"COMPARATIVE PHOTOELASTIC STRESS ANALYSIS BETWEEN ALL-ON-FOUR IMPLANT SUPPORTED COBALT-CHROMIUM FRAMEWORK AND CARBON FIBER REINFORCED FRAMEWORK WITH VARYING CANTILEVER LENGTHS – AN IN-VITRO STUDY"

BY

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(BRANCH – I)

Under the guidance of

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No endeavor can start, continue and complete without the blessings of ***LORD GANESHA.*** *I thank him for blessing me with the strength and patience to complete the task entrusted to me.*

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"The task of the excellent teacher is to stimulate "apparently ordinary" people to unusual effort. The tough problem is not in identifying winners: it is in making winners out of ordinary people."

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DR. SHAH RUTVI ATULKUMAR

LIST OF ABBREVIATIONS USED IN THE STUDY

AP spread	Anteroposterior Spread
CAD-CAM	Computer Aided Design and Computer Aided Manufacturing
CFRC	Carbon Fiber Reinforced Composite
Co-Cr	Cobalt-Chromium
DMLS	Direct Metal Laser Sintering
FDP	Implant-Supported Fixed Dental Prostheses
FEA	Finite Element Analysis
FFP	Full-Arch Implant-Supported Fixed Prosthesis
ISPs	Fixed Implant Supported Prosthesis
MPa	Megapascal
N	Newton
SBS	Shear Bond Strength
SD	Standard Deviation
SR	Survival Rate
STL	Stereolithography

ABSTRACT

STATEMENT OF PROBLEM

In implant prosthodontics, metal frameworks are used to rigidly spilt the implants together to provide rigidity and stiffness to the prosthesis and reduce possible complications such as prosthetic fracture. However, due to the limitations associated with the metal framework fabrication; the recent advances and improvements in fiber reinforced materials, has now made it possible to fabricate metal free ISPs using fiber reinforced composite frameworks.

PURPOSE

The purpose of this study was to evaluate and compare photoelastic stresses between All-on-four implant-supported cobalt-chromium (Co-Cr) framework and carbon fiber reinforced composite (CFRC) framework at varying cantilever lengths.

MATERIALS AND METHODS

Two photoelastic models of an edentulous mandible were fabricated according to the All-on-four concept. Following which, two identical implant-supported frameworks with bilateral cantilever extension of 20mm, one with CFRC and other one with Co-Cr were fabricated. The models were subjected to progressive loads of 120 N-180 N, applied five times at 6 designated loading points. The results were obtained using the mean of maximum fringe order obtained from 5 repetition stresses, and by using formula for calculating maximum principal stress ($\boldsymbol{\sigma}$).

RESULTS

The results demonstrated that for both the frameworks, the principal stresses increased significantly with the increase in the posterior cantilever length. The CFRC framework

showed a more homogeneous stress distribution, with mean principal stress values significantly lower than the Co-Cr framework under all loading conditions, however deformation of the framework was observed at the cantilever lengths of 15 mm and 20 mm. Whereas, the Co-Cr framework showed mean principal stress values and crestal stress higher than the CFRC framework.

CONCLUSION

The study and its findings have indicated that the CFRC framework appears suitable for fabrication of framework for “All-on-four” prosthesis with a recommended short cantilever length of 10 mm. Whereas, Co-Cr framework can be recommended in clinical scenarios, necessitating full arch ISPs requiring distal cantilever greater than 10 mm due to high stiffness and yield strength of the material

KEY WORDS

All-on-four, cantilever length, carbon fiber reinforced composite (CFRC), cobalt-chromium framework, Photoelastic stress analysis

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INTRODUCTION

Edentulism, may it be partial or complete continues to be a major oral health problem and has always proved to be a challenge for prosthodontists all over the world. There are various treatment options like complete dentures, removable partial dentures, fixed partial dentures and implant based restorations.

