Effect of Internal Hex Height and Collar Height on Marginal Fit of Implant Abutment Connection after Dynamic Cyclic Loading: (In Vitro Study)

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Abstract

Limited comparative data are available regarding the effect of internal hex height and abutment collar height on screw loosening and microgap formation.

Eighty stock straight abutments with different internal hex height and collar height were divided into four equal groups (N=20): twenty each according to height of hex and collar height of abutment itself. Group I: abutment with.1 mm hexagon height and 1mm collar height, group II: abutment with 0.6 mm hexagon height and 1mm collar height, group III: abutment with 0.6mm hexagon height and 3mm collar height, group IV: abutment with 0.6mm internal hexagon height and 4mm collar height. Each fixture was vertically placed in the center of epoxy resin block using modified dental surveyor. Metal tubes were fabricated to fit accurately on abutments. The samples were subjected to eccentric cyclic loading at three different intervals 10000, 100000,500000 cycles. Marginal fit was evaluated before and after each cycle by measuring microgap size in (µm) using scanning electron microscope with a magnification700x. The values of microgap size in µm before and after cyclic loading were analyzed using paired t-Student test one way ANOVA followed by Tukey's post-Hoc test.

Statistical significance differences were found between all study groups with the highest value was recorded to Group IV abutments (20.966±2.795) while minimum value recorded to Group I abutments (8.400±2.166).

Increasing the internal hexagon height and decreasing the collar height leads to increase the marginal fit of implant abutment connection.

Experimental article (J Int Dent Med Res 2021; 14(1): 79-86)

Keywords: Collar height, Cyclic loading, Hex height, Marginal fit, Scanning electron microscope.

Received date: 29 September 2020 **Accept date:** 26 November 2020

Introduction

Failure of dental implants is not only due to biological factors, such as unsuccessful osseointegration or the presence of peri-implantitis, but also results from mechanical complications such as implant body/fixture fracture, abutment screw fracture, abutment fracture, fractured prosthesis with the most frequently observed complication of screwed and cemented prosthesis is screw loosening leading to microgap formation and misfit of the implant-abutment interface.[1]

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Abutment screw loosening is a multifactorial complication; these factors either related to the screw itself, connection type, diameter of the screw, platform diameter, surface condition, vibrating micro movement, microleakage, abutment diameter, dynamic fatigue, abutment angulations, lateral cyclic loading, inadequate tightening torque and retorque, settling effect, collar length and hex height or depth.[2-15]

In external hexagon systems; the hex height was directly related to the force applied to the abutment screw with any lateral load. The external hexagon connection was proved to be ineffective anti-rotation means and can not withstand intraoral forces.[16]

The lack of intimate fit between an implant and abutment can provide an area for bacterial growth which in turn can lead to inflammation, sof tissue recession and crestal bone loss.[17] Also, implant-abutment misfit may induce screw loosening or fracture, and cause biological issues as bacterial penetration within fixture-abutment gaps.[18,19]

Internal hex implant-abutment connections were developed to overcome the clinical complications associated with external hex connections, they have a greater potential for obtaining a microbial seal between the abutment and implant than do external connections,[20] but it has the disadvantage of thin lateral fixture wall that may become compromised with large lateral force.[16]

Abutment collar height selection according to gingival thickness or in deep subcrestal positioned implants is a critical mechanical factor; selection of longer abutment may lead to increased vertical cantilever which acts as force magnifier.[21] These vertical cantilever designs increase forces on screw and lead to increase the implant abutment microgap due to the lever effect and, therefore, should be avoided.[22,23]

However, considering the abutment height from the implant platform to the top of abutment (including abutment collar height), to reduce the possibility of screw loosening reducing the cantilever length has been recommended.[24,25]

While there have been several researches investigating screw loosening, limited comparative data are available regarding the effect of different abutment collar height on screw loosening and microgap formation.

To our knowledge concerning internal hex height; none or rare researches were published evaluating the effect of its height on microgap formation.

So, the aim of this in-vitro study is to evaluate effect of three different abutment collar heights and two different internal hex heights on marginal fit before and after dynamic cyclic loading. The tested null hypothesis is that there is no effect of collar height and hex height on marginal fit between abutments and implants.

