

Evaluation of stress distribution of fixed partial dentures over straight and inclined implants in various macrodesigns by the photoelastic stress analysis method

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ABSTRACT

Aims: Tooth loss results in many problems, such as functional and esthetic problems, which may also have psychological implications. Dental implants are revolutionary improvements in functional and esthetic rehabilitation. Biomechanics is the one of the main factors for achieving the long-term success of implant-supported prostheses. It is important to distinguish the effects of macrodesign differences over stress distribution. **Materials and Methods:** In this study, the photoelastic response of four different types of implants that were inserted with different angulations and restored with 3-unit fixed bridges were comparatively analyzed. The implant types investigated were screw cylinder (ITI, Straumann AG, Basel, Switzerland), stepped cylinder (Frialit2, Friadent GmbH, Mannheim, Germany), root form (Camlog Rootline, Alataec, Wilshelm, Germany) and cylindrical implant with microthreads on implant neck (Astra, AstraTech, Mölndal, Sweden). In the test models, one of the implants was inserted straight while the other one was aligned mesially with 15° angles. Superstructures were prepared as 3-unit fixed partial denture FPD restorations. A 150 N loading was applied to the restorations throughout the test. Observations showed that misaligned implants caused less stresses than the straight implants, but the stress concentrations were not homogenous. **Results:** The comparison of implant designs showed that there were no significant differences between straight implants; however, between inclined implants, the most favorable stress distribution was seen with the stepped cylinder implants. The least favorable stress concentration was observed around the root-formed implants. Microthreads around the implant neck appeared to be effective in homogenous stress distribution. Observations showed that misaligned implants caused less stresses than the straight implants but the stress concentrations were not homogenous. **Conclusion:** While loading on a single implant, the remaining implant was not very effective at stress distribution. Cylinder type implants were better at stress distribution than the tapered implants while stress concentrations were lower around the inclined implants than the straight implants.

Key words

Biomechanics, inclined implants, implant macrodesigns, implant-supported fixed partial denture, photoelastic stress analysis, stress distribution

INTRODUCTION

Implant design is a crucial factor in implant biomechanics. In each situation, certain implant types, shapes and sizes and restorative scheme might be more or less advantageous. Selection of a specific implant system should be made after careful consideration of the specific needs of the patient.

Many designs have been introduced to optimize bone and soft tissue loading under conditions of applied axial and oblique direction of compression, tension and torque. Macroscopic geometric characteristics are used to distribute applied forces under conditions of compression, tension and shear along the implant-tissue interferences.^[1]

Major stresses occur around implants during mastication. If these stresses are too great, they can cause resorption of bone, leading to infection around the implants and failure of oral rehabilitation.^[2] To prevent these complications, it is necessary to understand where the maximum stresses occur during mastication around the implants.^[3]

There are many implant manufacturers with many implant designs, regarding the best choice is their

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implant. Macrodesign are one of the main differences of the commercially available implants. At this point it is important to distinguish the implant macrodesigns and their affects on the stress distribution.

Photoelastic stress analysis (PSA) is based on the optical property of certain resins, that shows stress formation inside the model by color changes. The greatest advantage of the photoelastic method is the ability to visualize the stresses in complex structures such as oral structures, and to observe the stress patterns in the whole model, allowing to localize and to quantify the stress magnitude. The higher the N (fringe order) and fringes number are, the greater the stress intensity.

Using the photoelastic stress analysis method (PSA), the main objective of this study was to determine whether macrodesign changes affect the stress distribution around splinted straight and inclined implants.

MATERIALS AND METHODS

The photoelastic approach was selected to determine the load transfer differences between the straight placed and inclined implants. The models were prepared with photoelastic resin (PL-2; Measurements Group Vishay Measurements Group, Raleigh, USA). A 7 cm × 5 cm × 1 cm glass mould was used to mould resin and to prepare the models.^[4,5] A block model was used instead of a life-size mandible model as it was briefed that smaller models were suitable for parameter studies.^[6-12] The photoelastic model was prepared according to the manufacturer's directions and by the poured resin technique that has been used to represent a complete osseointegration.^[13]

Four different implant types were included into the study. Implant lengths and diameters were selected as close as possible to each other. The differences of the lengths and the diameters were dependent on the different manufacturers of the systems [Table 1].