Dental implants have proven to be a durable and predictable option to restore function and esthetics in patients with partial or total edentulism.[1] The use of dental implants offers several advantages in comparison with conventional fixed restorations and partial and complete removable dentures. In edentulous patients, the use of dental implants have shown to improve the masticatory efficiency, esthetics, comfort, have decreased bone resorption and prosthesis mobility and improved oral health–related quality of life in comparison with conventional dentures.[2,3]

Due to the recent advances in implantology, patients with edentulous or partially dentate jaws can today be restored with different types of implant-supported fixed dental prostheses (FDP).[4]

In fully edentulous patients with biomechanically compromised environment due to alveolar atrophy in the posterior regions, implant supported prosthesis (ISPs) is nearly impossible without invasive surgical procedures like nerve transposition and bone grafting in the atrophic posterior sites in the maxilla and mandible. The All-on-four concept is one such treatment procedure to avoid these unfavourable posterior areas by the use of tilted implants to improve the anterior posterior spread (AP spread) of dental implants which in turn favours a better load distribution.[5]

"All-on-four" treatment approach was designed in 2003 by Paulo Malo and Malo Clinic team, to rehabilitate edentulous patients with immediately loaded full arch restorations supported by only four implants in each edentulous arch.[5]

This treatment approach was designed to allow immediate function, while maximizing the use of available bone in the atrophic jaws; as an alternative to regenerative procedures, which increase the treatment time, cost, patient morbidity, and the complications inherent to these procedures.[6]

The All-on-four treatment approach involves placement of 4 implants in the inter foramina region of the jaw or in the anterior part of the maxilla, with two anterior axial implants and two posterior titled implants to support a full arch immediately loaded fixed prosthesis (FFP).[7] The posterior tilting of implant, avoids the vital anatomic structures, reduces the posterior cantilever and produces a well distributed four point stability leading to both implant and prosthesis success.[8] This allows rehabilitation of atrophic edentulous jaws, with fewer bone grafting procedures, less surgical time, and reduced number of implants.[5]

The All-on-four treatment procedure has given successful outcomes in short term, long term and retrospective studies that have been done in the past. There are various factors which affect the longevity of fixed ISPs such as implant position, anteroposterior spread, implant length and angulation, prosthetic connection, cantilever length and type of framework material used. So, the analysis of the mechanical stress that occurs in the bone surrounding the implant is an important factor to assess the long-term clinical success of prostheses.[9]

The choice of implant framework material is important for success. Various types of implant framework materials have been used in the past like cobalt-chromium, titanium alloys, gold alloys, nickel-chromium, ceramic, but studies with carbon fiber reinforced framework are scare inspite of it's good strength and low cost.

There are various methods to study the amount of stresses induced in the dental implants and the adjacent bone. It is not always possible to check or analyse these stresses intraorally so in-vitro methods like photoelastic stress analysis, strain gauge analysis, and finite element analysis (FEA) can be used.

These methods can be used to assess the effect of framework on the bone and implant components before conducting in-vivo trials of the new upcoming dental implant systems.[10] Each of these methods have their own advantages and disadvantages.

Strain gauges are efficient in quantifying strain and give a direct indication of the stress exerted within the structures.[11] The sensitivity of strain measurements depend on the relative alteration in dimension and in the basic resistance of a material when it is bent or extended under loading. Strain gauge can also be used in clinical conditions due to comparatively smaller size and their minimal to no interference during function. The disadvantage of this method is that, the strain is only measured at the area where the gauge is embedded or bonded, so they provide information about these specific points only and do not provide location and area of the concentration of stresses.[12]

Photoelastic stress analysis is based on the interpretation of isochromatic colour fringes produced in the photoelastic materials, when they are stressed and analysed under the polariscope setting. It allows direct observation of stress

distribution throughout the model, thus providing the location and pattern of the concentration of stresses.[13] The limitation of this method is its inability to replicate the physical properties of the peri-implant tissues, which exhibit a variable modulus of elasticity depending on the area. However, it is an adequate method of comparison as it isolates multiple variables in terms of patients with total rehabilitation on implants and can be used for complex systems.[14]