Materials and methods

Eighty stock straight abutments with different internal hex height and collar height were selected for this in-vitro study and divided into four equal groups, twenty each according to height of internal hexagon and collar height of abutment itself:

- **Group I**: abutment with 1 mm internal hexagon height and 1mm collar height
- **Group II**: abutment with 0.6 mm internal hexagon height and 1mm collar height
- **Group III:** abutment with 0.6mm internal hexagon height and 3mm collar height
- **Group IV:** abutment with 0.6mm internal hexagon height and 4mm collar height

Specimen preparation:

Eighty blocks were fabricated from epoxy resin material **(Solvent free transparent epoxy, KEMAPOXY 150)**, mixed according to manufacturer's recommendation and poured in specific stainless mold with special indicator to determine the point of implant site. After complete setting of epoxy resin blocks all implant fixtures with a length of 10 mm and diameter 4.25 mm **(Roott Dental Implant System company, Switzerland)** were inserted vertically in the center of epoxy resin block using modified dental surveyor until the implant platform situated approximately 1mm above the resin level.

Abutment preparation:

Implant abutments with different internal hex height and collar height were secured to their corresponding fixtures. The abutment screw was initially tightened with digital torque gauge at 15 N/cm according to manufacturer's recommendation. After tightening; two locations were marked on upper aspect of abutment and implant neck till the top part of the fixture as one line using carbide fissure bur, so that the same locations were observed before and after cyclic loading and also act as a guide for accurate placement of abutments in right direction and location.

Identical resin patterns for the metal tubes of each group were milled by the milling machine **(Roland, WI, USA)** and fabricated to fit accurately on abutments with an opening on top part wide enough to facilitate tightening and removal of abutment screw. The titanium abutments were sprayed with a special spray which enables the abutment to be scanned with three-dimensional (3D) scanner **(Smart optics Bochum, Germany)**. The desired design and dimensions of metal tube was achieved by (3D) software, **(Dentcrate, Exocad)** with flat occlusal surface parallel to the horizontal plane and 10 mm in width. In the center of flat occlusal surface, a small rounded hole was designed exactly opposite to the abutment screw hole.

These patterns were casted by a lost wax technique. Sprues were attached to the wax patterns, invested with a phosphate bonded investment (Bellavest SH, Bremen, Germany), heated until all remnants of wax were burned away. After burn-out, molten metal was casted into the mold created by the wax pattern and sprue. Once the investment was broken away, the sprue was removed, these castings were divested with aluminum oxide air abrasives and the casting is polished, then checked to ensure that each tube fit accurately on corresponding abutment and the screw driver easily inserted and removed.

Water balance device is adjusted over the top of the metal to ensure 180-degree surface and parallel to the floor just before cementation to the corresponding abutment, this procedure will be repeated after securing the specimens to the customized jig just before application of dynamic cyclic loading**.**

After fabrication of the metal tube, implant abutments were cleaned with ethyl alcohol then secured to their corresponding fixtures. Teflon was applied on the top part of the fixture that appear above the epoxy resin block to protect them during cementation. Cotton role and flowable composite resin were adapted above the access of screw hole of each abutment for adequate protection and preservation of the screw. Metal tubes were coated with a very thin layer of separating medium (Vaseline) left for ten minutes then glass ionomer type II cement (GIC Fuji Gold Label type II, Japan) was applied on the inner surface of the metal tube using bond brush. Excess cement was removed by using a soft baby brush. (fig-1)

Figure 1. The metal tubes attached to the four abutments.

