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Stresses transmitted by two different implant angulations in All-on-Four supporting fixed detachable prosthesis. (In-vitro study)

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Background: *The objective of this study was to compare between stress produced by maxillary fixed-detachable prosthesis around the implants placed with different angulations following All-On-Four Concept.* ***Methods****: For this study, two standardized maxillary epoxy models were made, surgical guides were fabricated by CAD/CAM according to desired angulations. Two groups were designed, for group A implants were inserted following All-On-Four concept with 45 degrees distal angulation of distal implants while for Group B implants were inserted following All-On-Four concept with 30 degrees distal angulation of distal implants. Fixed detachable prosthesis was made for 2 groups by plastic castable abutments and casting procedure. After that, strain gauge was installed around implants in buccal, palatal, mesial and distal aspects, and a load of 100N was applied vertically and anther load of 65N was applied obliquely by digitalized testing machine upon occlusal plate 10 times.* ***Results****: There was a significant difference between posterior implant tilted by 45 degrees and posterior implants tilted by 30 degrees under vertical and oblique load without taking into consideration the effect of cantilever. The anterior implants are significantly less subjected to stresses than posterior tilted implants. Oblique load has generated higher stresses than vertical loads over all implants.*

Conclusions: *Within the limitations of this in-vitro study, it can be concluded that with short cantilever implant supported prosthesis avoiding the increase in the tilt of implants more than 30 degrees is recommended to decrease stresses transmitted to surrounding structures around both anterior and posterior implants. Off axial loads will generate more stresses around implants.*

Keywords*: All-On-Four, Dental Implants, Tilted Implants, fixed detachable prosthesis, Strain gauge analysis.*

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I. Introduction

The use of intraosseous dental implants is a widely accepted and encouraging treatment that can be used for the rehabilitation of patients with partial or complete tooth loss. Despite the high success rate of implants, biological and technical complications surrounding the implants have been reported. In recent years, dental implantology has experienced a well-deserved innovation. In an increasing number of carefully selected cases, dental implants are now considered the preferred treatment option[1,2].

In many cases, the treatment of edentulous upper jaw is more challenging and requires more selective surgery than lower jaw, especially in terms of [3,4]: degree of atrophy of the residual jaw, location of the implants,tiltingthe axis of the implants, soft and hard tissue volume, facial profile, esthetics, function and phonetics.

In recent years, it has been proposed to use inclined implants to restore the upper and lower edentulous jaws. Implants of regular length can be placed, allowing as much cortical bone joining as possible to increase primary stability.[5]

The All-on-4® concept is designed to maximize the use of residual bone available in atrophic jaws. Therefore, it allows for immediate effect and avoids regeneration procedures that increase treatment costs and patient morbidity and complications inherent in these procedures. All-on-Four four treatment concepts provide predictable results for the treatment of atrophic jaws. The evidence provided shows a promising prognosis for treatment. The results showed that after three years of follow-up, the survival rate of prostheses and implants was high. There is no statistically significant difference between the clinical results of the upper and lower arches and the axial and oblique implants[6-8].

The stress transferred from the dental implant to the surrounding bone is affected by many factors, such as the type of load, the interface of the bone implant, the length and diameter of the implant, the shape of the implant, the structure of the implant surface, the superstructure, and the quality and quality. Number of surrounding bones[9]. Biomechanical analysis shows that regardless of the number of intermediate implants, the foremost anterior and posterior implants that support reconstruction occupy the main load share when cantilevered. Compared to vertically placed implants, tilted implants transfer more pressure to the bone. The increased pressure may cause bone resorption and micro-injury. The bending motion caused by the non-axial overload of the dental implant may cause stress concentration around the implant.[10]

After osseointegration is achieved; long-term clinical follow-ups reported biological or mechanical complications[11,12].The factors that contribute to the prognosis of dental implants should be carefully considered before attempting to rehabilitate the patients with implants. These factors are periodontally compromised patients, age, bone density, occlusion, smoking, genetics, systemic diseases, microorganisms, antibiotics, and type of implants[13].

A strain gauge is a device used to measure the stresses and strains of an object. The most common type of strain gauge is electrical strain gauge which consists of an insulating flexible backing that supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive. As the object is deformed, the foil is deformed, causing its electrical resistance to change[14-16].

In this in-vitro study strain gauge technology has been used to measure micro strains induced by maxillary fixed detachable dental prosthesis supported by implants using All-On-Four treatment concept with different angulations.

