Pharos University Dental Journal (PUDJ)

Vol. 01, No.011, 2025
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The Effect of Two Implant Drilling Protocols on Primary Stability and Strain Developed Under Functional Loading of Implants Using Different Thread Designs (An In Vitro Study)

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ABSTRACT

Background: Osseodensification is a novel drilling protocol that enhances contact at the bone implant interface.**Objectives:** This study aimed to compare the influence of Osseodensification drills compared to conventional drills on the strain developed under functional occlusal loading of crown restorations on implants using different thread designs. **Materials and Methods:** Two implant thread designs: standard and deep threaded implants were fixed in twenty-four Polyurethane blocks and divided into four parallel groups (n=6). **Group (I) and (II)** –Standard thread depth placed with conventional vs Osseodensification drills, **Group (III) and (IV)** –Deep threads placed with conventional vs Osseodensification drills. Twenty-four E-max CAD maxillary right first premolar crowns were fabricated on implant abutments. Mean values of primary stability and insertion torque were calculated and compared. The specimens were vertically loaded with a universal testing machine [ne and a force up to 100 N was applied to the central fossae. Two strain gauges were attached to the buccal and palatal surfaces of the restoration to record the resulting strain. Mean values of strain were recorded in each group and compared. **Results:** Group IV exhibited the highest mean IT and ISQ values, followed by groups III, II, and I, respectively. Groups II and IV exhibited lower mean micro strain than Groups I and III. There were statistically significant differences between groups ($p \leq 0.05$). **Conclusions:** Osseodensification may aid in achieving higher insertion torque and ISQ values of tapered implants in medium quality bone and decrease the amount of strain in dental implant prostheses during functional loading.

Introduction

The establishment of a direct structural and functional connection between living bone and an implant surface, known as osseointegration, is fundamental to the long-term success of dental implants. A prerequisite for successful integration and subsequent loading is the attainment of adequate primary stability at the time of implant placement.

Implant stability is categorized into two phases: primary stability, a mechanical parameter linked to bone quality, quantity, and implant design; and secondary stability, a biological phenomenon involving bone healing and remodeling. The surgical technique employed for preparing the implant bed is recognized as a key determinant of osseointegration success.

Early efforts to modify the surgical technique focused on improving peri-implant bone conditions. The osteotome technique, which uses lateral compression to condense alveolar bone, was developed to enhance bone-to-implant contact (BIC). However, this technique demonstrated limited improvements in mechanical properties and BIC, despite increasing peri-implant bone density.

More recently, research has focused on osseous densification to enhance bone density. Studies comparing different protocols—standard drilling, osteotome, and Osseodensification—have indicated that Osseodensification drills result in significantly higher insertion and removal torque, smaller osteotomies, and a greater increase in BIC (up to threefold).

Osseodensification (OD)

Osseodensification (OD) is a novel biomechanical method for preparing the implant site, introduced in 2013. It is a bone non-extraction procedure that uses specialized, fluted burs (Densah™ burs) to cause controlled, low-level plastic deformation of the bone. Unlike conventional drills, which excavate bone, or osteotomes, which may cause micro-fractures, Densah burs function by a rolling and sliding contact, leading to lateral condensation and compaction autografting. This process preserves the bone bulk, augments density in the peri-prosthetic area, and is hypothesized to shorten the bone healing time required after drilling.

Thread Design and Stability

Beyond the drilling protocol, implant design features like thread depth are believed to influence primary stability, particularly in poorer bone quality. Thread depth is the vertical measure between the major and minor diameters. A deeper thread increases the contact surface area with the bone, theoretically promoting better osseointegration and greater primary stability. This feature is particularly desirable when placing implants in soft bone or areas with high functional loads.

Rationale

Given the relative novelty of Osseodensification, there is a lack of comprehensive literature comparing it to conventional drilling, especially regarding its combined effect with varying implant thread depths on both initial anchorage and the strain generated during functional loading of the final crown restorations. The present study aims to address this gap by evaluating the effect of OD drills versus conventional drills on implant primary stability, insertion torque, and the compressive strength of all-ceramic restorations on implant abutments.