Application of cyclic loading:

All samples were inserted in a custom jig and mounted in the lower fixed compartment of a computer controlled universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) and a dynamic cyclic load of 133 N was applied eccentrically (at a distance of 2-3 mm) away from the center of abutment using a metallic rod with round tip which was connected to the upper movable compartment of the machine. A target 500,000 cycles was defined. The load was applied at three intervals of 10000, 100000, 500000 cycles. A dynamic loading between minimum (10 N) but non-zero to avoid lateral dislocation of the loading tip during test. Force application was not randomized but in a cyclic manner and was cyclically ramped between two limits. (fig-2)

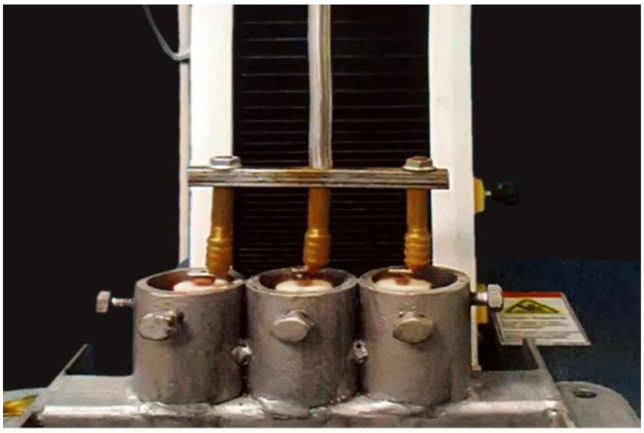

Figure 2. Loads applied using the universal testing machine.

Load profile was in the form of a sine wave at rate of (1Hz). After each interval of dynamic loading, the loading machine was stopped to visually and tactically inspect the specimen for abutment loosening or any deformation.

Measurement of micro gap at implant/ abutment interface:

After cyclic loading, each assembly was embedded in warm water to allow easily removal of metal tube from the abutment, cleaned with ethyl alcohol in an ultrasonic cleaning bath for five minutes to remove any remnants at implant abutment interface before scanning to provide clear environment for proper measurements. Each assembly was plated with thin layer of gold (20-30nm) for roughly three minutes to make the samples conductive and provide proper resolution.

Marginal fit was analyzed by measuring micro gap size at five locations (three at middle part and two for borders) at implant abutment interface before and after each cyclic loading using a scanning electron microscope (SEM) (JEOL, JSM-5500, Tokyo, Japan) with700x magnification and digital image software (Voyager EDS R 3050, Noran Instruments Inc, WI, USA). (fig-3)

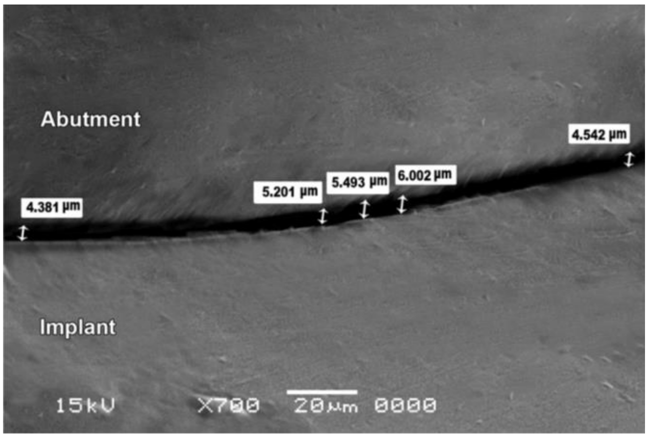

Figure 3. Scanning electron photograph of marginal fit before and after cyclic loading.

Measurements were collected, tabulated and statistically analyzed using t-Student test and one way ANOVA test followed by Tukey's post-hoc value when ($P < 0.05$) to compare mean of micro gap values between different groups and between different loading periods within the same group. **(SPSS 20; Inc. Chicago, IL, USA)**.

Results

Concerning microgap within the same group:

The microgap measurements of the four groups before cyclic loading increased significantly after different loading cycles (10000cycles, 100000 cycles and 500000 cycles) as indicated by paired t-Student test ($p < 0.05$) as shown in **table (1)** with the minimum value recorded to Group I abutments (8.400±2.166) while the highest value was recorded to Group IV abutments (20.966±2.795).

Concerning microgap measurements of different groups:

Before cyclic loading and after 1000, 100000 cycles:

The difference between four abutments with different internal hexagon height and collar height was statistically significant as indicated by one way ANOVA test ($P<0.05$) followed by pair-wise Tukey's post-hoc test ($p<0.001$) as shown in tables (1-4).