II. Material & Methods

Two identical ready-made maxillary completely edentulous epoxy resin models having a ridge thickness of 7 mm diameter and the modulus of elasticity approximately equals to that of bone, covered by 2 mm of silicon resilient material to simulate oral mucosa were used for this study. The two models were divided into two groups as following: Group (A): In which the two anterior implants were placed vertically, while the two posterior implants were placed at distal angulation of 45 degrees. Group (B):in which the two anterior implants were placed vertically, and the two posterior implants were placed at distal angulation of 30 degrees.

Implant installation:

Fabrication of trial denture base from self-cure acrylic resin is done over stone cast made from impression for the epoxy resin. After that setting of artificial acrylic teeth was done upon trial denture base to determine the exact location of teeth .Radiographic markers (gutta-percha) were placed upon trial denture in palatal and buccal holes 1 mm deep and 1.5 mm wide at the canine and first molar region to make radiographic stent then Cone Beam Computer Tomography was taken once for radiographic stent alone and another one for model and stent together. Implant planning was done using 3Diemme RealGuideSoftware according to position of teeth determined by radiographic stent. Two Surgical guides were 3D Printed, checked on corresponding models for adaptation and accuracy.

Fixation of the surgical guides on corresponding model was done after being sure that the surgical guides is seated properly on both models. Tissue punch was used to remove area of silicon layer to gain access to the drilling site. Drilling was performed by using Biohorizons guided drilling kit using green key and full sequence of drilling burs to the selected implant size was used.

For both models four holes were drilled, two in canine regions with 10 mm depth, and two in second premolar regions with 15 mm in depth on both sides. The Implants were selected from Biohorizons implant system, two implants measuring 3.8 mm diameter and 10 mm length were inserted in the canine region, and two implants system measuring 3.8 mm diameter and 15 mm length were inserted in the second premolar region in both models. The implants were inserted in the prepared sites and rotated clockwise with a torque equals 40 N. Complete implant insertions till the implant become flushed with the epoxy resin model.

After implants placement were checked, from connection set of Biohorizones, straight multiunit abutments were tightened to anterior implants while 30^{o} angled multiunit abutments were tightened to posterior implants to achieve Parallelism between abutment and ensure passive fit of prosthesis. Plastic castable coping with hex driver were attached to anterior and posterior multiunit abutments. Waxing up for metallic framework connecting four castable coping was done for both models to cast metal framework. After that casting the wax up was done using casting machine to produce metallic framework. The waxed framework was then sprued in casting ring. Then Casing ring was inserted in casting machine to produce metallic framework.

Metallic frameworks were checked on model to ensure passive fit, then a thin layer of metal opaquer was placed over metallic framework to mask dark shade of metal. Later, overlay porcelain made by conventional technique and contain holes for screws to attach the prosthesis to abutments was fabricated, finished, and polished. For every prosthesis consists of twelve teeth ending with first molar teeth with fixed cantilever length in both restorations.

Fabrication of occlusal plate for load application:

Occlusal plate has been fabricated by making waxing up on occlusal surface of the fixed detachable prosthesis so that the wax up takes the shape of occlusal surface of prosthesis and adapted on it. After finishing wax up, it was placed in casting machine and casted into metal plate which has one surface occluding with prosthesis and another flat surface. Flat metal plate placed on top of occlusal plate to apply load upon it.

Installation of strain gauge:

The strain gauges were used for this study with the specification according to the manufacture:For each model four tunnels (3 mm in depth, 4 mm in width and 5 mm in length) were prepared at the top of the epoxy resin model just around the implant surface parallel to the long axis of the implant in mesial, distal, buccal and lingual surfaces, four strain gauges installed in each tunnel in the epoxy resin on the surface which was toward the implants to measure the micro strains in the medium surrounding the implant in model A and model B

A strain gauge adhesive was used to cement the strain gauges on the epoxy resin parallel to the long axis of the implant and held in their sites for 5 minutes. And the wires of the strain gauges were connected to a digital multichannel strain meter. The strain meter was connected to a compatible laptop containing the meter control software (EDX 10A).