Materials and Methods

The study utilized a standardized model of a missing maxillary right first premolar.

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Model Preparation and Grouping

A 3D-printed model of the edentulous space was created, sectioned, and secured to Polyurethane blocks. Polyurethane was chosen because it mimics the mechanical properties of human cancellous bone, providing a reproducible medium for stability assessment. A surgical stent with a titanium sleeve, guided by CBCT data, was designed and 3D-printed.

The polyurethane test blocks were randomly allocated into four groups (n=6 each), based on the drilling protocol and implant thread depth:

- Group I (CSI): Standard threads, Conventional drills.
- Group II (DSI): Standard threads, Osseodensification (Densah™) drills.
- Group III (CDI): Deep threads, Conventional drills.
- Group IV (DDI): Deep threads, Osseodensification (Densah™) drills.

Implant and Abutment Placement

All implants were 4.5 mm in diameter and 10 mm in length. The osteotomy sites were prepared using the designated drilling protocol (conventional or Osseodensification) through the surgical stent. (Figure 1) Following insertion, a 4.5 mm titanium straight abutment was secured to each implant according to manufacturer guidelines study utilized a standardized model of a missing maxillary right first premolar.

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1. Assessment of Strain Developed by Occlusal Loading: Two strain gauges were attached to the buccal and palatal surfaces of each crown. (Figure 2) A universal testing machine applied a vertical load up to 100 N to the crown's central fossae. The resulting micro-strain (με) was recorded using a connected strain meter. (Figure 3)

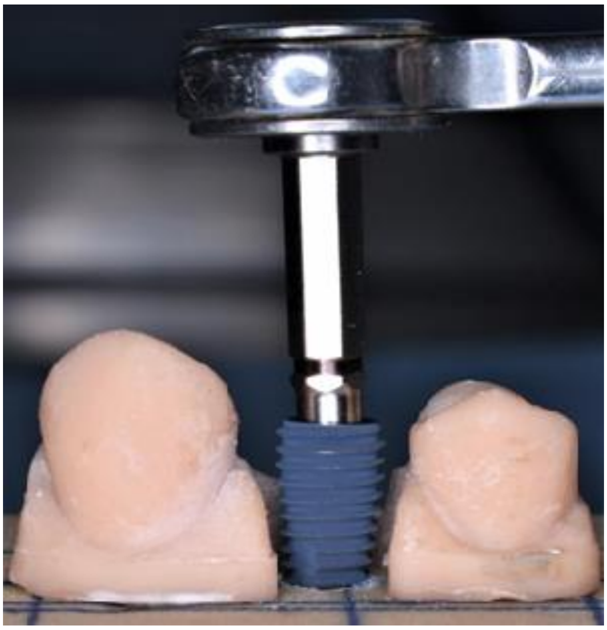

Figure 1: Group I: Implant being placed into osteotomy using calibrated torque wrench

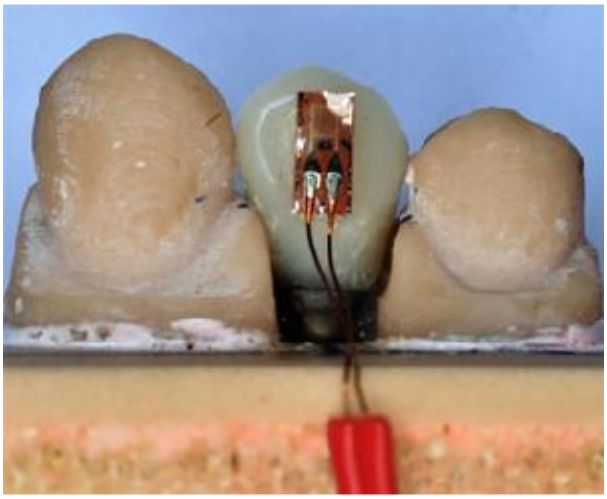

Fig. (3): Load application (Proximal View)

