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STRAIN GAUGE ANALYSIS OF TOOTH-IMPLANT-SUPPORTED FDP WITH NON-RIGID CONNECTORS USING DIFFERENT IMPLANT-ABUTMENT CONNECTIONS: INVITRO

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ABSTRACT

Purpose: To evaluate and compare the strains generated around tooth and implant supported FDPs, including a non-rigid connector, arranged in a linear configuration.

Problem Statement: clinical evidence about the connection between the tooth and implant in a fixed dental prosthesis is limited. Certain clinical situations mandate such combination however the prognosis of such treatment is of concern.

Methods: Two models were fabricated to mimic missing lower second premolar, the anterior abutment was a natural tooth and the posterior one abutment was an implant attached to its corresponding abutment. 3-unit FDPs with a non-rigid connector and of 8 mm pontic mesio-distal width were constructed, alternating the location of the non-rigid connector at either abutments. Four strain gauges were attached mesially, distally, buccally and lingually to natural tooth and implant. Uniform static axial load of 300 N was applied to the central fossa of the FDP units parallel to the long axis. Strain (μm) induced at both the implant and tooth were recorded and analyzed.

Results: Lower mean strains were induced around the tooth on placing the non-rigid connector at the implant side and using cone connection, while around the implant insignificant difference was found. Lower mean strains were induced around both tooth and implant on placing the non-rigid connector at the tooth side and using cone connection.

Conclusion: connecting teeth -to-implants must be limited to cases with only one missing tooth. Placing the non-rigid connection at implant side and using cone connection provide favorable strain distribution.

KEYWORDS: Implants, perimplant strain, implant-abutment connections, tooth implant supported prosthesis TISP, prosthodontics.

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INTRODUCTION

Nowadays, the high success rate of osseointegrated dental implants has become a clinical reality [1,2]. To restore missing posterior teeth with implant-supported fixed prostheses represents a reliable treatment option. Occasionally, due to anatomical limitations or implant failure to osseointegrate it becomes necessary to connect natural teeth and implants as abutments for fixed restorations [3]. The main difference between natural teeth and endosseous dental implants is that a natural tooth has a support design that minimizes the forces to the surrounding bone crest compared to the same region around an implant. A dental implant is in direct contact with the bone through osseointegration contrary to the natural tooth that is suspended by the periodontal ligament [PDL]. The PDL is a shock absorber that dissipates occlusal stresses away along the long axis of natural teeth, while the endosseous dental implant is in direct connection with the bone by osseointegration and thus lacks the advantage of shock absorbing capacity of the PDL [4]. Therefore, the biomechanical behaviour of implant connected to natural teeth is a complicated process due to the dissimilarity in mobility of osseointergrated implants and natural teeth [5]. Thus, whether endosseous implants should be connected to natural abutments or be self-supporting has always been an issue of controversy[6]. Osseointergrated implant is in rigid connection with dental bone allowing only 10μ movement in the apical direction, whereas natural teeth with healthy periodontal ligaments allow a movement of 25-100μ[7]. Thus, under occlusal load, the dissimilarity of movement in the splinted implant-tooth superstructure may result in high bending moment caused by the mismatch between the implant and tooth resulting in abutment screw loosening [screw-retained] or fracture of implants or prosthesis. Loss of osseointegration and increased marginal bone loss may also occur around the implant as a result of overload. One proposed design to connect implant-tooth supported fixed dental prosthesis [FDP] is the rigid connection, however, such connection maybe far from favorable as it will expose the implant to much more load than natural tooth resulting in additional strain on the implant and tissue atrophy around the natural tooth[8, 9]. Therefore non-rigid connectors were suggested to compensate for the dissimilar mobility between the dental implant and natural tooth and thus acting as stress breakers with the ability to separate the splinted units [3].The rationale is that key and keyway, with the matrix on the tooth side, would allow physiological tooth movement independent from implant which will reduce the amount of stresses when the load applied is within the implant by a factor of 24 [6]. However, an incidence of 3.4 to 37% natural teeth intrusion has been declared as a major complication of such design [3]. The intrusion phenomenon has been explained through several theories [5].The ratchet effect is one of the most common hypotheses, being described as mechanical binding between the matrix and the patrix of precision and semi-precision attachments that prevents the tooth from returning to its natural position. Debris becomes micro-jammed within the attachment acting in the same way and thus a vicious cycle is formed, where intrusion become progressively increasing. Also, the impaired rebound memory of the tooth PDL is assumed to act independently or as a contributing factor to the above mechanisms. The PDL being continually depressed in the socket under the occlusal load causes its remodeling together with orthodontic tooth movement to reduce the constant trauma [10]. Furthermore, the flexing of the FDP framework and the mandible also contributes to the intrusion of the natural tooth abutment [11]. To overcome the problem of natural tooth intrusion literature suggested the use of non-rigid connection [Key way] with the matrix on the implant side as another alternative that will allow lateral movement of natural teeth under occlusal forces [12]. However, such lateral movements may induce more stresses and thus, increase the amount of strains in the crestal bone area [13].