Micro GAP (um)		Groups												ANOVA	
		Group I			Group II			Group III			Group IV			F	P-value
Before	Range	0.3	-	0.6	0.8	-	1.1	1.5	-	2.5	2.9	-	3.5	621.873	<0.001*
	Mean ±SD	0.460	±	0.105	0.950	±	0.103	2.000	±	0.331	3.180	±	0.238		
10000 Cycles	Range	1.1	-	2.8	3.2	-	4.4	4.9	-	7.52	8.82	-	10.42	514.535	<0.001*
	Mean ±SD	1.878	±	0.589	3.816	±	0.435	5.984	±	0.923	9.652	±	0.582		
100000 Cycles	Range	2.04	-	4.6	5.5	-	8.4	9.7	-	10.9	11.5	-	13.9	446.394	<0.001*
	Mean ±SD	3.408	±	0.966	6.500	±	1.064	10.280	±	0.461	12.558	±	0.812		
500000 Cycles	Range	6.3	-	12	8.46	-	12.51	10.66	-	13.27	17.7	-	24.43	158.416	<0.001*
	Mean ±SD	8.400	±	2.166	10.374	±	1.441	11.686	±	1.051	20.966	±	2.795		
B-T1	Differences	-1.418	±	0.487	-2.866	±	0.334	-3.984	±	0.670	-6.472	±	0.380		
	Paired Test	<0.001*			<0.001*			<0.001*			<0.001*				
B-T2	Differences	-2.948	±	0.915	-5.550	±	0.969	-8.280	±	0.644	-9.378	±	0.663		
	Paired Test	<0.001*			<0.001*			<0.001*			<0.001*				
B-T3	Differences	-7.940	±	2.099	-9.424	±	1.429	-9.686	±	1.138	-17.786	±	2.737		
	Paired Test	<0.001*			<0.001*			<0.001*			<0.001*				

Table 1. Mean ± SD of μ-gap distances for four abutments with different internal hexagon height& collar height before and after cyclic loading. *: significant statistical difference

Groups	Micro GAP (um) Before						ANOVA	
	Range			Mean	±	SD	F	P-value
Group I	0.3	-	0.6	0.460	±	0.105	621.873	<0.001*
Group II	0.8	-	1.1	0.950	±	0.103		
Group III	1.5	-	2.5	2.000	±	0.331		
Group IV	2.9	-	3.5	3.180	±	0.238		

TUKEY'S Test					
I&II	I&III	I&IV	II&III	II&IV	III&IV
<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*

Table 2. Mean ± SD of μ-gap distances for four abutments with different internal hexagon height &collar height before cyclic loading. *significant statistical difference.

After 500000 cycle

The difference between four abutments with different internal hexagon height and collar height was statistically significant as indicated by one way ANOVA test ($P<0.05$) followed by pair-wise Tukey's post-hoc test ($p<0.001$) except between GII & GIII which are statistically insignificant ($P = 0.164$) as shown in tables (1, 5) and (fig-4).