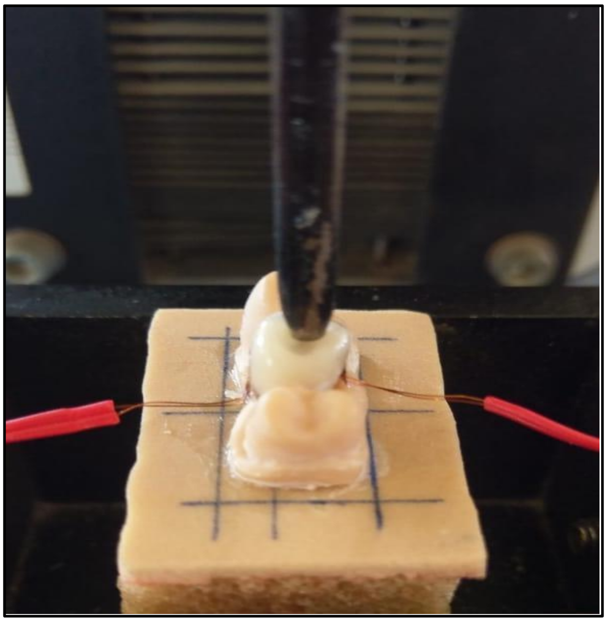

Figure (2): Strain Gauges placed on restoration (Buccal View)

Statistical Analysis.

The data (IT, ISQ, and micro-strain) were analyzed using appropriate statistical tests, including the F-test, ANOVA, and Tukey's post hoc test (Tukey) for pairwise comparisons, to determine significance and correlation across the groups.

Results

Quantitative results for insertion torque, primary stability, and micro-strain are summarized below.

Insertion Torque (Ncm)

Group IV registered the highest mean IT value, with the ranking from highest to lowest being: Group IV, followed by Group III, Group II, and Group I. The overall mean IT was 45.6±10.2 Ncm. Differences among the groups were statistically significant, except for the comparison between Group III and Group IV (p6). (Table 1)

Table (1): Comparison of Insertion Torque Values for the four studied groups

Insertion Torque (Ncm)	Group I	Group II	Group III	Group IV
Min. – Max.	25.0 – 35.0	40.0 – 50.0	50.0 – 55.0	50.0 – 60.0
Mean ± SD.	30.83 ± 3.76	44.17 ± 3.76	51.67 ± 2.58	55.83 ± 3.76
Median (IQR)	30.0(30.0–35.0)	45.0(40.0–45.0)	50.0(50.0–55.0)	55.0(55.0–60.0)
Sig. bet. grps.	$p_1<0.001^*$,$p_2<0.001^*$,$p_3<0.001^*$,$p_4=0.007^*$,$p_5<0.001^*$,$p_6=0.201$			

Primary Stability (ISQ)

Group IV yielded the highest mean ISQ value, followed by Groups III, II, and I. The mean ISQ for all groups was 74.2±1.0. ISQ values over 70 are indicative of high stability. Significant differences in ISQ values were found for all comparisons except between Groups I and II, and Groups III and IV. (Table 2)

Micro-Strain (με)

Group I exhibited the highest mean micro-strain, followed by Groups III, II, and IV. Micro-strain values were statistically significant between groups. Pairwise comparisons confirmed significant differences for all comparisons except between Groups II and IV and between Groups I and III. (Table 3)

Table (2): Comparison of Primary Stability (ISQ) Values for the four studied groups