The design of the implant system may be another primary factor influencing the mechanism of force transmission in tooth-implant supported FDP.

Cone Connection and internal hexagon represent two types of connections for securing the abutment to the implant. However, still, it has to be determined which of these two implant connection systems will deliver even amount of stress distribution under occlusal loads, together with an optimal mechanical stability for the tooth-implant supported FDP.

The biomechanics of implant-tooth supported restorations are currently subject to investigations and to predict their behavior researchers undertook invitro studies, strain gauge analysis is used by several examiners to investigate the biomechanical loading of implants during biting actions and to determine how the stress concentration on jaw bones is affected by different types of loading [14].

Since the ideal location of non-rigid connection for implant-teeth splinting systems and the type of implant-abutment connection is till now a controversial issue; therefore the aim of the present study is to investigate the amount of microstrain induced in bone surrounding tooth-implant in fixed dental prosthesis on using non-rigid connectors at the tooth or the implant side and using two types of implant-abutment connection [internal hexagon and cone connection], under simulated occlusal vertical loading using strain gauge analysis. The first null hypothesis tested that there will be no difference in the strains generated around implant-tooth system whether the nonrigid connector is located either at the tooth side or the implant side. The second null hypothesis is there will be no difference in the strains generated around implant-tooth system on using either cone connection or internal hexagon at the implant fixture - abutment interface.

MATERIALS AND METHOD

Sample Size Calculation

Based upon the results of Harel et al [15], the computed effect size for the microstrain values was found to be [1.5], using alpha [α] level of [5%] and Beta [β] level of [20%] i.e. power = 80%; the minimum estimated sample size was four samples. Sample size calculation was performed using G*Power Version 3.1.9.2

Two representative models [1 and 2] were fabricated to mimic missing lower second premolar. In both models, the anterior abutment was a natural tooth, and the posterior abutment was an implant. The mesio-distal width of the pontic used in the study was 8 mm representing the average mesio-distal width of the mandibular second premolar.

Each implant was attached to its corresponding abutment and tightened to its required torque. Fixed dental prosthesis [FDP] with a non-rigid connector was constructed to be tooth-implant supported. FDP design was fixed-fixed bridge with a non-rigid connector. Eight FDPs were fabricated for each model; four FDP had the non-rigid connector placed mesial to the pontic [at natural tooth side], and four had the non-rigid connector placed distal to the pontic [at implant side].Table [1] and Fig.[1]

TABLE (1) Implants used in the study

Implant-abutment connection	Representing System	Manufacturer
Cone connection	InKone	http://www.ttdental.eu/ Tallinn Estonia
Internal Hexagon	Zimmer TSV(Tapered Screw-Vent® Implant System)	Zimmer-Biomet, Warsaw, IN