Another method is Finite Element Analysis (FEA), which is a numerical method of evaluating stresses and contortions in a model of any given shape to obtain an answer to a complex mechanical problem by breaking down the problem into much simpler and smaller elements. FEA has proven to be a useful tool to simplify complicated dental situations and to evaluate the various dimensional parameters of implant systems and associated structural mechanics e.g., bone implant interface, implant diameter, shape, load direction, minor implant components like prosthetic screws, implant failure mechanism etc. However, the disadvantage of FEA analysis is that the bone is assumed to be linearly elastic, isotropic and homogenous, whereas the natural bone is anisotrophic and heterogenous material. Also, a state of optimum osseointegration is assumed between bone and implant in the FEA analysis model, which may not occur in all clinical scenarios.[15]

There are very limited studies of stress analysis of comparison of carbon fiber reinforced composite (CFRC) implant framework material with conventional Co-Cr implant framework material at varying cantilever lengths. As this CFRC material is recently introduced, an in-vitro study was planned to evaluate the stress in CFRC framework at varying cantilever lengths.

NEED FOR THE STUDY

In implant prosthodontics, metal frameworks are used to rigidly spilt the implants together to provide rigidity and stiffness to the prosthesis and reduce possible complications such as prosthetic fracture.[16] Stiff prosthesis material distributes the stresses more evenly to the abutments and implants.[17]

Splinting of the implant may improve the distribution of masticatory load, can reduce the stress in the peri-implant tissue and prevent overloading of individual implants, can also reduce mechanical complications and the total financial cost of implant therapy by the use of fewer implants.[18]

Implant-supported FDP frameworks can be made of different alloys like gold alloys, titanium, cobalt-chromium and nickel-chromium. Gold alloys have lower modulus of elasticity as compared to base metal alloys, this reduces their ability to distribute forces more uniformly over the integrated implants, also for gold alloys the deformation of framework during high ceramic firing is more.[19]

Titanium has excellent biocompatibility, high corrosion resistance, good mechanical properties, has low thermal conductivity and is inexpensive. As a result, commercially pure titanium (cp-Ti) has gained popularity as a framework material for implant retained prostheses. However, titanium has disadvantages like high melting point, low density, extreme high reactivity with surrounding elements at high temperatures and it also undergoes structural changes at high temperature which affects its ability to bond with dental porcelain.[20]

Cobalt-chromium (Co-Cr) alloys have high stiffness, high yield strength, dimensional stability and corrosion resistance, adequate bond strength between

porcelain and alloy, also they exhibit higher dimensional stability when used with high fusing ceramics.[20] Because of the above-mentioned properties cobalt-chromium should be considered the first choice of metal alloy for fabricating the framework for implant-supported fixed prostheses.[19]

Metal frameworks have long been considered the gold standard in full arch FFPs to rigidly splint the implants together, and to protect implants from micromotion and overloads. However, metal framework fabrication is expensive, time consuming, technique sensitive with high melting point and high casting shrinkage.[21] So, to overcome these drawbacks, recent improvements in composite materials have made it possible to fabricate metal free prosthesis by using fibre reinforced frameworks.[22, 23]

The prosthodontic frameworks made of carbon fiber reinforced composites (CFRC) appear to be a suitable substitute for traditional metal frameworks in full arch implant-supported prostheses (ISPs).[24] They offer high stiffness, biocompatibility, are easy to fabricate, have high fracture strength and creep resistance, provide good adhesion with the veneering acrylic resin, exhibit low density and abrasion, chemical inertness, and no expensive machineries are required for their fabrication by the manual process, and are light weight in nature.[24,25] The above properties make CFRC to be an excellent material for fabrication of frameworks for full arch ISPs.

When compressive stresses are applied perpendicular to the denture's surface in a CFRC framework; stresses are expected to occur on the opposite side of the denture, because of the continuity of fibers.[24] This aspect has not been investigated in the previous studies. Additionally, minimal compressive stresses and strains are desirable in an immediate loading concept following implant insertion.

So, in the present study, the stresses in the All-on-four implant supported CFRC framework will be analysed and compared with the Co-Cr framework at varying cantilever lengths.

HYPOTHESIS

NULL HYPOTHESIS:

There is no difference in stress distribution between All-on-four implant-supported Co-Cr framework and CFRC framework at different cantilever lengths.