Primary Stability (ISQ)	Group I (n = 6)	Group II (n = 6)	Group III (n = 6)	Group IV (n = 6)
Min. – Max.	66.0 – 72.75	68.50 – 74.50	74.50 – 76.50	76.50 – 79.50
Mean ± SD.	71.08 ± 2.57	72.17 ± 2.23	75.50 ± 0.76	77.88 ± 1.15
Median (IQR)	72.0(71.0–72.8)	73.0(70.5–73.5)	75.6(74.8–76.0)	77.9(76.8–78.8)
Sig. bet. Grps.	$p_1=0.739$,$p_2=0.002^*$,$p_3<0.001^*$,$p_4=0.024^*$,$p_5<0.001^*$, $p_6=0.146$			

Table (3): Comparison between the Four studied groups according to micro strain

Micro Strain	Group I (n = 6)	Group II (n = 6)	Group III (n = 6)	Group IV (n = 6)	F	p
Min. – Max.	138.6 – 147.2	60.68 – 88.31	135.4 – 147.4	60.86 – 88.61		
Mean ± SD.	142.9 ± 2.75	81.14 ± 10.47	141.5 ± 3.90	82.05 ± 10.60		
Median(I QR)	142.7(142.6–143.5)	85.17(80.3–87.2)	141.5(140.2–142.9)	86.0(82.6–88.2)		
Sig. bet. grps.	$p_1<0.001^*$,$p_2=0.989$,$p_3<0.001^*$,$p_4<0.001^*$,$p_5=0.997$,					

Correlation Analysis (Table 4)

- IT vs. ISQ: A negative correlation was observed between insertion torque and ISQ for all groups. (Figure 4)
- IT vs. Micro-Strain: A positive correlation was found between insertion torque and micro-strain for all study groups, except for Group IV, which showed a negative correlation. (Figure 5)
- ISQ vs. Micro-Strain: A negative correlation was detected between ISQ and micro-strain for all study groups. (Figure 6)

Table (4): Correlation between the three studied parameters in each group

	Group I (n = 6)		Group II (n = 6)		Group III (n = 6)		Group IV (n = 6)	
	r	p	r	p	r	p	r	p
Insertion torque vs. Primary stability (ISQ)	-0.603	0.206	-0.457	0.362	-0.255	0.625	-0.145	0.785
Insertion torque vs. Micro strain	0.441	0.381	0.618	0.191	0.611	0.197	-0.522	0.288
Primary Stability (ISQ) vs. Micro strain	-0.167	0.751	-0.414	0.414	-0.146	0.782	-0.706	0.117

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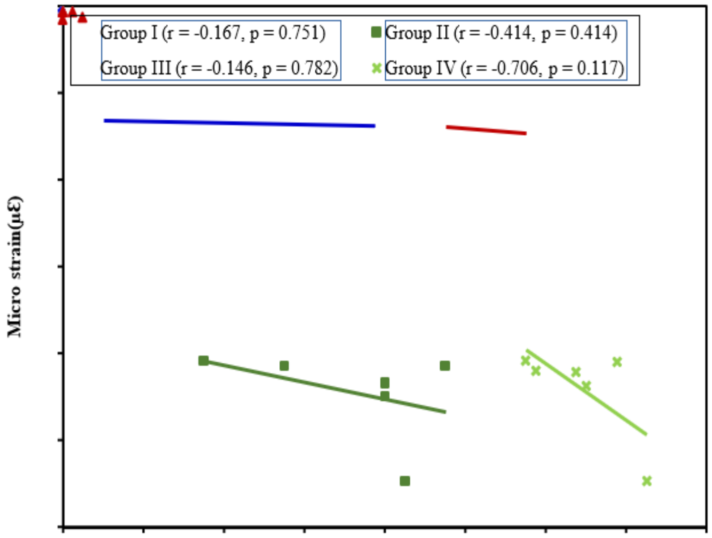

Figure (4): Comparison of correlation between insertion torque and primary stability Values for all groups: Insertion Torque (Ncm) vs. Micro Strain