Each of the two models placed on the base of the loading device of universal testing machine and then before running the test, the occlusal plate was put on the occlusal surface of the prothesis then the strain meter was balanced to zero. Point of load application was the center of occlusal plate. The forces were delivered to the flat surface of the occlusal plate using a loading pin (applicator) attached to the digitalized testing machine. Both was placed with the fixed detachable prothesis in its place in a horizontal plane of the base of the loading device base and bilateral static 100 N vertical load was applied. Also, both models were placed with the fixed detachable prothesis in its place on the surface of an oblique wooden segment which made angle equal 35o with the applied load and bilateral static 65 N oblique load was applied. The load is applied 10 times for each model vertically and obliquely to ensure the reproducibility of the results with at least 5 minutes interval between the readings to allow relief of formed strains before making the next reading.

Statistical analysis:

The micro strain data were collected of the present study was collected and tabulated and statistically analyzed using the mean, standard deviation, and student t- testto compare mean of post loadvalues between two groups. Statistical analysis was performed by using SPSS program version 20 (SPSS Inc. Chicago, USA).

III. Results

The results showed the mean and standard deviation of the values recorded from the four strain gauges at the buccal, lingual, mesial, and distal around each implant under bilateral 100 N vertical load and 65 N oblique load for Groups.

From table (1) which compare between both groups under vertical load, it was founded that:

1- In group A there is no significant difference between right and left anterior implants under vertical load

2- In group B there is no significant difference between right and left anterior implants under vertical load

3- Comparing between both groups under vertical load, it is concluded that there is no significant difference between both groups at both right and left implants

when comparing between both groups regarding posterior implants under vertical load it was founded that:

1- In group A there is no significant difference between right and left posterior implants under vertical load.

2- In group B there is no significant difference between right and left posterior implants under vertical load.

3- it is founded that there is a significant difference between both groups under vertical load at both right and left posterior implants with higher values assigned to Group A.

while comparing both groups at anterior and posterior implants under vertical load is shown in table (3) as follow:

1- In group A there is a significant difference between anterior and posterior implants under vertical load.

2- In Group B there is a significant difference between anterior and posterior implants under vertical load.

3- Comparing both groups shows a significant difference between posterior implants, while there is no significant difference between anterior implants under vertical load.

Comparing both groups regarding oblique load is shown in table (2) as follow:

1- In group A there is no significant difference between right and left anterior implants under oblique load.

2- In group B there is no significant difference between right and left anterior implants under oblique load.

3- It is founded that there is no significant difference when comparing both groups at right and left anterior implants under oblique load.

Comparing both groups regarding posterior implants under oblique load which is:

1- In group A there is no significant difference between right and left posterior implants under oblique load.

2- In group B there is no significant difference between right and left posterior implants under oblique load.

3- Comparing between two groups at right and left posterior implants under oblique load, it is founded that there is a significant difference between the implants with high values assigned to Group A.

Comparing both groups at anterior and posterior implants under oblique load showed that:

1- In group A, there was no significant difference between the anterior implants under oblique load between both groups.

2- In group B, there was a significant difference between posterior implants under oblique load between both groups.

3- Comparing both groups under oblique load, it is founded that there is no significant difference at anterior implants while there is a significant difference at posterior implants.

Comparing between vertical and oblique forces between both groups is shown in table (3) and showed that:

1- There is a significant difference between vertical and oblique loads between anterior implants in Group A.

2- There is a significant difference between vertical and oblique loads between anterior implants in Group B.

3- There is no significant difference between both groups under both vertical and oblique loads regarding anterior implants.

Comparing between vertical and oblique forces between both groups at posterior implant level showed that:

1- There is a significant difference between vertical and oblique loads between posterior implants in group A.

2- There is a significant difference between vertical and oblique loads between posterior implants in group B.

There is a significant difference between both groups under both vertical and oblique loads regarding posterior implants

IV. Discussion

Prosthetic treatment for completely edentulous patients shows great variation and that depends on several factors. The huge improvement in technology of dental implants has made the replacement of missing teeth with endo-osseous implants the standard care and an implant supported prosthesis as the first line of treatment[17].

The treatment of the atrophic edentulous maxilla is more complicated and requires more elective procedures than are necessary for the mandible. Treatment protocols for implant-supported prostheses advocating the insertion of tilted implants are gaining increasing acceptance in the literatures[18,19].

This study has observed the stresses generated around implants in all-on-four treatment concept which uses the tilted implants protocols. The All-On-Four treatment concept allows the rehabilitation of an atrophic edentulous jaw in a single operation and eliminating nerve transposition and/or bone grafting procedures. Also, many biomechanical advantages are obtained by achieving a wide antero-posterior distance, providing better load distribution in the occlusal plane, avoiding a long cantilever distance, and increasing the bone-implant contact with the use of longer implants[20-22].