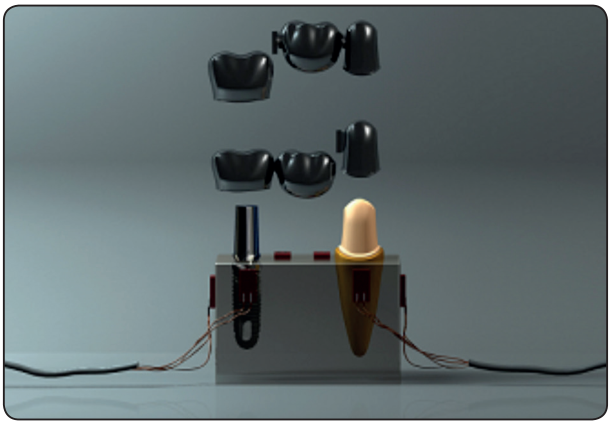

Fig. (1) Study assembly; implant,tooth and FDP with non-rigid connector

Model Construction

Two freshly extracted lower first premolars and two implant systems with their respective abutments were used [16]. The premolars were cleaned to remove periodontal ligament remnants, and then they were both prepared using a milling surveyor to receive a planar occlusal reduction of 1.5 mm, a deep chamfer finish line of 1mm thickness, and 6^0 taper. The roots of the prepared premolars were coated with wax 1 mm below the cemento-enamel junction [CEJ].

In this study two types of implant-abutment connections were used; cone connection and internal hexagon, represented by InKone and Zimmer TSV respectively. The InKone implant used was of 4.5 mm diameter and 11.5mm length with cylindrical external design; a cone-connection abutment was screwed onto it using a hand screw at 15 Ncm. The Zimmer TSV implant used was of 4.7 mm diameter and 12mm length with its ready-made 4.5 mm contoured abutment 1mm finish line, 6^0 taper. The abutment was screwed onto the implant using a torque wrench tightened at 30 Ncm.

Natural tooth and implant parallelism, pontic distance, and submersion depth in epoxy resin blocks were secured by using a custom made paralleling device. The space between vertical rods of the device was controlled by increasing or decreasing the distance between them to adjust the required pontic space mesiodisally. The vertical rods were shifted up and down to control the descent of the abutments. Both tooth and implant were secured to the vertical rods of the paralleling device using sticky wax; mesiodistal width was set at 8 mm. After complete hardening of the wax, both abutments [tooth and implant] were checked for absence of any movement. This method was separately repeated for each of the study models employed.

Epoxy resin models. A custom-made mold fabricated of putty [Elite HDS, Zermach] bearing dimensions 20 mm in height X 30 mm mesiodistal length X 15 mm buccolingual width, was placed under each tooth-implant assembly. The rods of the paralleling device were lowered into the molds at 7 mm away from its base. Auto polymerizing epoxy resin [Epoxy resin, CMC, Polypox 150, Egypt] was mixed according to manufacturer's instructions and poured into the silicone mold. This epoxy was treated as the boney block and was left to set for 24 hours. To simulate the periodontal ligament, condensation silicone [ZetaPlus Oranwash L, Zermach]. Both premolars were carefully taken out of the epoxy block, their wax coating was removed, then silicone was injected into the mold space and the premolars were re-inserted and stabilized using firm hand pressure till silicone had completely set and excess was removed . On a model trimmer the formed epoxy mold was adjusted and finished from the outside to bear dimensions 20 mm in height X 25 mm mesiodistal length X 1 mm buccolingual width.

Restoration assembly. Ready-made male and female attachments parts were used to fabricate the non-rigid connectors in both tooth-implant supported FDPs model assemblies. These parts were waxed, invested, cast and finished in the conventional manner within the FDPs waxing up. Eight FDP were fabricated; four for each tooth-implant assembly. Non-rigid Attachments were placed distal and mesial to the pontic respectively.

Wax patterns for the FDP were constructed in the usual manner ensuring their passive frictional fit. The FDPs were made as metal copings only. The alloy used to fabricate the framework was Wiron 99 [Bego, Germany].

Strain Gauge fixation: Strain gauges used were FLA-1-11, of grid size 2 mm length, gauge factor 2.12+1%, and an electrical resistance of 119.5 ± 0.5 ohm [Ω][TSL, Japan]. Manufacturer's bonding instructions were followed to bond the strain gauges. Four strain gauges were placed on each model at each aspect; mesially, distally, buccally and lingually [M,D,B,L] of the natural tooth and implant making a total of eight gauges.