RESEARCH HYPOTHESIS:

There is a significant difference in stress distribution between All-on-four implant-supported Co-Cr framework and CFRC framework at different cantilever lengths.

AIM AND OBJECTIVES

AIM OF THE STUDY:

"To evaluate and compare photoelastic stresses between All-on-four implant-supported Co-Cr framework and CFRC framework at varying cantilever lengths."

OBJECTIVES:

- To assess the photoelastic stresses produced by All-on-four implant-supported CFRC framework at different cantilever lengths under progressive load.
- To assess the photoelastic stresses produced by All-on-four implant-supported Co-Cr framework at different cantilever lengths under progressive load.
- To compare the photoelastic stresses between All-on-four implant-supported Co-Cr framework and CFRC framework at different cantilever lengths under progressive load.

REVIEW OF LITERATURE

White et al (1994), evaluated the effect of increase in cantilever length on load distribution to an edentulous mandible. A photoelastic model following the morphology of edentulous mandible with five branemark implants, placed at an anteroposterior spread of 15 mm was fabricated. A Pd-Cu-Ga-In-Au alloy fixed splinted prosthesis with a long posterior cantilever of 30 mm was fabricated. The model was subjected to vertical loads of 89 N and 134N, applied in a increment of 5mm from the terminal implant to the maximum posterior cantilever length of 30mm. The results revealed that the maximum stresses were concentrated near the crest of the ridge of the distal implant. Also, maximum stresses on the distal and second most distal implants increased in a non-linear fashion with the increase in the cantilever length.[26]

Shackleton et al (1994), evaluated the survival rate of the implant supported fixed prosthesis and also tried to establish a correlation between the survival rate and posterior cantilever length. The study included 25 participants undergoing rehabilitation of 28 edentulous arches (24 in the mandible and 4 in the maxilla). The participants were divided into 2 subgroups based on the cantilever lengths; group 1 included prosthesis with cantilever lengths upto 15 mm and group 2 included prostheses with posterior cantilever greater than 15 mm. Survival analysis revealed that fixed ISPs with cantilever lengths less than or equal to 15 mm, showed a better survival rate as compared to prostheses with posterior cantilever lengths exceeding 15 mm. The findings of this study provided clinical evidence that fixed ISPs with shorter cantilevers have a higher survival rate or life duration as compared to the prosthesis with longer cantilevers.[27]

Sertgöz A and Güvener S (1996), studied the stress distribution occurring at the bone/implant interface in an fixed ISPs at three varying cantilever lengths and implant lengths using finite element analysis. Nine distinct simulation models were used, each with a different combination of cantilever lengths i.e. 7mm, 14mm and 28 mm; and implant lengths of 7mm, 15mm and 20 mm supported by 6 implants placed in the mandibular bone at an AP spread of 14mm. The terminal end of posterior cantilever was subjected to a vertical load of 75 N and horizontal load of 25 N. For all the simulation models, maximum stresses were localised distal to the bone/implant interface on the most terminal implant corresponding to the site of loading. Also, increase in the cantilever length resulted in an increase in the stress value at the bone to implant interface. However, there was no discernible influence of the implant length on stress distribution.[28]

Paulo Maló (2003), evaluated the clinical outcomes for All-on-four immediately loaded fixed prosthesis in the completely edentulous mandible. The study included 176 immediately loaded implants in 44 participants placed in the interforaminal region of the jaw, supporting a fixed complete arch prostheses. The study demonstrated cumulative implant survival rate of 96.7% after 3 years of follow up; the prosthesis survival rate was 100% and the average marginal bone resorption was low. The study concluded that the “all-on-Four” immediate-function concept using branemark system implants is a viable treatment for rehabilitation of atrophic mandible.[29]

