MICROSTRAIN AROUND DENTAL IMPLANTS ASSISSTED MAXILLARY OVERDENTURE USING TWO DIFFERENT ATTACHMENT DESIGNS IN VITRO STUDY

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ABSTRACT

INTRODUCTION : Tilted implants were suggested as a treatment option for sever bone resorption. The use of angle correcting attachments is a must in the cases of tilted implants.
OBJECTIVES: Comparing the micro strain around tilted implants and axial implants placed according to the all on four concept which were connected to two different attachment designs using.
Material and methods:Identical maxillary epoxy resin models were used. Four implants were placed in each model. The two anterior axial implants in the incisors area and two posterior 25-degree tilted implants in the canine – premolar area. For Group I model OT-Equator attachment were connected to all four implants and smart box female housing were used on posterior tilted implants for angle correction. for Group II model Straight Positioner attachments connected to anterior parallel implants and angulated Positioner attachment connected to posterior tilted implants. Two strain gauges were placed mesial and distal to each implant. A universal testing machine and strain meter were used to evaluate micro strain after load application.
RESULTS : There were statistically significant higher micro strain values around tilted implants when compared to micro strain values around axial implants of both groups. There was no statistically significant difference when comparing micro strain around tilted implants and axial implants of both groups.
CONCLUSIONS: There was no difference in micro-strain around tilted implants connected to both attachment designs. the tilted implants showed micro strain values higher than axial ones in both groups. Tilting the implants was associated with unequal force distribution.
KEY WORDS: Tilted, Axial, OT Equator, Smart Box, All on Four.
RUNNING TITLE: Comparing micro strain around tilted implants with different attachment designs.

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INTRODUCTION

The success of the complete denture is affected by quality and form of the remaining residual ridge. The denture's retention, stability and chewing efficiency were reduced When restoring an atrophied residual ridge which reduces the patient's satisfaction and overall quality of life. (1, 2)
The introduction of implants to retain denture was proven to be a successful treatment option. (3) However, increased implant failure rates were observed in the posterior maxilla due to the poor bone quality. (4, 5) This was further complicated by the pneumatization of the maxillary sinus which reduces the amount of bone available for the construction implant supported restoration. (6)
Sinus lift procedure was suggested to help restoring atrophied maxilla. poor acceptance of this procedures was met due to its invasive nature, high cost and post-surgical complications. (6,7)
Multiple treatment alternatives were proposed as placing the implants in zygoma or pterygoid region but they were also found to increase cost, duration of

treatment and possible complications. (8) Short implants offered reduce surgical complications but were not yet proven to be a successful option due to the reduced implant to bone contact and the poor bone quality. (9)

Tilting the implants allows the placement of longer implants, which increases the degree of implant-to-bone contact area, implant primary stability and inter-implant distance. It's considered as a less invasive option than sinus lift and bone grafting procedures. (10)

The all on four concept suggested the use of anteriorly placed axial implants and posterior tilted implants for the treatment of atrophic maxillary arches. (10) This implant placement protocol was used when restoring the resorbed maxilla with an implant overdenture. (11)

The tilt of the implants requires the use of angle correcting attachments. The OT Equator attachment is a low-profile attachment which is characterized by its small dimensions and divergence correcting features (up to 28 degrees). Smart Box housing was recently developed that can compensate for extreme divergence of the implants due to its inner tilting mechanism that allows for a passive insertion. (11)

The Locator attachment is considered one of the widely used attachments to support an overdenture . (12) It's a universal hinge, resilient overdenture, self-aligning and low-profile attachment. It can correct up to 30-degree divergence per implant. (13) The use of angled Locator attachments utilizes the benefit of conventional Locator attachment while correcting severe implant angulations. (14)

One of the drawbacks of implants tilting is the unequal force distribution. In vitro studies found that increasing the implant angulation may result in unfavorable stress concentration. In a clinical situation, unfavorable forces may result in bone resorption and ultimately implant failure. (15-17)

Multiple techniques are available to evaluate stress around dental implants which include elastic photos analysis , finite element analysis and strain gauge analysis. (14,17,18)

This study compared the micro-strain values around tilted implants connected to straight attachments (OT Equator) with angle correcting housing (Smart Box) in group I and when connected to angled attachments (Positioner) using strain gauges in group II.

