	60.19	115.13	68.24	0.572NS
T_{22}	136.62	63.48	160.26	64.64	0.019*
T_{32}	189.85	33.49	200.70	28.35	0.104NS

P = Probability for the effect of screw type
NS = Insignificant (P>0.05)
* = Significant at $p \leq 0.05$
T_{02} = Bone density measurement for 2nd zone at time of insertion
T_{12} = Bone density measurement for 2nd zone after 1 month
T_{22} = Bone density measurement for 2nd zone after 2 month
T_{32} = Bone density measurement for 2nd zone after 3 month

Table 4: The descriptive analysis data of bone density measurements at 3rd zone.

Screw	Tapered		Cylindrical		p
Time	Mean	±S.D.	Mean	±S.D.	
T_{03}	123.83	40.73	155.45	26.70	0.035*
T_{13}	109.42	60.30	114.74	68.02	0.566NS
T_{23}	135.88	63.61	159.75	64.63	0.017*
T_{33}	189.23	33.54	200.39	28.24	0.108NS

P = Probability for the effect of screw type
NS = Insignificant (P>0.05)
* = Significant at $p \leq 0.05$
T_{03} = Bone density measurement for 3rd zone at time of insertion
T_{13} = Bone density measurement for 3rd zone after 1 month
T_{23} = Bone density measurement for 3rd zone after 2 month
T_{33} = Bone density measurement for 3rd zone after 3 month

Table 5: The descriptive analysis of bone density measurements at 4th zone.

Screw	Tapered		Cylindrical		p
Time	Mean	±S.D.	Mean	±S.D.	
T_{04}	123.36	40.65	155.71	25.92	0.033*
T_{14}	108.96	60.52	114.32	67.96	0.560NS
T_{24}	135.50	63.67	159.33	64.47	0.016*
T_{34}	188.88	33.70	200.36	28.17	0.108NS

P = Probability for the effect of screw type
NS = Insignificant (P>0.05)
* = Significant at $p \leq 0.05$
T_{04} = Bone density measurement for 4th zone at time of insertion
T_{14} = Bone density measurement for 4th zone after 1 month
T_{24} = Bone density measurement for 4th zone after 2 month
T_{34} = Bone density measurement for 4th zone after 3 month

Table 6: The descriptive analysis data of bone density measurements at 5th zone.

Screw	Tapered		Cylindrical		p
Time	Mean	±S.D.	Mean	±S.D.	
T_{05}	123.11	40.43	155.18	26.20	0.032*
T_{15}	108.73	60.59	114.05	67.93	0.557NS
T_{25}	133.64	65.29	158.91	64.30	0.014*
T_{35}	188.55	33.72	200.32	28.07	0.106NS

P = Probability for the effect of screw type
NS = Insignificant (P>0.05)
* = Significant at $p \leq 0.05$
T_{05} = Bone density measurement for 5th zone at time of insertion
T_{15} = Bone density measurement for 5th zone after 1 month
T_{25} = Bone density measurement for 5th zone after 2 month
T_{35} = Bone density measurement for 5th zone after 3 month

DISCUSSION

Though their usefulness, stability of TADs is an issue which can be a source of inconvenience. Several authors have relatively low success rates of orthodontic temporary anchorage devices (TADs); the reported success rates were ranging from 70% to 91% (17-23), which has been considered relatively low success rates compared with dental implants (15). Therefore, the influencing factors of TADs stability need to be investigated, and their effects to be disclosed. This study was aimed to investigate bone density around two types of most commonly used drill-free TADs (Tapered and Cylindrical TADs) as it is one of the important factor affecting the stability (24, 25). Twelve TADs (six tapered and six cylindrical miniscrews) with identical length were used in this study, so elimination of all factors except the tapering of the miniscrews (25, 26). Six dogs were used in this study. Insertion of miniscrews was done according to *Zhao et al.* (27), who determined safe zones for miniscews insertion in dogs**.**

Pre-insertion bone density:

As revealed from the results of the present study, the difference of bone density between the roots P^3 and M^1 pre-insertion of miniscrews was insignificant, which ensured that both cylindrical and tapered screws were inserted within the same bone density in the posterior maxilla of the dogs.

Bone density at insertion (T_0):

Significant difference in bone density was revealed at the cylindrical group just after the insertion at (T_0), this difference might reveal a biomechanical change than a biological tissue change in this early stage, as miniscrews depended on primary stability for its success (12)**.** The cylindrical screw with same shaft and thread diameter at the coronal part and at the apex along its length had low insertion torque, so stresses would be manifested at the apical part. However all other threads along the remaining screw length would only rotate through the pre-formed bone hole (28). This finding has been revealed by *Siegele and Soltesz* (29), who investigated numerically the cylindrical shape dental implant on stress distribution in the jaw bone; they found that the implant would slide along the axial boundary of bone without friction, so that the load was mainly transferred to the bone section near the apical end of the implant. In the case of tapered miniscrews there were more bone contact along the whole screw length, as the thread and shaft diameter decreased apically.