Sample Testing

Loading. Samples were placed on the testing platform of the Universal Testing Machine to remain stable during load application [Instron: model LR5, LIoyd Instrument Ltd, Fareham, UK] [fig.2]. The induced strains were evaluated by applying 300N static axial load, simulating average functional loads in the posterior area[17,18]. A custom fabricated fork was used to apply simultaneous vertical load to the central fossa of FDP; the fork was fabricated in a manner that it had 3 rods of spherical shaped tips 6 mm diameter, the distance between the tips was measured equal to the distance between the central fossae of the FDP.

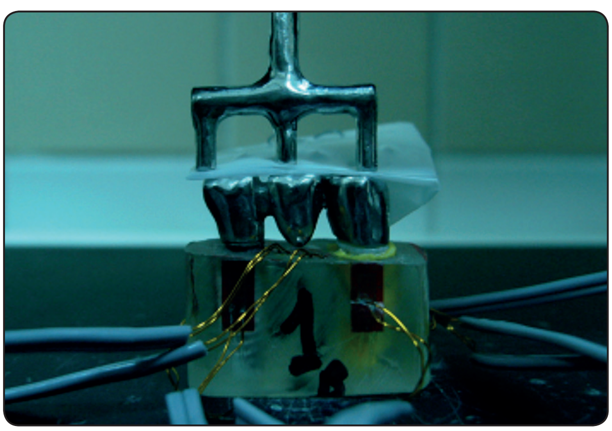

Fig. (2) Model assembly on platform of universal testing machine with fork attachment

Thin plastic sheets were placed between the fork and FDP units to evenly distribute load. The strain gauge leads were fixed to the appropriate channel on the gauge meter [PCD30A], connected to a computer programmed with the reading software [version 4.3 software - Nexygen- MT-4.6, Lloyd Instruments Ltd, Fareham, UK] to convert the volt readings to micorstrain [μm] values. Strain gauges resistive element changes its electric resistance when strained; to calculate the amount of induced strain at the attachment site [both the implant and tooth] change in resistance in response to load application was measured [μm].

For each of the natural tooth and implant the buccal, lingual, mesial, and distal strains were recorded separately from each strain gauge. All recordings were repeated 3 times, allowing the strain indicator to recover to zero strain before reloading. The generated strain was tabulated and statistically analyzed.

Statistical Analysis

Data were presented as mean and standard deviation [SD] values. Data were explored for normality by checking data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Strain data showed parametric distribution; so repeated measures ANOVA test was used to compare between the different variables. Tukey's post-hoc test was used for pair-wise comparisons when ANOVA test is significant.

The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® [IBM Corporation, NY, USA], SPSS® [SPSS Inc. an IBM company] Statistics Version 20 for Windows.

TABLE (2): Descriptive statistics and results of comparison between strains induced in the two implant – abutment connections

Non-rigid connector location	Abutment	**Cone connection**		**Internal Hexagon**		*P*-value
		Mean	SD	Mean	SD	
Implant side	Tooth abutment	81.5	23.5	194.9	54.6	***<0.001****
	Implant abutment	57.9	16.9	49.6	17.1	0.065
Tooth side	Tooth abutment	83.4	20.2	322.8	92.3	***<0.001****
	Implant abutment	104.5	36.6	136.1	40.1	***<0.001****

**: Significant at $P \leq 0.05$*

RESULTS

Results of the two implant systems [Cone connection and Internal Hex] Table [2]

Placing the non-rigid connector at the Implant side; cone connection displayed *statistically significantly lower mean strains* [81.5±23.5] than internal hexagon [194.9±54.6], around the tooth. While they displayed *no statistically significant* difference around the implant; the cone connection was [57.9±16.9], and internal hexagon was [49.6±17.1]

Placing the non-rigid connector Tooth side; cone connection displayed statistically significantly lower mean strains than internal hexagon around both the tooth [83.4+20.2; 322.8 +92.3] and the implant [104.5±36.6, 136.1±40.1] respectively.