It also compared the micro-strain values around OT Equator attachment with Smart Box housing connected to tilted implants and OT Equator attachment with conventional housing connected to axial implants in group I and around angled Positioner attachments connected to tilted implants and straight Positioner attachments connected to axial implants in group II.

MATERIALS AND METHODS

A ready-made completely edentulous maxillary models made from epoxy resin were used (Ramses medical products factory, Alexandria, Egypt). A uniform layer of polyurethane 2 mm in thickness was added to simulate resistant mucosal tissue. For the fabrication of the acrylic removable denture, stone replicas were made of the epoxy models.

Complete denture fabrication

Chemical cure acrylic resin was used for construction of trial denture base on which wax occlusion rims were made on maxillary and mandibular stone casts.

The models were mounted on a mean value articulator and maxillary trail denture bases were constructed with the same set size of acrylic teeth on the same mounting while keeping the opposing mandibular trail denture to ensure standardization.

The trial denture bases were waxed up, flasked, packed with heat cure acrylic resin and cured using conventional methods. Following the deflasking procedure they were finished and polished.

3D printed surgical guide fabrication

Dual scanning of epoxy resin model and the completely edentulous denture was done to design the 3d printed surgical guide using an extraoral scanner. (PaX I Insight, Vatech, Seoul, Korea). DICOM files were used on 3d planning software (OnDemand3D, Cybermed Inc., Seoul, Korea) to determine the position, angulation, length and diameter of each implant. The virtual plan was to place four implants in the inter bicuspid region. The two anterior implants were planned to be placed axially corresponding to the positions of the laterals with 10 mm length and 4 mm width. The two posterior implants were planned to be placed divergent to 25° corresponding to the positions of the first and second premolars with 12 mm length and 4 mm width. The virtual plan was saved as a STL file and then sent to be printed using a 3D printer (Formlabs, Somerville, MA, USA).

Implant placement procedure

The surgical guide was placed on the epoxy model and tags of the mucosal simulating material was removed using a rotary tissue punch. (Figure 1)

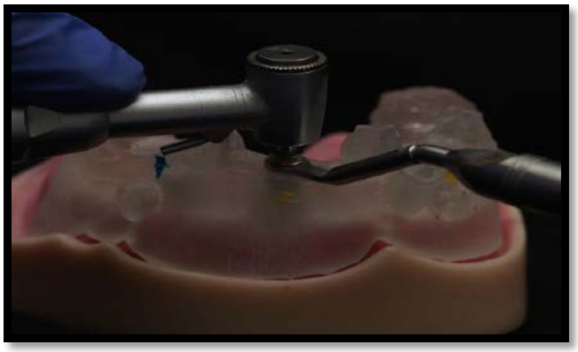

Figure (1) : After the CAD/CAM Surgical guide was placed on the epoxy model. Drilling using the universal drilling kit to ensure accurate preparation of the implants site to the desired length, diameter and angulation while maintaining standardization across all groups.

A universal surgical kit was used to drill in the epoxy model using the recommendations of the manufacturer. The kit contains successive diameter drill sleeves with horizontal indicators that was used with the surgical guide during the drilling procedure to accommodate the successive increasing in drills diameters.

The universal kit drills and sleeves were used up to 3.8 mm diameter then the surgical guide was removed. After the surgical guide was removed the final drill of the implant system (4 mm) was used to finish drilling the anterior and posterior implant sites.

The implant was placed in the drilled sites and rotated clock wise until noticeable resistance was meet then a torque wrench was used to insert the implant to the crest of the ridge 2mm below the gingival simulating layer.

Pick up of the attachments

Group I four OT Equator attachments were placed on anterior and posterior implants and tightened using torque wrench according to manufacture instructions. Conventional housing was used on anterior implants and Smart Box housing on posterior implants. (Figure 2)

Group II two straight Positioner attachments were used on anterior implants and 25-degree Positioner attachments were used on posterior implants. Their standard housing was used on all implants. (Figure 3)

The location of the housings was marked by seating the denture on the epoxy model after marking the housings with indelible pencil. The denture was gradually relived until the denture was completely seated on the model. Four vent holes were created palataly to allow excess material to be released. Chemically cured acrylic resin was mixed and used when it reached dough stage in the denture s relieve holes which was then seated on the mode model until the material has set.