The two ready-made identical epoxy resin models were used to have an appropriate elastic modulus for a bone analog material[23.]It was also found to produce better results than plaster models used in other studies[24]. Using of mucosa simulating layer from flexible polyurethane to ensure simulation of oral environment[25].

The surgical guides that were used in this research were manufacturing using CAD CAM technology to control implant position, angulation, and drilling depth.Virtual implant placement makes it possible to account for anatomic limitations and visualize available bone relative to the ideal position of the final restoration [26,27].

Radiographic stent was manufactured in this study to allows the placement of the implant along planned prosthetic axes during surgery. A radiographic stent allows visualizing the planned implant axis, position of the definitive prosthesis, emergence site, available space for the attachment components, and thickness of the mucosa overlying the bone.[28,29]

The canine area was selected to be the site of implantation for anterior implants. Resorbed maxilla shows limitation of implant placement due to anatomical insufficiency especially posteriorly, this makes the canine area is the preferable for implant.[30]

Second premolar area was preferred in this study for posterior implantation to avoid penetration of the maxillary sinus and consequently the need for extensive grafting. However, first molar area may be a key for implant position since the bite force doubles in a molar area when compared to the premolar area. [31,32]

Group A in this research has posterior implants with 45 degrees of tilt while in group B has posterior implants tilted by 30 degrees. This was planned according to different anatomic needs (anterior sinus wall) for different patients, and allow the use of implants with longer length, besides reducing the extension of the cantilever by increasing the anterior-posterior (AP) distance. Furthermore, implant tilting can contribute to the anchorage of the distal implant and support primary stability. The anterior implants in both groups were planned to be placed vertically.[8, 33-35]

Straight multiunit abutments were used for anterior implants and 30 degrees angled multiunit abutments were used for posterior implants to achieve good parallelism between abutments and ensure passive fit of fixed detachable prosthesis.[36]

In this study the indirect fabrication technique was used via castable plastic cylinders for waxing up metallic framework and subsequent steps of prosthesis fabrication to makes sure for accurate passive fit of the prosthesis and reduce casting errors to minimum levels. Also, it helps to reduce fatigue fracture of prosthesis and improve fracture resistance.[37,38]

The cantilever length was designed to be the same in both casts. This was to neglect the effect of increasing or decreasing the cantilever length on stress transmission to implants as cantilever length generate different stress pattern around implants.[39]

In this study, tunnels were made at the sites of the strain gauges installation for gaining deeper insight into the stress distribution at the implant-bone interface. [40-42]

Installation of the strain gauges was done from the top of the models because the cervical region of the implant is the site where the highest stresses occur, regardless of the type of bone and the design of the implant.[43,44]

The installation of strain gauges was done in prepared flat surfaces in the epoxy resin parallel to the long axis of the implant fixture instead of placing it directly on the root surface or implant surface because it is preferred to bond the strain gauge on completely flat surface to minimize the possibility of obtaining incremental apparent strain that result from mounting the strain gauge on curved surface.[45,46]

Using four strain gauges installed to the mesial, distal, buccal and palatal aspects to ensure proper recording to all the stress around the implants.[47]

The occlusal plate was fabricated in a manner to occlude with restoration to ensure equal distribution of forces on all implants and simultaneous loading on both sides of the prosthesis, so it allows to capture the force in all the implants.[48,49]

Universal testing machine was used to deliver the load in this study. It is digital and easy to use. Besides, it offers high accuracy position measurement, rapid data acquisition and full personal computer integration. Also, it allows determination of stresses either compressive or tensile while avoiding complications caused by the catching system of the samples.[50,51]

In this study, a bilateral vertical static load of 100 N and oblique static load of 65 N were applied[40]. Strain gauge studies in implantology generally use loads varying from 20 to 300 N. [40,4551,52]

The load is applied 10 times for each model vertically and also obliquely to ensure the reproducibility of the results and for the accuracy of the results, an interval of at least 5 minutes between each reading was given to give a chance for heat dissipation from the strain gauge sensors and to allow relief of formed strains before making the next reading.[53]

This study Showed that there is no statistically significant difference between right and left implants anterior implants in the same group. These results may be due to the loading was applied at the same manner for the same group under both vertical and oblique load, also when comparing the two groups with each other we observed that there was no statistically significant difference between anterior implants of both groups under both vertical and oblique loads as load was distributed equally in the buccal, palatal,, mesial and distal surfaces around each vertical implant. [54]

When comparing right and left posterior implants, we observed that there is no statistically significant difference between posterior implants of the same group under both vertical and oblique load as anterior implants was observed.[54]

However, results of this study showed that there is a significant difference between both groups regarding posterior implants under both vertical and oblique loads. The stress is increasing in case of increasing implants angulations from 30 to 45 degrees. These results was supported by Begg et al[55] , Silva et al[56] , Cidade et al[57] who stated that increasing implant angulation may cause stresses to increase around implants every condition.