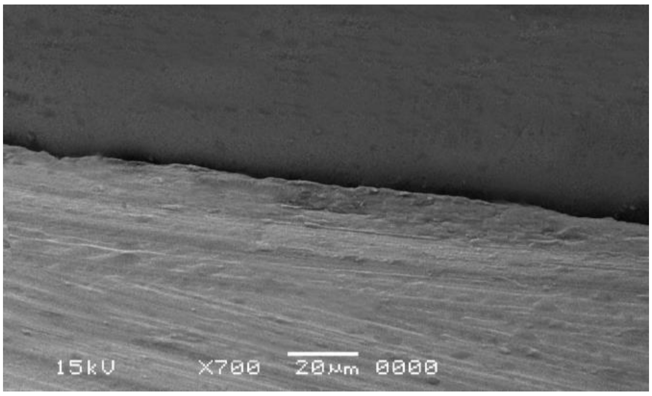

Figure A

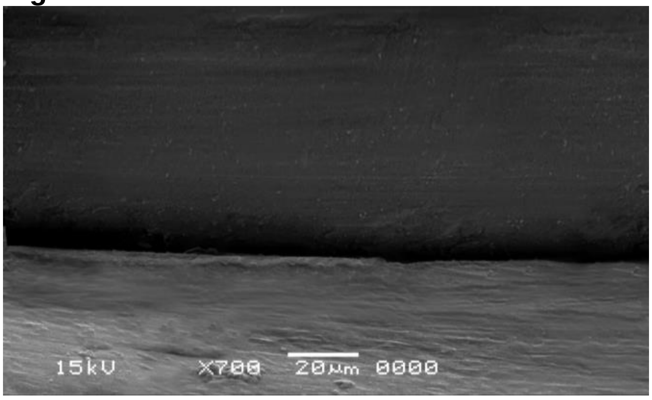

Figure B

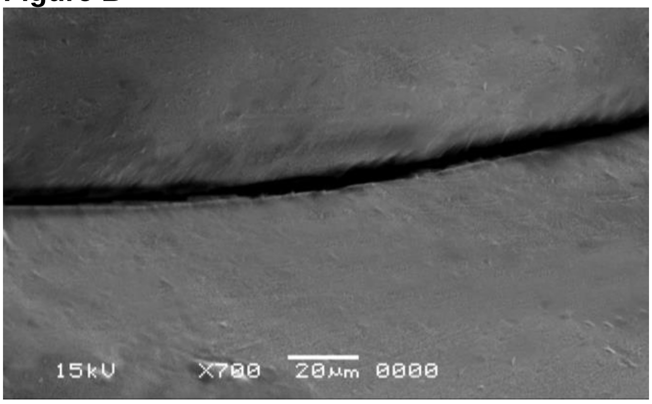

Figure C

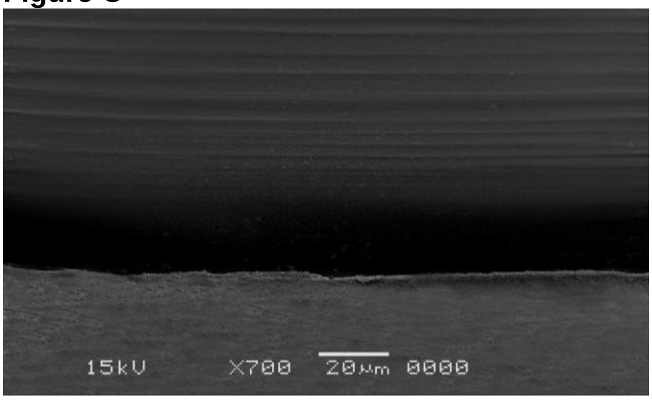

Figure D

Figure 4 A-D. Scanning electron photographs of microgap formation for the four groups after 500000 cycles dynamic cyclic loading.

Groups	Micro GAP (um) 10000 Cycles						ANOVA	
	Range			Mean	±	SD	F	P-value
Group I	1.1	-	2.8	1.878	±	0.589	514.535	<0.001*
Group II	3.2	-	4.4	3.816	±	0.435		
Group III	4.9	-	7.52	5.984	±	0.923		
Group IV	8.82	-	10.42	9.652	±	0.582		

TUKEY'S Test					
I&II	I&III	I&IV	II&III	II&IV	III&IV
<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*

Table 3. Comparison µ-gap distance results (Mean±SD) for four abutments with different internal hexagon height &collar height after 10000 cycle cyclic loading. *significant statistical difference.

Groups	Micro GAP (um) 100000 Cycles						ANOVA	
	Range			Mean	±	SD	F	P-value
Group I	2.04	-	4.6	3.408	±	0.966	446.394	<0.001*
Group II	5.5	-	8.4	6.500	±	1.064		
Group III	9.7	-	10.9	10.280	±	0.461		
Group IV	11.5	-	13.9	12.558	±	0.812		

TUKEY'S Test					
I&II	I&III	I&IV	II&III	II&IV	III&IV
<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*

Table 4. Comparison µ-gap distance results (Mean±SD) for four abutments with different internal hexagon height &collar height after 100000 cycle cyclic loading. *significant statistical difference.