After the denture was removed from the model excess material was removed and the dentures was finished and polished. Processing inserts were removed and replaced with the final nylon caps. (Figure 4)

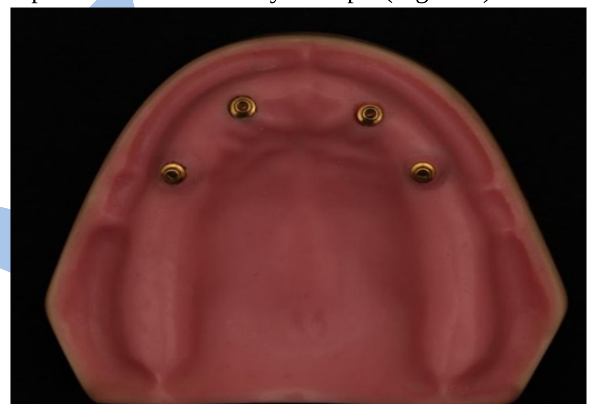

Figure (2): Group I where OT Equator attachment was placed on anterior axial implants and posterior tilted implants.

Figure (3): Group II where straight positioners attachments were placed on anterior axial implants and angled Positioner attachments were placed on posterior tilted implants.

Stress analysis

preparation of the epoxy model

The areas where the strain gauges were to be placed where marked and gingival simulating layer was removed with a number 15 scalpel blade. The surface of the model was prepared by lightly smoothing any irregularity using a stone bur on a low speed hand piece. Channels or openings were created using a carbide bur below the denture flanges to allow the wires of the strain gauge to pass between the flanges of the denture and the border of the cast.

Installation of the strain gauges

Self-protected 1mm in length linear strain gauges were used (KFG-1-120-C1- 11L1M2R, KYOWA strain gages, Tokyo, Japan). Their gauge factor was 2.13 ±1% and resistance of 119.6 ±0.4 Ω.

Two strain gauges were bonded to the crestal epoxy resin 1mm mesial and distal to the implant sites using a strain gauge adhesive (CC-33A, Kyowa, Japan). The long axis of the strain gauge was placed to be parallel to the long axis of the implant and perpendicular to the crest of the ridge. After cementation the stain gauges were left for 24 hours to allow complete setting of the adhesive (19, 20). (Figure 5)

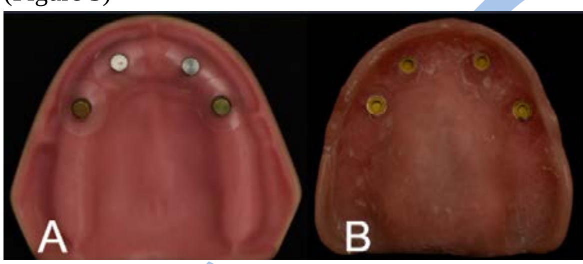

Figure (4) : Smart Box housing used on tilted implants in group I for angle correction

A- Smart box housing with the black processing insert placed on posterior tilted implants prior to pick up of the attachments

B- Smart box housing with the final insert after the pickup procedure.

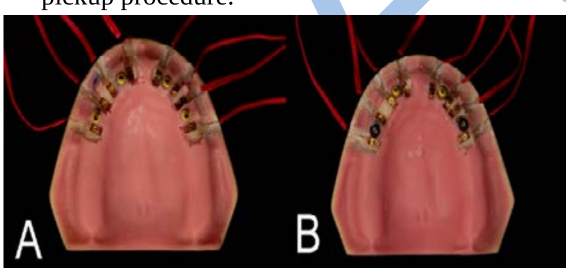

Figure (5) : Models following strain gauge fixation:

A- Group I OT Equator / Smartbox housing.

B- Group II straight/ angled Positioner attachment.

Load application and strain measurement

A universal testing (Mecmesin, Multi Test5-XT (5KN), USA) machine was connected to a computer to allow precise application of the desired load. A metal bar (6 cm in length, 1 cm in width, and 2 mm in thickness) was placed occlusaly at the premolar/molar region from one side crossing the other to allow stress application by universal testing machine. A metal rod was fabricated and attached to the upper member of the load testing machine to allow load application on the predetermined point on the metal bar. The model and the metal bar were placed to be centralized on the table below the load application rod.