Paulo Maló (2006), analysed the clinical efficacy of a novel implant design when paired with immediate function concept in rehabilitating completely edentulous jaws. The results demonstrated a 98.9 percent cumulative survival rate at one year follow-

up, alongside favourable esthetic results and excellent soft tissue contour. Whereas, after one year of implant loading, the marginal bone loss observed was 1.2 ± 0.7 mm beneath the implant-abutment interface. The results of this pilot investigation demonstrated that completely edentulous jaws with varing bone densities can be rehabilitated successfully and with good aesthetics utilising the immediate function concept with the proposed design, while maintaining favourable marginal bone levels.[30]

Capelli M et al (2007), assessed and compared the treatment outcomes of immediately loaded FFP supported by upright and tilted implants in the rehabilitation of edentulous jaws. The study included 65 participants with a total of 342 implants placed in the maxillary and mandibular arches supporting full arch FFP fabricated using titanium framework. The distal implants were placed at an angulation of 25° to 35°. The results demonstrated an cumulative implant survival rate of 97.59% for the maxilla, and 100% for the mandible; also the success rate for the prosthesis was 100% at a follow-up period of 40 months. Results showed no significant differences between the mean marginal bone loss values between the straight and tilted implants. The findings from the preliminary report of this study indicate that the immediate rehabilitation of the edentulous maxillary and mandibular arches with a hybrid FFP supported by four or six implants, appears to be a suitable alternative to more invasive surgical procedures.[31]

Bevilacqua et al (2008), studied the load distribution in an edentulous mandible at varying implant inclinations, and also evaluated the effect of posterior cantilever. The distal implants were positioned vertically in the first design, with the posterior cantilever of 15 mm; whereas the posterior implants were positioned at an distal

inclination of 15 degrees, 30 degrees and 45 degrees in the second, third and fourth design respectively, with the corresponding cantilever lengths of 11.6, 8.3 and 5 mm. The assessed designs showed that, tilting distal implants decreased the associated posterior cantilever, which in turn decreased the peri-implant stress and resultant framework stresses. The shorter cantilever length associated with the full fixed prosthesis (FFP) design contributed significantly to the decrease of peri-implant stresses.[32]

Francetti L et al (2008), assessed the treatment outcomes of immediately loaded FFP supported by 2 axial and 2 titled implants placed according to the "All-on-four" concept in the completely edentulous mandible. The study included 62 participants with a total of 248 implants supporting a full arch FFP fabricated using titanium framework. The provisional FFP were placed with 48 hours of implant placement, whereas the definitive FFP were inserted after 4 to 6 months of healing. The results of the study showed no implant failures, providing a 100% cumulative implant and prosthesis survival rate. Also, no significant differences between the mean marginal bone loss values between the straight and tilted implants was observed. The present clinical study demonstrated favourable clinical outcomes for the mandibular FFP using 2 axial and 2 tilted implants placed according to the "All-on-four" concept and recommended that immediate loading in conjunction with tilted implants appears to be a suitable treatment modality for rehabilitation of completely edentulous mandible.[33]

Geremia et al (2009), assessed the effect of cantilever length and inclination of distal implant on the intensity and pattern of distribution of axial forces and bending moment using strain gauge analysis. Ten metallic bars simulating the framework of

ISPs were fabricated on two master models with five implants each; one with all 5 implants parallel (n=5) and one with two distal implants angled 27 degrees (n=5). Following which, 50N load was applied to the predetermined cantilever lengths of 10, 15 and 20mm; and the deformation values were noted and analyzed. The results demonstrated that with the increase in posterior cantilever from 10 to 20 mm, the axial force increased by approximately 50% and the sagittal bending moment increased by 70%. However, tilting distal implants lowered the amplitude of the axial force without impairing the sagittal bending moment when compared to straight implants for all cantilever lengths examined.[34]

Bellini et al (2009), evaluated and compared the stresses at the bone-implant interface of two implant configurations i.e. tilted and non-tilted configuration for the rehabilitation of edentulous maxilla using FEA analysis. Two models for the tilted configuration and one model for the non-tilted configuration were simulated in the FEA. The results showed that maximum stresses were concentrated near the cervical area of the terminal implant in all the tested models. Also, the tilted configuration demonstrated lower compressive stress values as compared to the non-tilted configuration, suggesting a potential biomechanical advantage in lowering stresses at the bone-implant contact interface.[35]