On the other hand, different researches[58-60] proved that there is unexpected decrease in stresses around 45 degrees tilted implants and they related it to decrease cantilever length of prothesis that counteract increased stresses due to increasing angulation. However, in this study cantilever length was fixed in both models to eliminate the effect on cantilever effect.

This study showed that the least stress was found around two anterior vertical implants in comparison to the two posterior tilted implants in the same group under both vertical and oblique loads, this is supported by different studies who explained it by considering the angulations of the posterior implants and the formation of bending moments at these sites which in turn distribute load unequally around implant causing stress concentration at cervical region of tilted implants.[54,61-63]

In the study performed by Begg et al[55] by using photo elastic analysis it was concluded that there is a notably difference between anterior and posterior implants in case of tilting the posterior by 45 degrees while there is no notably difference is noticed between anterior and posterior implants in case of tilting implants by 30 degrees.The data obtained in the previous study are qualitative, unclear and no statistical analysis was performed whether these observed differences are significant.

Also, when comparing both anterior implants between two groups under both vertical and oblique load, it is founded that there is no significance between both groups regarding anterior implants. However, the mean and stander deviation were higher in group A than Group B. This can be referred to increasing tilt of posterior implants will increase stresses around anterior implantsTherefore, not only would the stress concentration in posterior implants be higher, but anterior implants would also be subjected to higher amounts of stress.[62,63]

When comparing both posterior implants between two groups under both vertical and oblique load, it is founded that there is a significance between both groups regarding posterior implants. This explained by different researchers due to increased implant angulation which will subject tilted implants to higher stresses.[56,57]

Results of this study showed that the stress was increased around implants in case of oblique loading of force more than the vertical loading by a significant difference.

These results were supported by many studies which proved that the higher stress values of the oblique loading compared to the vertical loading, this could be attributed to the fact that the non-axial forces tend to cause uneven stress distribution leading to areas of higher stresses and others of low stresses. it can be concluded that occlusal contacts positioned laterally along the axis of the implant produce higher stresses around the implant and contribute to peri-implant bone resorption.[40,64-66]

V. Conclusions

Within the limitations of this in-vitro study, it can be concluded that:

- Without the cantilever influence, increasing the implant tilting to 45° degrees lead to more stress formation around implants than 30° degrees of inclination. Also increasing the tilt of posterior implants will subject anterior implants to more stresses.
- Tilting implants will produce more stresses than placing them vertically regarding neck of implant fixtures.
- Whenever possible, avoid non axial loading on implants to reduce amount of forces over dental implants.

Ethical approval and consent to participate

Approval for this research was obtained from Faculty of Dentistry, Tanta University, and Research Ethics Committee (REC). The design and procedures of the present study were accomplished according to the research guidelines published by the (REC) Faculty of Dentistry, Tanta University

Consent for publication

Eslam Dawood, Fadel Elsaid and Nahed Kashef; The Author agreed to deliver to the responsible Editor(s) on a date to be agreed upon the manuscript created according to the Instructions for Authors.

Availability of data and material

Authors declare that they have full control on all data and materials of this study.

Competing interests

Eslam Dawood, Fadel Elsaid, and Nahed Kashef declare that they have no conflicts of interest.

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Authors' contributions

ED carried out samples preparation, measurements, data collection, and drafting the manuscript. FE participated in the design of experiment and performed the statistical analysis and interpretation of data, and NK participated in conception, design, and revising manuscript critically for important intellectual content. All authors read and approved the final manuscript.