A strain meter (Data Logger model TDS-150, Japan) was connected to all eight strain gauges of each model which was connected to a computer to measure and record the micro stain during load application

Prior to testing all strain gauges were zeroed and calibrated. The universal testing machine was used to apply loads of 50N.

The metal rod applied compression to the metal bar with a cross-head speed of 10 mm/min at the predetermined point. Five minutes were left to allow for stress dissipation between each loading. The procedure was repeated for every over denture of both studied groups under the same conditions. (Figure 6)

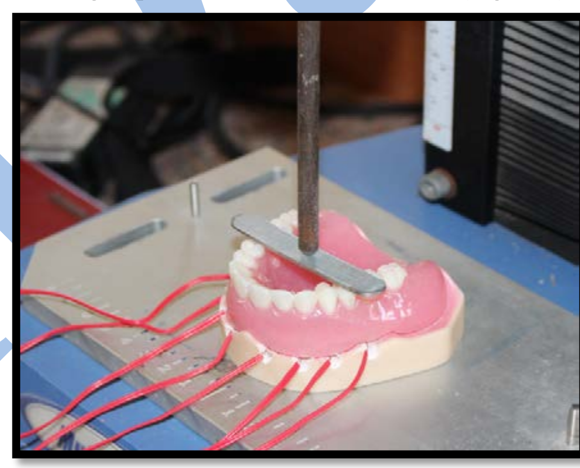

Figure (6): load application using the universal testing machine using a metal rod to apply vertical static load of 50 N on a metal bar placed on the occlusal surface of the overdenture.

Statistical analysis

Data were collected and entered into the personal computer. Normality was checked using Shapiro Wilk test, box plots and descriptives. Micro-strain values were compared between the OT-Equator and Positioner groups using independent t test. Comparison between tilted and axial implants within each group and comparison between mesial and distal surfaces within each implant were done using paired t test or its non-parametric alternative “Wilcoxson Sign Rank test”. Significance level was set a p value 0.05. Data were analyzed using SPSS version 25.

RESULTS

This study was conducted to analyze the stress distribution at peri-implant tissues in overdenture utilizing four implants. Two anterior implants were placed axial and parallel to each other, and two posterior implants tilted distally with divergence of 25 degrees.

When comparing strains around posterior and anterior implants of each group at vertical static load of 50N. There was a statistically significant higher strain around posterior tilted implants with OT Equator attachment and smart box housing (5.17) than the anterior axial implants with OT Equator attachment (4.37) in group I. p value was 0.008.

In group II there was also statistically significant higher strain values in posterior tilted

Implants with angled Positioner attachment (5.24) than anterior axial implants with straight Positioner attachment (3.61). p value was 0.004.

The Strain around posterior tilted implants with OT Equator attachment and Smart Box housing in group I was 5.1 while median of strain observed around posterior tilted implant with angled positioner attachment was 5.24. There was no statistical significant difference between attachments connected to tilted implants of both groups P value was 0.922

There was no statistically significant difference in micro-strain values around OT Equator attachments (4.37) and straight Positioner attachments (3.61) connected to axial implants of each group. P value was 0.072.

At vertical static load of 50N there was no statistical significant difference between total strain values of group I (OT Equator/smart box) with a median strain value of 4.77 and group II with a median strain value of 4.42. p value was 0.446.

When comparing the mesial and distal of each posterior tilted implant group I (OT Equator) showed that there were no statistical significant difference between the higher strain developed at distal of the left implant with a median value of 6.44 when compared to its mesial surface with a median of 5.06 while the right tilted implant and OT Equator attachment with smart box housing showed statistical significant difference in observed strain values which were also higher on the distal surface (median 4.60) than on its mesial surface (median 2.76). p value was 0.032.

In group II (positioner) statistically significant difference in observed strain values at vertical static load of 50N which were higher at the distal side of both tilted implants (angled positioner attachments) when compared to their mesial surfaces with the left implants distal surface median strain value of 8.74 and a mesial median strain value of 4.60. p value was 0.0001. The right tilted implants distal median strain value was 5.98 and its mesial median strain value was 1.84. The p value was 0.006.