So the increase of bone density around the cylindrical design compared to the tapered one might be due to apical condensation of bone around the cylindrical screw, and lateral condensation of the tapered one. *Yano et al.* (30) in 2006**,** investigated the bone-screw cohesion of tapered miniscrew following immediate loading, reported that cortical bone was seen in the screw threads of tapered miniscew and the cortical bone contact area was shown in the whole surface of the screw threads. This finding goes well with the result of this study. Measurements of bone density were done in the apical third of the screws, due to superimposition of crowns of P^3 and M^1 on the coronal and middle third of the miniscrew length. So most of the bone condensed in the tapered miniscews wasn't considered in this study that was revealed also by *Buchter et al.* (31)**.**

Bone density after 4 weeks post- insertion (T_1):

Bone density measurement at (T_1), had no significance difference between both cylindrical and tapered group. This might be due to bone resorption and fibrotic remodeling effect, which took place in both groups, after bone damage during the insertion of both types of miniscrews, this was in agreement with *Nkenke et al.* (22), and *Buchter et al.* (31)**,** who revealed the same findings. In contrary, *Yano et al.* (30) reported in an immediate-loading group of miniscrews, which lasted 2 weeks that the bone-screw contact ratio in tapered type miniscews is significantly higher than that of the cylindrical type miniscrews. This might be due to the short loading period (2 weeks) rather than this study (4 weeks).

Bone density after 8 weeks post- insertion (T_2):

Bone density measurement at (T2), had significant difference between both cylindrical and tapered group, the cylindrical group had more bone density surrounding its interface than the tapered type. This finding might be explained by that bone remodeling effect was greater in the interface of cylindrical screws compared to the tapered ones. And this might be due to the cylindrical screws had lower insertion torques compared to the tapered ones [(22, 32)]. So high stresses were manifested on bone during tapered screw insertion compared to the cylindrical screws insertion, and this led to decreased bone remodeling on the tapered screw interface compared to the cylindrical one [(33,34)]. Furthermore, *Lee and Beak* [(35)], and *Kalarickal* [(36)] concluded that mini-screws with larger diameters and tapered shapes caused greater microdamage to the cortical bone and that might affect bone remodeling, hence 1.3 mm -1.4mm diameter and a length of 10 mm microscrews were used in this study. However, *Yano et al.* [(30)], postulated that tapered miniscrews had higher bone-screw contact ratio than the cylindrical ones. The loading period was made for 2 weeks only while it was 8 weeks in this study. This might lead to a difference.

Bone density after 12 weeks post-insertion (T_3):

Bone density measurement at (T_3), had no significance difference between both cylindrical and tapered groups. This might be due to the bone surrounding the tapered screw caught up the remodeling sequence of the bone surrounding the cylindrical screw, this took 12 weeks of time, due to the high impact of tapered screw on bone during its insertion as explained by *Kim et al.* [(37)]. While some studies disagreed with the results of the present study as *Vandeweghe et al.* [(38)] and *He et al.* [(39)], who said that tapered implants were less successful than cylindrical implants. The implants were loaded for 6 months. This result disagreed to the present study, however osseoinetgrated dental implant differ than orthodontic miniscrews to some extent.

Bone density at zone 1, 2,3,4 and 5:

Different zones were measured in this study to evaluate any bony changes along different layers interfaced with the miniscrew contacted with bone. No significant difference was found between them, which revealed that no change had happened between the inner interface and the outer layer. This result might prove that miniscrews depended on snug fit rather than osseointegration on its stability. Some authors agreed to the results of the present study as *Manni et al.* [(40)] who reported that implant design had a strong impact on the primary stability of mini-implants for orthodontic anchorage, and *Yoo et al.* [(41)], who concluded that bone mineral density of cortical bone and screw type significantly influence the primary stability of miniscrews regardless the design of the miniscrews. However other authors disagreed with the results of the present study as *Eliades et al.* [(42)], who found that randomly organized osseointegrated islets on smooth titanium-alloy miniscrew surfaces. And this might be enhanced by the extended period of retention (3.5-17.5 months) on alveolar bone in spite of the smooth surface and immediate loading pattern of these implants. This disagreed to the present study, however there was higher period of retention compared to the present study.

Conclusion: TAD's design has an influence on the bone density. Bone density around the cylindrical TADs is more than that around than tapered TADs.

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