All the restorations were cement retained. Conventional restorative techniques were used to fabricate the fixed restorations. Impressions were taken with

polyvinyl siloxan impression material (Affinis, Coltené Whaledent AG, Altstätten, Switzerland) and restorations were fabricated on stone casts. Ni-Cr alloy was used for metal substructure and finished with conventional porcelain (Vita Omega Metalkeramik Vita Zahanfabrik Badsackingen Germany). The dimensions of the restorations were kept constant with a silicone putty matrix.

The restorations were cemented with temporary cement (RelyX Temp NE, 3M ESPE, Seefeld, Germany) in order to prevent any movement of the restoration while loading.^[4,14]

Vertical loads of 150 N were applied on the central fossas of the premolar (over the straight implant), first molar (pontic) and second molar (over the inclined implant) separately. This load was selected because it was within the realistic load levels and provided satisfactory photoelastic response.^[4,8,12,13,15-17]

The models were immersed in a mineral oil tank to minimize surface refraction and facilitate photoelastic observation. The load-induced stresses were monitored in the field of a circular polariscope and the images were captured at the loading area with a digital camera (Panasonic DMC-FZ30EG, Matsushita Electric Industrial Co. Ltd., Japan). Each loading was repeated at least two times to ensure reproducibility of the results.

The evaluation of the stresses was made according to the concentration, number and localization of the fringe orders formed around the implants [Table 2].

RESULTS

Loading over straight placed implants

Stress concentrations were observed at the loaded implant's apex at all the implants and also around the implant neck [Figure 1]. Stress distributions were similar between the stepped cylinder and root form implants. The highest stress concentration was observed at the stepped cylinder implant's apex. Root form implants and then screw cylinder implants followed this. The lowest

Table 1: Implant types used in the study

Trade mark	Diameter (mm)	Length (mm)	Abutment angle (°)	Type	Manufacturer	Implant-abutment connection
Astra	4.0	11	15°	Screw cylinder with micro threads on implant neck	Astratech, Mölndal, Sweden	Conical seal design
Camlog	3.8	11	15°	Rootline. Root form	Alatatec GmbH Wilshelm, Germany	Tube in tube, camslot fixation
Frialit 2	3.8	11	15°	Stepped cylinder	Friadent GmbH Manheim, Germany	Internal hexagonal
ITI Straumann	4.1	10	15°	Screw cylinder	Institut Straumann AG Basel, Switzerland	Morse taper

stress at the apical site was observed around the screw cylinder-type implant with microthreads, which had a flat apex unlike the other types' rounded apices. The most homogenous stress distribution was observed around this type of implant.

Lower stresses were observed around the inclined implant. Stress concentrations were mostly observed around the implant neck, at distal sides and at apical sites. Highest stress was observed at the root form implant's apex. Screw cylinder-type implants (ITI, Astra, AstraTech, Mölndal, Sweden) had similar stress concentrations, while the lowest stress concentration was observed around the stepped cylinder implant.

At marginal sites, the highest stress was at the root form implant. Screw cylinder w/microthreads at implant neck and stepped cylinder implant had similar stress concentrations. Almost no stress was observed around the screw cylinder.

When the stresses at distal sides were observed, stresses were very low at all of the implants.

Loading on inclined implants

When the load was applied, the stresses occurred mostly around the loaded implant. The highest stress was observed at the apex of the root form implant. Stress distribution was similar between stepped cylinder and screw cylinder w/microthreads around the neck implant. The stresses at the apical of the screw cylinder were slightly lower than that of the other implants. The highest stress concentration around the marginal site was observed at the root form implant. Screw cylinder w/microthreads on implant neck, stepped cylinder and screw cylinder implants followed this.

The highest stress concentrations around the straight placed implants were observed at screw cylinder and screw cylinder w/microthreads at implant neck implants' apices. The stress distributions of these two implants were formed similar. There were also lower stress concentrations at the mesial side of the marginal sites. At the tapering implants' (root form and stepped cylinder) apices, very low stress concentrations were observed. There were also low stress concentrations at the distal side of the marginal sites [Figure 2].

Loading on pontic

Stress distributions around the implants were distributed more balanced when the restoration was loaded on the pontic. Besides this, stress concentrations were mostly observed around the straight placed implant.