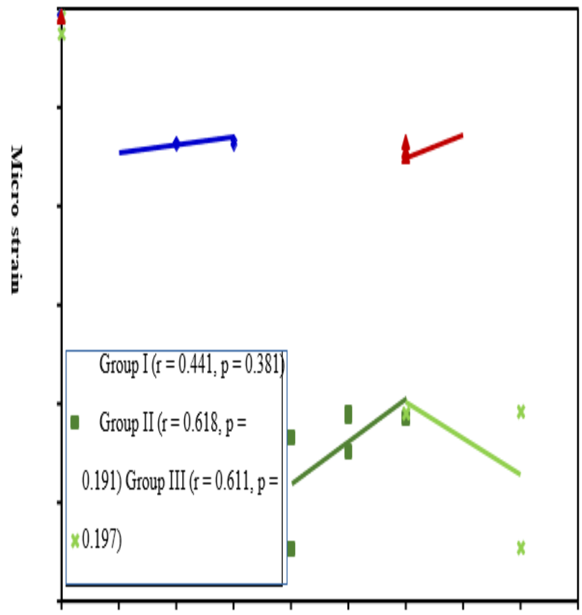

Figure (5): Comparison of correlation between insertion torque and Micro Strain Values for all groups

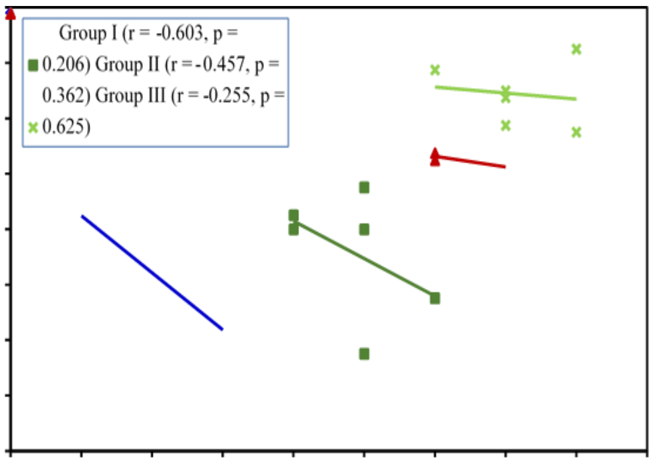

Figure (6): stability (ISQ) and Micro Strain Values for all groups

Discussion

The current findings align with previous studies showing that insertion torque (IT) and ISQ are greater for implants placed using Osseodensification (OD) drills compared to standard drilling. The OD technique's ability to preserve and condense bone during osteotomy is attributed to the creation of a denser bone environment around the implant, which enhances both mechanical stability indicators (IT and ISQ).

The positive influence of deep-threaded implants on IT and ISQ, regardless of the drilling technique, also concurs with established literature. Deeper threads provide a greater bone-to-implant contact area and better anchorage, which is especially advantageous in lower-density bone.

Strain and Bone Response

The mean micro-strain values recorded in the OD groups (II and IV) were significantly lower than those in the conventional drilling groups (I and III). The recorded micro-strain values for the OD groups (approximately 81–82με) fall within a range (200–400με) where bone remodeling is generally inactive. Conventional drilling resulted in strain values (approximately 141–142με) which are still below the threshold of 400με, a level reported as the minimum for bone formation induction and the maximum before pathological bone overload. This suggests that Osseodensification creates a more favorable, lower-stress biomechanical environment at the implant-prosthesis interface under functional load.

Conclusions

Based on the study's limitations, the following conclusions were drawn:

1. Osseodensification is an effective method for enhancing both the insertion torque and ISQ values of tapered implants in medium-quality bone.
2. Osseodensification can significantly decrease the amount of strain in dental implant prostheses during functional loading.
3. Deep-threaded implants provide comparatively higher primary stability but also exhibit a slight reduction in strain during functional loading compared to standard-thread implants.

4. Insertion torque and ISQ are important, but independent, parameters for assessing primary implant stability.
5. Greater primary stability, as indicated by ISQ results, correlates with a decrease in the overall strain observed in the implant crowns under functional loading.

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