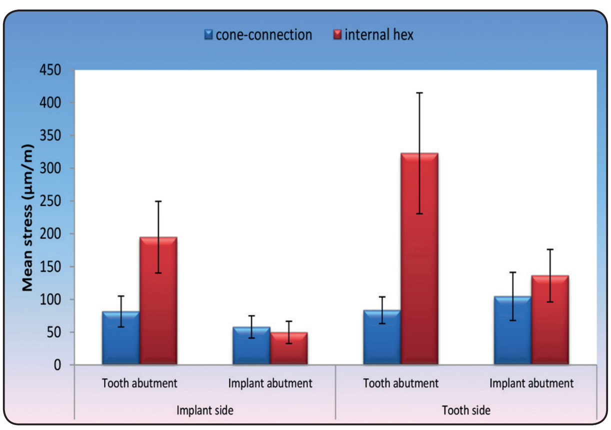

Fig. 3. Bar chart representing mean and standard deviation values of strains induced using the two implant systems

DISCUSSION

The first null hypothesis of this study stated that there will be no difference in the strains generated around the implant-tooth system whether the non rigid connector is located either at the tooth side or the implant side, was rejected. According to the results placement of the non rigid connector significantly affected the microstrains, being placed at implant side showed lesser strains than placing it around the tooth.

The second null hypothesis stated that there will be no difference in the strains generated around implant-tooth system whether cone connection or internal hexagon is used was also rejected. According to the results the type implant-abutment connection significantly affected the microstrains; cone connections showed significantly lower strains compared to the internal hexagon. Literature demonstrated that microstrain values of 200-2500 μm fall within the physiological range [19] thus the results of the present investigation were all found to be within the physiological range.

Although totally implant-supported FDPs are more success predictable; sometimes there are several situations where clinicians must consider a restoration connecting implants and natural teeth. This combination is most commonly indicated in the posterior areas with anatomic limitations, where there is insufficient bone housing for implants [20].

Connecting implant to natural tooth abutment is thought to provide additional support for the restorative system [21] For decades, tooth-implant-supported fixed prosthesis have been questioned due to differences in the degree of mobility between the abutments, the risk of natural tooth intrusion, mobility, as well as atrophy of the periodontal ligament[22]. On the other hand, high risk of mechanical complications has been found on the implant side, such as screw loosening or fracture, abutment or prosthesis fracture, or even implant fracture which are signs of occlusal overloading for such design [22]. Bone resorption or apposition are also influenced by the level of strain induced in bone [23,24].

Therefore, due to the great difference in mechanism of absorption and dissipation of force between osseointegrated implant and natural tooth a biomechanical dilemma was raised from such union [25].

Since tooth and implant are elements of different nature, the movement of prosthetic abutments represents a major restorative challenge, especially with immobile rigid connections. Natural teeth have a certain degree of movement ten times greater than osseointegrated implant, thus when connecting natural teeth to dental implants using a rigid fixed prosthesis, the total load is supported by each element in proportion to their hardness, which in return increases the additional overload exerted on the implant bone interface. Therefore, non-rigid connections have been considered to compensate for the differences in stiffness and to act as stress-breakers[3]. Placing a non-rigid connection with the matrix at the tooth side offers a great advantage as it allows physiological tooth movement under occlusal load [20]. However, clinically natural tooth intrusion was correlated to this type of connection [3,26], together with increased cantilever stresses to the implant and supporting bone, inducing both technical and biologic complications [27,28].

Placing the non-rigid connection at the implant side is another alternative that rationally addresses the problems of bending forces to the implant as a result of cantilevers and natural tooth intrusion by distributing loads between the two abutments [tooth and implant][29].Previous studies revealed that implant connected to natural tooth with non-rigid connector was of good prognosis. Also long-term radiographic evaluation revealed less bone loss around the implant compared to rigid connectors [3,30].

In view of that, a three unit fixed partial denture restoration was constructed with non-rigid connector being placed either at the tooth or implant side.