Stresses around the straight implants were concentrated mostly at the apical site of the implant. The highest stress at the apical site was observed around the stepped

Table 2: Fringe order

Color	Approximate relative retardation		Fringe order
	nm	in $\times 10^d$	
Black	0	0	0
Pale yellow	345	14	0.60
Dull red	520	20	0.90
Red/blue transition	575	22.7	1.00
Blue-green	700	28	1.22
Yellow	800	32	1.30
Rose red	1050	42	1.82
Red/green transition	1150	45.4	2.00
Green	1350	53	2.35
Yellow	1440	57	2.50
Red	1520	60	2.65
Red/green transition	1730	68	3.00
Green	1800	71	3.10

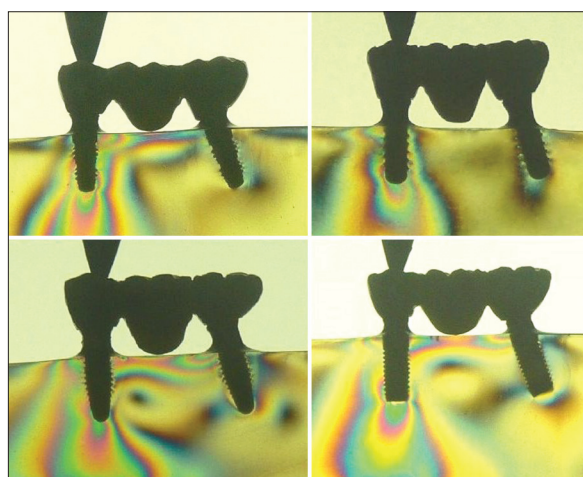


Figure 1: Loading on straight implant

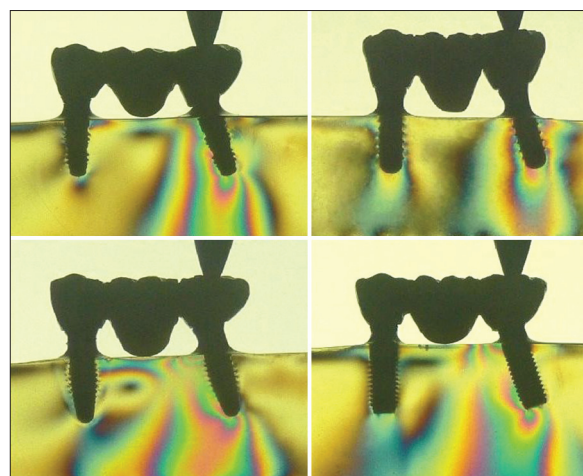


Figure 2: Loading on inclined implant

cylinder, root form, screw cylinder w/microthreads around implant neck and screw cylinder implants in order. At the margin, the highest stress was observed

around the stepped cylinder implant. Screw cylinder and root form implants followed this. The lowest stress was observed around the screw cylinder w/microthreads around neck type implant.

The highest stress at the apical site of the inclined implants was observed at the screw cylinder. Root form and screw cylinder w/microthreads around neck implants followed this. The lowest stress was observed around the stepped cylinder implant.

At the distal side of the inclined implants, highest stress was observed around the screw cylinder implant. At the distal side of the root form implant, low stress was observed while no stress was observed in the screw cylinder w/microthreads around implant neck and stepped cylinder implants.

Highest stress at the marginal site was at the screw cylinder implant. Low stress was observed at the mesial of the screw cylinder w/microthreads around the neck implant's marginal site. Stress at the margin of stepped cylinder and root form implants were lower than the others.

Most balanced stress distribution was observed around the screw cylinder implant. The stress distribution forms were alike at the apical site [Figure 3].

DISCUSSION

As the stress distribution around the dental implants cannot be measured by sensors, their quality and quantity inside the bone is hard to measure.^[4] Because of these difficulties, biomechanical studies are mostly done *in vitro*. Photoelastic stress analysis (PSA) is used extensively to study the biomechanics of stress transfer in dentistry, besides other methods. However, the PSA has some limitations like other methods. The resin that was used to simulate the bone is homogenous and has