Groups	Micro GAP (um) 500000 Cycles						ANOVA	
	Range			Mean	±	SD	F	P-value
Group I	6.3	-	12	8.400	±	2.166	158.416	<0.001*
Group II	8.46	-	12.51	10.374	±	1.441		
Group III	10.66	-	13.27	11.686	±	1.051		
Group IV	17.7	-	24.43	20.966	±	2.795		

TUKEY'S Test					
I&II	I&III	I&IV	II&III	II&IV	III&IV
0.012*	<0.001*	<0.001*	0.164	<0.001*	<0.001*

Table 5. Comparison µ-gap distance results (Mean±SD) for four abutments with different internal hexagon height &collar height after 500000 cycle cyclic loading. *significant statistical difference.

Discussion

The purpose of this study was to test the effect of internal hex height and collar height on marginal fit of implant abutment connection before and after dynamic cyclic loading.

In external hex connection, it was recommended that hex height should be a minimum of 1.2 mm to provide both lateral and rotational stability, particularly in single tooth applications.[26]

Although axial load produces similar level of stress on the interface regardless of design, the internal–hex interface design yields a lower stress concentration than the external–hex interface design under an off-center load.[27,28]

The current study is in agreement with El-Ashry et al.,[29] who proved that conical hybrid connection, as one of the different internal connection types, demonstrated the best stress distribution as it has a mechanical friction grip that enhance resistance to lateral forces decreasing the probability of screw loosening and microgap formation so it was the best connection to be used.[30]

Sammor et al.,[31] suggested that conical hybrid connections showed a better screw stability than an internal hex connection. Therefore, the use of conical implants can be promoted as they have better screw stability compared to other systems.

Metal tube resin pattern of each group was fabricated by CAD / CAM system to ensure standardization as CAD / CAM system has the ability to produce physical models using digital methods instead of traditional impression techniques to produce a mold for duplication with its high error rate, time consuming procedures and standardization.[32]

Each specimen was subjected to dynamic cyclic loading using universal testing machine with 133 N cyclic and frequency of 1 HZ was applied to simulate values in human mastication.[33] Dynamic cyclic loading used to simulate masticatory function mimic oral cavity that might lead to a biological and mechanical complication of implant abutment connection. Also, it is a reliable method to test the effect of mechanical fatigue on the implant abutment joint stability.[34]

Load was applied eccentric at a distance five mm away from the center of abutment to simulate the intra oral lateral component forces that have critical effects on joint instability.[35] Target of 500000 cycles was applied in this study which is equivalent to an in vivo six months mastication period.[35, 36]

According to the results of this study the more abutment collar height after dynamic cyclic loading application the more microgap formation at implant abutment connection. This finding matches previous studies of Siadat et al., [14] and El-Sheikh et al.,[37] who reported that the abutment collar length acts as vertical cantilever which acts as force magnifier.

The present in vitro-study revealed that the size of microgap measurement at implant abutment interface increased with increasing the cyclic loading up to 500000 cycles, this could be explained with the back off theory. Cibirka and colleagues;[38] described the abutment screw as a spring stretched by preload that is maintained by the frictional fit of threads. External forces can create a vibratory movement and cause threads to “back off” which leads to a reduction in effective preload and diminishes the ability of the screw to maintain the joint stability thereby increasing the implant-abutment interface gap space.

In the current study; long internal hex of abutments has the least microgap formation and more marginal fit at implant abutment interface. This can be explained that the length of the implant–abutment joint could be a reason for the differences in bacterial penetration finding a much lesser degree of bacterial leakage in internal conical connections.[39-41]

Also, it was declared that the size of microgap measurement of internal hex is less because most of the tensile force may be transferred to the internal wall instead of the abutment screw. So, this will protect the screw from loosening and increasing the gap size.[42]

Till now; no implant connection system provides an implant-abutment interface seal against bacterial penetration. Factors controlling implant-abutment connection and interface level should be considered during the choice of the implant-abutment connection system.

Conclusions

Within the limitations of this in-vitro study, it is concluded that increasing the abutment internal hexagon height and decreasing collar height will lead to decrease microgap formation between implant and abutment.

Clinical significance

Using implant systems with abutments having long internal hexagon and short collar height (if it is clinically suitable) will increase the marginal fit of implant abutment connection.

Acknowledgements

“All authors have made substantive contribution to this study and/or manuscript, and all have reviewed the final paper prior to its submission.”

Declaration of Interest

The authors report no conflict of interest.

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