The transfer of occlusal loading is also influenced by the precision of the implant-abutment connection, cone connection and internal hexagon represent the most common type of implant-abutment connection that induces passivity of fit. Therefore this study aimed to determine the amount of strain induced by occlusal vertical loads in bone surrounding tooth-implant fixed partial dentures using non rigid connectors at the tooth or implant side and two types of implant-abutment connection.

The amount of peri-implant strains induced in bone are more excessive during horizontal movements than vertical and are usually more pronounced in the anterior region. Thus connecting implant to natural posterior teeth may increase the success of implant-tooth supported restorations [31]. Therefore, for this study two posterior models with missing mandibular second premolar were constructed having mandibular first premolar tooth as anterior abutment and implant as posterior abutment at the site of mandibular first molar.

In the present study, the implant-tooth assembly was embedded in a homogeneous epoxy resin model having similar modulus of elasticity to bone and around the natural tooth a layer of polyvinyl siloxane impression material was injected to simulate the modulus of elasticity of periodontal membrane and its cushion effect [32].

When an occlusal load is applied upon implant-tooth assembly, the load is partially transferred to the bone, with the highest stresses occurring in the implant's most cervical region [33].Therefore in the present investigation, four strain gauges were placed cervically on the mesial, distal, buccal and lingual surfaces of the epoxy resin adjacent to the implant and the natural tooth which was proved by previous studies to be the location of high strain concentration after load application[34,35]. The strain gauge analysis was selected since it is a non-destructive approach; and it provides better understanding of the biomechanical behavior of dental implants [36, 15]

For strain measurements, 300 N static axial load was applied to the whole assembly which is considered the average functional loads in the posterior region[37, 18]. A custom-made fork was fabricated to apply uniform multiple axial functional load to the central fossa of the FDP units parallel to the long axis.

The results of this study displayed that on placing the non-rigid connector at the implant side, the induced peri-implant strains were lower than those around the tooth. However on placing it at tooth side strains around the tooth showed an increase compared to those when the non-rigid connector is placed at implant side.

The results of this investigation, were in agreement with Cohen and Orenstein [38] and deSilva et al [39] who explained that placing the female component of the non-rigid connector on the crown of the implant will prevent implant moment, they also justified that this conduct would guarantee stability of the tooth, avoiding its intrusion by means of the support provided by the implant. Furthermore, the implant would be protected from excessive lateral forces by means of the reduction in the cantilever effect exercised by pontic extension to the tooth.

The results of the present study were also in consistence with Lin et al [40] who declared that use of semi-rigid connection increased the stresses around the implant as it was the only support to the load. They attributed their findings to the location of the female connector being placed on the crown of the tooth.

Regarding the Influence of implant–abutment connection literature has displayed that the mode of implant-abutment connection is of a considerable role in biomechanics, where cone connection shows more favorable results compared to other internal abutment connections [41]. In this study using cone connection displayed strain results less than internal hexagon, this finding can be attributed to the conical interface of the Morse taper which helps to disperse the forces to the fixture [42]. This finding is concordant with Chu et al [43] who demonstrated that the peri-implant bone stresses were reduced due to either an increase in the thickness of the inner wall of the implant body or decrease of the width of the implant–abutment connection. The outcomes of the present study were also in agreement with Hansson's studies [44,45] who stated that marginal bone resorption could be reduced on using a conical interface, as the peak bone-implant interface shear stress takes a more apical location

Therefore connecting teeth to implants still remains a practical treatment modality, provided that natural tooth abutments involved be of good prognosis preferably not root canal treated or periodontally compromised, to warrant satisfactory long term prognosis [46]

One of the limitations of this study was that no osseointegration was actually accomplished as the results of this study were only limited to models highlighting the biomechanical trends under average situations of axial loading. Further studies are needed to evaluate the effect of obliquely directed load, also other types of non-rigid connection must be investigated.

CONCLUSION

Within the limitations of this in vitro study the following conclusions were drawn

1. The connection of teeth –to-implants must be limited to cases with only one missing tooth, with the non-rigid connection being placed at implant side.
2. Cone connection provides favorable strain distribution.

Disclosure/ Conflict of Interest

The authors declare no conflict of interests in the companies or products used in this paper.

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