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Tables Legends

Table (1): Mean ±SD of microstrains around implants in both groups under vertical load:

	Group A			Group B			T-Test	
	Mean	**±**	**SD**	**Mean**	**±**	**SD**	**t**	**P-value**
Vertical IMP AR	39.051	±	5.752	37.726	±	8.016	0.425	0.676
Vertical IMP AL	41.566	±	9.781	38.204	±	8.423	0.824	0.421
Differences	-2.515	±	13.148	-0.478	±	9.776		
Paired Test	0.560			0.881				
Vertical IMP PR	55.307	±	14.573	43.612	±	5.859	2.355	0.030*
Vertical IMP PL	57.997	±	12.524	43.805	±	4.434	3.378	0.003*
Differences	-2.690	±	21.894	-0.193	±	8.490		
Paired Test	0.707			0.944				
Vertical Anterior	40.308	±	4.601	37.964	±	6.611	0.920	0.370
Vertical Posterior	56.651	±	8.049	43.709	±	2.995	4.765	<0.001*
Differences	-16.343	±	8.095	-5.745	±	7.040		
Paired Test	<0.001*			0.030*				

Table (2): Mean ±SD of microstrains around implants in both groupsunder oblique load:

	Group A			Group B			T-Test	
	Mean	±	SD	Mean	±	SD	t	P-value
Oblique IMP AR	46.005	±	12.504	41.347	±	13.365	0.805	0.431
Oblique IMP AL	48.657	±	12.589	41.025	±	15.515	1.208	0.243
Differences	-2.652	±	20.018	0.322	±	25.055		
Paired Test	0.685			0.968				
Oblique IMP PR	65.998	±	18.741	51.530	±	11.366	2.087	0.051*
Oblique IMP PL	68.826	±	17.912	54.266	±	13.100	2.075	0.053*
Differences	-2.828	±	26.403	-2.736	±	18.374		
Paired Test	0.743			0.649				
Oblique Anterior	47.331	±	7.566	41.186	±	7.261	1.853	0.080
Oblique Posterior	67.412	±	12.719	52.898	±	8.124	3.041	0.007*
Differences	-20.081	±	16.136	-11.712	±	13.249		
Paired Test	0.003*			0.021*				

Table (3): Mean ±SD of microstrains around implants in both groups comparing vertical andoblique load:

	Group A			Group B			T-Test	
	Mean	±	SD	Mean	±	SD	t	P-value
Vertical Anterior	40.308	±	4.601	37.964	±	6.611	0.920	0.370
Oblique Anterior	47.331	±	7.566	41.186	±	7.261	1.853	0.080
Differences	-7.023	±	9.541	-3.222	±	3.921		
Paired Test	0.045*			0.029*				
Vertical Posterior	56.651	±	8.049	43.709	±	2.995	4.765	<0.001*
Oblique Posterior	67.412	±	12.719	52.898	±	8.124	3.041	0.007*
Differences	-10.761	±	15.350	-9.189	±	9.026		
Paired Test	0.054*			0.011*				

Figure Legends

Figure (1):.Surgical guide fit in both model

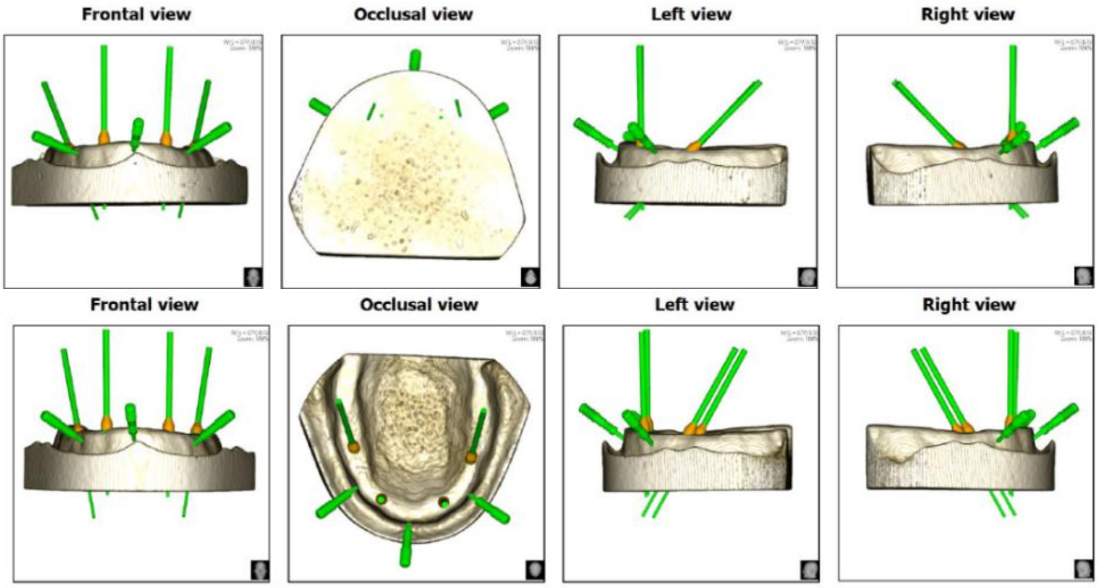

Figure (2):implant planning in both models.