Kim et al (2011), examined the influence of change in inclination of two distal implants in an mandibular all-on-four model using photoelasticity. Two photoelastic models following the morphology of edentulous mandible, with four implants placed in the interforaminal region of the model; with two distal implants placed axially in one model and with 30 degree distal inclination in another model were fabricated. Followed by the fabrication of two acrylic resin cantilevered prosthesis. A vertical

load of 129 N was applied to the prostheses at three designated loading sites, and circular polariscope was used to monitor stresses dissipated to the supporting structures. The results indicated that distal tilting of implants in a splinted full-arch prosthesis did not result in a rise in bone stresses surrounding the distal implants. Additionally, when tilted implants were used, the maximum stress was lowered by nearly 17% as compared to the axial implants.[36]

Butura et al (2011), described a clinical study of placement of 857 implants in 216 subjects to support "All-on-four" immediately loaded FDP in the mandibular arch. The results showed that in spite of the simultaneous dental extractions and levelling of the bone, relatively few implants failed or demonstrated bone loss.

The authors also stated that the original surgical prosthetic protocol given by Branemark recommended placement of fixtures in between the mental nerves; with 4 fixtures recommended for the atrophic mandible, and 6 fixtures for the mandible with mild to moderate resorption. However, this constituted a limiting factor in terms of posterior extension of the prosthesis; as it resulted in an increase in the posterior cantilever length, which can have a direct impact on the marginal bone loss. The authors of the present study stated that, the "All-on-Four" surgery can be performed with great confidence in the mandible, putting the need for further implants into question. This is because of the result of optimising the AP spread, which reduces the posterior cantilever and produces a well distributed four point stability, leading to both implant and prosthesis success.[37]

Babbush CA et al (2011), evaluated the survival rate and prosthesis success of FFPs placed using the "All-on-four" concept and using Nobel active implant. The retrospective study included 165 participants with a total of 780 implants. The results

showed cumulative implant survival rate of 99.6% and prothesis survival rate of 100%. The study concluded that rehabilitation of atrophic jaws using “All-on-four” concept and Nobel active implants showed favourable results in terms of both the implant and prosthesis survival rate.[38]

Malo P et al (2011), documented the long term follow-up data of the patients rehabilitated using “All-on-four” concept. The study included 245 participants with a total of 980 implants supporting a mandibular FFP. The results revealed cumulative patient and implant survival rate of 94.8% and 98.1% at five years, and 93.8% and 94.8 % up to ten years. The 10 year prostheses survival rate was 99.2%. The authors concluded that “All-on-four” immediate function concept appears to be a suitable treatment modality for rehabilitation of completely edentulous mandible in the long term.[39]

Malo et al (2012), documented the medium term and long-term follow up results of completely edentulous maxilla rehabilitated using “All-on-4” implant supported FFP. The study included 242 participants, with a total of 968 implants supporting a immediately loaded all acrylic FFP. The implants were positioned using “All-on-4” surgical guide. The follow-up visits were scheduled at 6 monthly intervals till 5 years; and after three and five years of function, radiographic examination of the marginal bone level was done. A total of 19 immediately loaded implants failed in 17 patients; providing a 5-year cumulative survival rate of 93% and 98%, at the patient and implant level respectively. Whereas, the prosthesis survival rate was 100%. The marginal bone levels observed were 1.52 ± 0.3 mm and 1.95 ± 0.4 mm from the implant abutment interface at 3 and 5 year follow-up respectively. The results obtained indicate that rehabilitation of completely edentulous maxilla using “All-on-

4” implant supported FFP, demonstrates high patient level and implant level survival rate at 5 year followup interval and is a viable treatment for rehabilitation of atrophic maxilla.[40]

Malhotra et al (2012), analysed the effect of cantilever length and distal implant angulation on the stress distribution in an mandibular ‘all-on-four’ scenario using FEA analysis. The distal implant angulations studied were 30° and 40°, whereas two cantilever lengths of 4mm and 12mm were analysed. Results showed that for both 30° and 40° distally tilted implants, the difference observed between the posterior cantilever lengths of 4mm and 12 mm was not significant. Also, the study demonstrates that increasing the distal implant inclination, does not considerably increase the stress.[41]