DISCUSSION

An epoxy resin model was used for this study as it has an acceptable elastic modulus of a bone analogue material. (18)

The implants were placed using the all on four protocol. (10) This allows the placement of longer implants while avoiding the anatomical interferences in order to restore the atrophic maxilla. Two anterior parallel implants and two posteriors 25-degree tilted implants were placed in each model. A surgical guide was used to place implants to ensure standardization across all models. (21)

One of the important factors affecting implants survival rate is peri implant bone level which is affected by stress transmitted from the implant and its abutment. Selection of the attachment system for over denture construction has a direct effect on the implant survival rate and patient quality of life. The off-axis forces are associated with higher stress on the per-implant bone which are the result of posterior implant angulation. The stresses around attachment systems should be investigated to be assured that the per implant stress in below physiological limit. (22)

Strain gauges were used in this study to analyze the developed strain following load application due to their accuracy in evaluation of micro-strain. They were found to ensure standardization, repeatability, ease of use and availability when compared to alternative methods. (23, 24)

When an inclined implant is placed under a perpendicular load the implant transfers the force in a specific manner. A high stress concentration is formed along the mesial and distal sides of a distally tilted implants. Strain gauges were placed mesial and distal of each implant. (19, 20)

The crestal bone is more subjected to preimplant strain so the strain gauges were bounded to the surface of the epoxy model as the strain measured on the bone surface depicted the stress transferred to the bone. Also surface placement of the strain gauges was necessary due to proximity of the implants to each other. The surface placement has another advantage as it utilized the flat surface of the epoxy resin at the crest of the ridge as the strain gauge is subjected to incremental apparent strain when placed on a curved surface. (23, 25)

A metal bar was used to allow bilateral force distribution. It's the site where the occlusal forces concentrated and the denture was subjected to large movement. (19, 26) 50 N force was selected as it was considered as the average biting force of a completely edentulous patient. implant. (13, 19, 20)

In this study, table (1) showed no statistically significant difference between micro-strain values observed around the tilted and axial implants connected to OT Equator attachments/Smart Box housings in group I and straight/angled Positioner attachments in group II. This could be postulated to the use of nylon inserts which may allow slight movement of the denture thus reducing the forces transferred to the implant. El Sayed (2016) (19), El Sayed (2017) (27) and Scherer (2019) (28) found that the use of nylon inserts that allows reduction of friction and slight movement of the denture base may reduce the stress transmitted to the implants. EL Nahla (2020) (29) in their study they concluded that all Equator attachments can considered equal to the Locator attachments. although the Locator attachment may be associated with a reduction in stresses in the peri implant bone. On the contrary Cicciù (2019) (30) compared the Locator and the Equator attachments and using the finite element method and Von Mises analyses. They found in their vitro study that the design of Locator attachments distributes the stresses over the implant while the design of the Equator may be associated with increased stresses over the head of the attachment resulting in increasing minor stresses around peri implant bone. Hegazy (2020) (31) found that when comparing the Locator to the OT Equator attachments in two and four implant configurations for supporting a maxillary over dentures that the difference in stress values of the Locator attachment were statistically significant when comparing to the OT Equator attachment. They found that lower values recorded around the Locator attachment may be due to the matchless design of the Locator and the design of it's the nylon inserts which holds onto the outside and inside contours of the attachments which may help in stress reduction. While the OT Equator was found to be simpler in design with no stresses absorbed.

The results may be further explained by the complete palatal coverage which may have contributed in distribution of forces in both groups. Park JH (2020) (32) found that regardless of the attachment type full palatal coverage showed lower maximum stress on implant, peri-implant bone and mucosa.

In this study under 50 N of applied loads both the OT Equator group and the positioner group the anterior implants of both groups had significantly lower stresses when compared to the posterior implants. This was similar to results found by Machado (2011) (33) where four implants supported over dentures were deemed to be associated with higher posterior load concentration when using photoelastic analysis. Also, Omer (2016) (34) when comparing Locator to OT Equator attachments using a metal bar placed at the first molar region. they found that although the four-implant supported over denture was associated with better stress distribution, increased stress distribution over the posterior implants was found when compared to the anterior ones in both right and left sides. Also, Hong (2012) (35) claimed that the more anteriorly placed implants have more optimal stress distribution with vertically and horizontally applied forces when compared to posterior positions.