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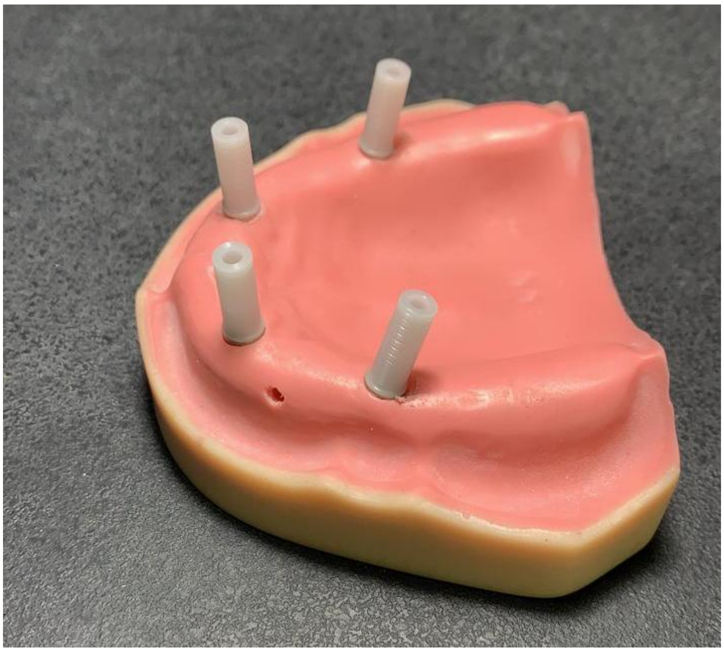

Figure (3):castable cylender coping placed on abutments.