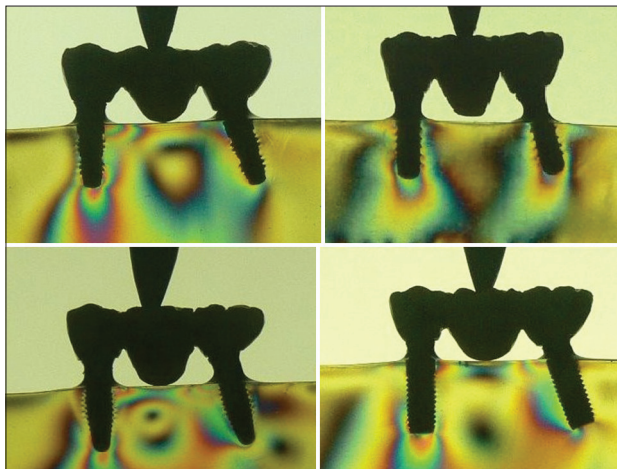


Figure 3: Loading on pontic

isotropic characteristics, but the bone is not homogenous and anisotropic. Photoelastic resin increases the stresses as well. Because of these reasons, the results of the studies do not resemble the actual values. But, in light of the answers taken from the studies, information about the behavior of the implants and the bone under stresses can be achieved.

PSA and finite element stress analysis (FEA) are two different ways to study biomechanical behaviors of dental implants. The main difference between these two analyzing methods is the localization of the stress concentrations. In a FEA study, stress concentrations tend to be higher mostly around the implant neck while in PSA studies, stresses at the implant apex tend to be higher.^[6-8] This situation is independent from the implant type used or the implant abutment connection.^[6-8] Implant surface characteristics and changes of implant designs would show differences in a homogenous photoelastic model.^[13]

In previous studies, various loading points were chosen. The two common loading points were functional cusps and central fossas.^[12-25] For ideal loading of implants used as posterior teeth, implants should be inserted under the central fossa.

Under loading conditions, straight placed implants show symmetrical fringe patterns while the inclined implants show non-symmetrical patterns.^[6] In this study, the results seemed to be parallel with Brosh's study.^[6] Fringe patterns were observed at the inclination side. At the inclined implants, vertical loading would not be parallel to the implant axis, which would act like oblique loading and cause non-symmetrical stress distribution and fringe patterns.

Inclined implants are told to survive longer than the straight ones.^[22] Mandibular molars are inclined 10° mesially and maximum stress values around the straight placed implants are higher than a 10° inclined implant. An inclined implant is said to have greater surface area to support occlusal plane.^[23-24] In this study, the stresses around the inclined implants were slightly lower than in the straight placed implants, but they were not homogenous and non-symmetric. Localization of the stress concentrations may induce bone resorbition.

There are various implant designs in the dental market. Studies showed that the implant design had a great effect in primer stabilization.^[26-28] Wider and longer implants had better stress distribution specialties.^[9,29,30] Besides this, very wide implants might cause a reduction in the bone support, which would cause the stresses to increase.^[31] The manufacturers are trying to improve their designs just to make a step forward and this enables the clinicians to find many implants with different characteristics, macrodesigns, microdesigns, lengths and

diameters. With this variety of implants the clinician will be able to use the optimum implant. On the other hand while comparing the implants in a study, like ours, it is unable to find implants with the same diameter and the same length. This absolutely affected the outcomes of the study which we had to accept.

While Petrie *et al.* and Mailath *et al.* stated that long, wide and straight (not tapered) implants had better stress distribution characteristics, Holmgren *et al.* stated that the stepped cylinder types had better stress distribution than the cylindrical and tapered implants.^[29-32] Stepped cylinder implants provide loading the cortical bone better than the root form implants.

Geng *et al.* stated that under vertical loading, stepped cylinder implants did not show significant differences, but, under oblique loading, they showed better stress distribution than the cylindrical implants.^[16]

Splinted crowns reduce the stresses around the implants.^[33-34] But, under localized loading, over one of the implants, the remaining implant did not participate in sharing the loads actively. In clinical follow-ups, some researchers found similar success rates between splinted and non-splinted crowns.^[35]

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

- When implants were splinted with restorations, stresses are shared by both implants when the load was applied between the two implants. When the load was applied on one of the implants, the remaining implant was not very effective at stress distribution. At splinted/bridge type restorations after vertical loading, highest stress concentrations were observed around the root form implant. At splinted/bridge type restorations after vertical loading, lowest stress concentrations were observed around the screw cylinder w/microthreads around implant neck implant
- Cylinder type implants are better at stress distribution than the tapering implants
- Stress concentrations were lower around the inclined implants, but the distribution patterns unfavorable.

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