Table (2) showed that the right tilted implants of the OT Equator group had statistically significant higher stress on the distal side when compared to the mesial side while the left tilted implant had higher distal stresses although it's not a statistically significant difference. While the Positioner group had significant higher forces on the distal side of the tilted same implants when compared to the mesial side. This is explained by the tilt of the implants which had considerable effect forces on the stress distribution. Tilting the implants resulted in increasing the compressive stresses around the side of the tilt as Watanabe (2003) (15) explained. This increased stress was exacerbated when the tilt of the implants was increased. This was explained as the result of torque on the implant body due to forces not being directed along the long axis of the implant

Pigozzo (2013) (36) found similar results. They compared parallel and tilted using photo elastic stress analysis method. He found increase stress around the tilted implants. This was the result of the implants tendency to intrude when a force is applied. In the case of the tilted implants stresses were also noticed to be concentrated on the distal side of the implant as the implant direct the forces in an inclined manner due to its angulation. On the contrary El Sayed (2016) (19) found that when using strain gauges to evaluate stress around distal inclined implants supporting an over denture increased stresses along the mesial side of the implant however, this was explained by the mesial movement of the denture base during posterior load application which would result in increasing the acrylic resin at the mesial surface of the implant.

Table (1) : showing the difference between group I OT Equator attachments with Smart Box housing and group II angled Positioner attachment with regular nylon caps.

Implants	Group I (OT-Equator attachments) (n=6)		Group II (Positioner attachments) (n=6)		*P* value
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
Posterior tilted implants	4.91 (0.89)	5.17 (1.10)	4.96 (1.25)	5.24 (2.19)	0.922
Anterior axial implants	4.17 (0.91)	4.37 (1.78)	3.13 (0.52)	3.61 (0.98)	0.072
***P* value**	0.008*		0.004*		
Total average;	4.54 (0.89)	4.77 (1.44)	4.14 (0.87)	4.42 (1.58)	0.446

Table (2): comparing the strain measured on the mesial and distal surface of each tilted implant of group I and group II.

Implants	Mesial (n=6)		Distal (n=6)		Test of significance p value
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
Group I (OT Equator/ Smart box) tilted left implant	5.06 (2.95)	5.06 (5.98)	6.75 (2.94)	6.44 (5.98)	0.479
Group I (OT Equator/ Smart box) tilted right implant	2.76 (0.58)	2.76 (0.46)	5.06 (1.90)	4.60 (3.91)	0.032*
Group II (angled Positioner) Tilted left implant.	3.98 (2.30)	4.60 (3.68)	8.12 (1.35)	8.74 (2.76)	0.0001*
Group II (angled Positioner)Tilted right implant	2.15 (0.47)	1.84 (0.92)	5.67 (1.87)	5.98 (3.68)	0.006*

In this study increased micro strain was observed around tilted posterior implants and was associated with unfavorable distribution pattern. This may have clinical implication as the excessive load around dental implants may be associated with bone resorption and may lead to implant failure. (22) Pozzi (2016) (37) found that the use of four implant overdenture with a similar implant placement protocol to this study (straight/tilted) can be considered as reliable option when restoring the severely atrophied maxilla when conventional fixed prothesis with extensive flanges may complicate hygienic maintenance. likewise, Metwally (2020) conducted a clinical trial using the all on four implant placement protocol to support a maxillary overdenture using OT Equator attachment and Smart Box housing as angle correcting attachments. They found significant increase in the modified gingival index, clinical attachment level and peri-implant probing depth when comparing posterior tilted implants to anterior axial implants. However, they were within parameters indicating the implants success.

The results of this study are descriptive, future biomechanical studies are recommended to study the effect of different implant angulations on the peri-implant strain when using these two attachment designs as seldom studies in the literature used the all on four implant placement protocol to support an overdenture and also, few studies addressing the benefits of using the newly developed OT Equator attachment /Smart Box housing when connected to a tilted implant. Also, clinical researches are still needed to determine the effect of different implant angulations on the peri-implant tissue. Dudley (2013) (38) claimed that evidence regarding the maxillary over denture in the literature are inconsistent and further standardized research is necessary to establish guidelines for maxillary over denture management.

CONCLUSION

No difference in micro-strain values was found when using straight/ angled Positioner attachments and OT Equator attachments with Smart Box housing.

Using the all on four protocol may be associated with increased strain values around posterior implants. The strain around posterior tilt implants were unequally distributed as it was higher in the distal sides of the distal tilted implants when compared to their mesial sides.

Conflict of interest

The authors declare that they have no conflicts of interest.

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