Figure (4): Conventional porcelain after finishing and polishing

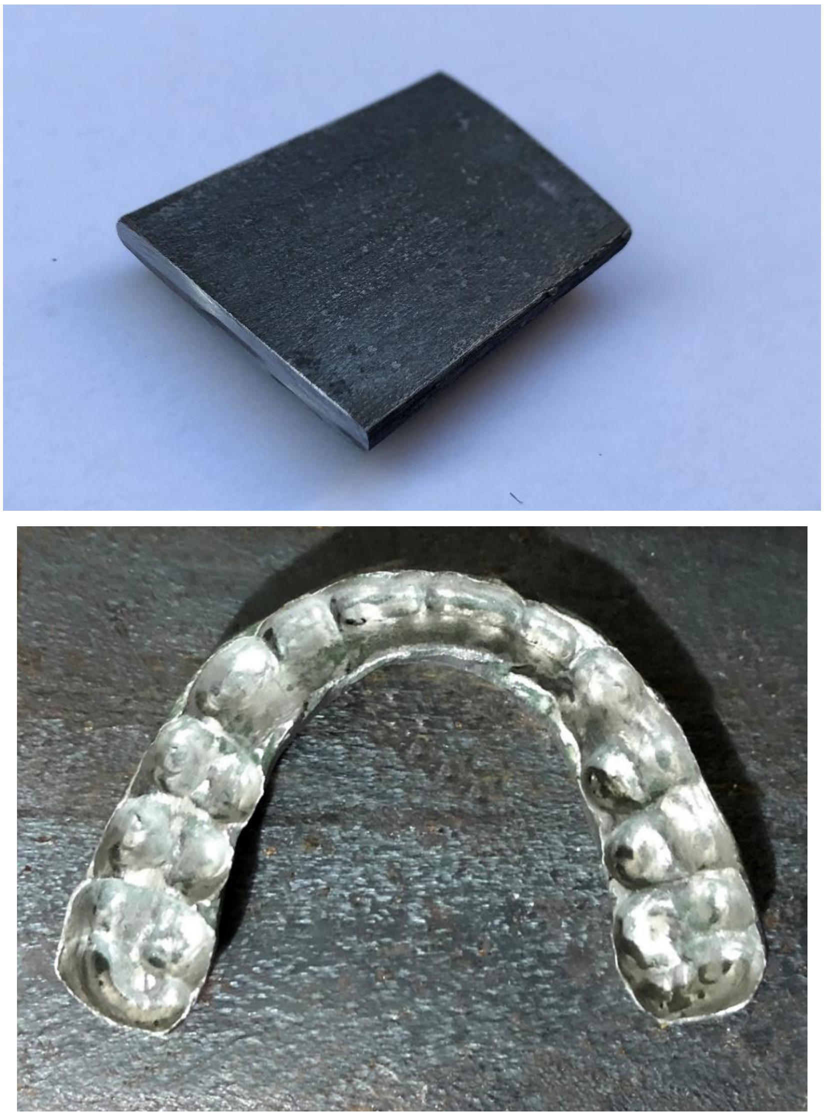

Figure (5): Occlusal Plate

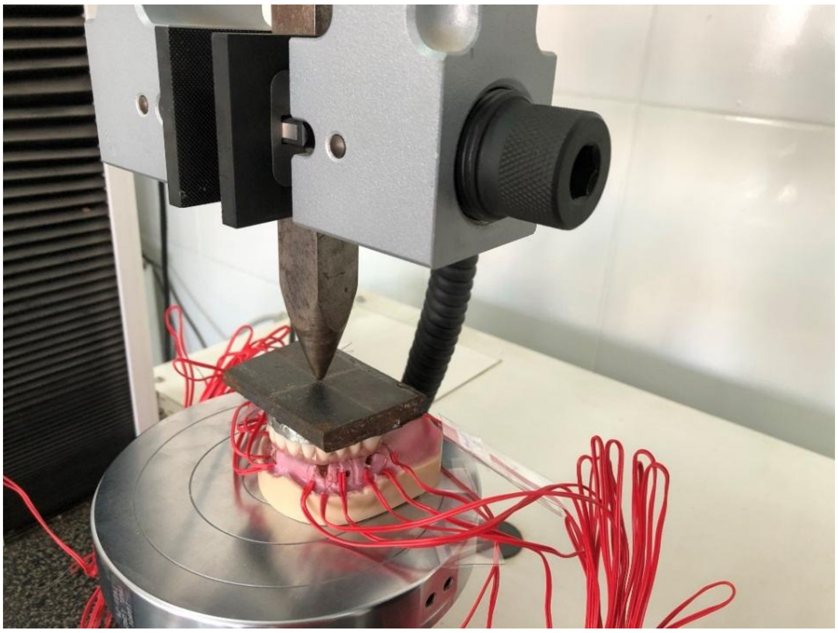

Figure (6): Measuring Vertical load

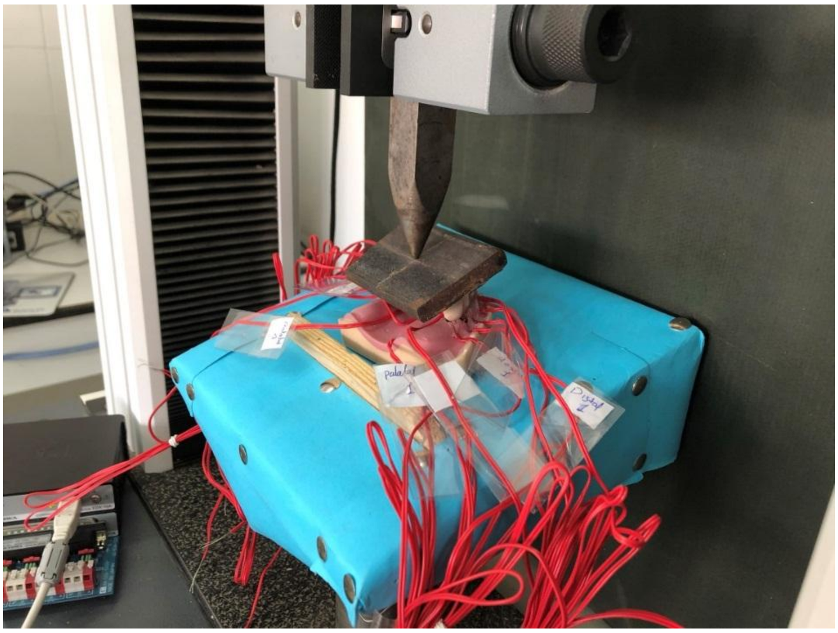

Figure (7): Measuring Oblique load

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