Patzelt et al (2013), conducted a systematic review to evaluate survival rate and bone loss in the FDPs, rehabilitated using the “All-on-four” concept. The systematic review included 13 full text articles, with a total of 4,804 implants being placed. Results showed failure of 74 implants from a total of 4,804 implants, with 74% failures reported in the first year of placement. The cumulative survival rate (SR) reported for the implants was 99.0 ± 1.0%, and 99.9 ± 0.3% for the prosthesis. The mean marginal bone loss seen was 1.3 ± 0.4 mm. The resultant data show no significant differences between the maxillary and mandibular arches, and axial and tilted implants. The resultant data showed favourable short term treatment outcomes for “All-on-four” FFP.[42]

Taruna et al (2014), discussed the “All-on-4” concept and its prosthodontic implications. They noted that the mechanical conditions in which implants serve as load bearing abutments plays a significant role in determining their clinical

effectiveness. Also, strain transmitted to the crestal bone can be decreased in the atrophic edentulous jaws and ridges with poor quality bone, by increasing the AP spread of implants, insertion of longer implants, and increasing the number of implants placed.[5]

Menini et al (2015), investigated the stresses in an maxillary “All-on-4 model” supporting an full-arch implant-supported fixed prosthesis (FFP) using FEA analysis. Three frameworks were compared i.e. FFP without rigid framework, reinforced with cast metal framework, and reinforced with CFRC framework. Results demonstrated that FFP with acrylic resin prosthesis without framework reinforcement showed stresses up to +55.16% on the implants, +56.93% in the peri-implant bone and +70.71% in the resin prosthesis, higher in comparison to the cast metal reinforced and CFRC framework. Whereas, the prosthesis reinforced with CFRC exhibited behaviour that was intermediate between the other two types. Therefore, reinforcement of a rigid framework in an FFP improves load distribution and thus reduces the maximum stress values at the implant, prostheses and peri implant bone levels. Also, CFRC appear suitable for fabrication of frameworks for implant-supported FFP, as they demonstrate rigidity and stiffness similar to the metal frameworks.[16]

Francetti et al (2015), evaluated the pattern of stress on the abutments in two different implant supported FFP using strain gauge analysis. One supported by 4 implants with anterior 2 implants straight and posterior 30° angulated (4IMP), whereas another one rehabilitated using 5 implants placed in an upright position (5IMP). A titanium framework one with a distal cantilever length of 5 mm was fabricated for 4IMP and one with distal cantilever of 15 mm was fabricated for 5IMP. Following which, the framework was subjected to loading between 20 N and 200 N,

and strain values obtained were evaluated. Results showed no difference in strain between the two FFP designs, indicating that the use of tilted implants along with angulated abutments to shorten the posterior cantilever might be regarded a clinically viable approach.[43]

Li et al (2016), investigated the clinical impact of reinforcement of carbon fiber in the All-on-4 provisional prostheses. The provisional prostheses were divided into 2 groups; control group and the carbon fiber reinforced group. The study included 60 participants in the control group rehabilitated with 71 provisional prostheses (28 in the maxilla and 43 in the mandible) and 23 participants in the carbon fiber group with 28 provisional prostheses (9 in the maxilla and 19 in the mandible). The carbon fibre reinforced group fractured at a considerably lower rate than the control group. Clinical evaluation revealed no evidence of carbon fibre exposure or mucosal discomfort. As a result, the reinforcement of carbon fibers in the All-on-four provisional prosthesis, may be clinically beneficial for preventing prosthesis fracture and offers various clinical advantages.[44]

Suedam et al (2016), studied the mechanical stresses dissipated to the peri-implant bone at varying cantilever lengths, while also comparing two different framework materials. A "U shaped polyurethane model" with two implants following the morphology of an edentulous mandible was fabricated. Two identical frameworks with a posterior cantilever length of 27 mm were fabricated, one with Co- Cr and another one with Pd-Ag alloy. Following which, 300 N load was applied in the pre-determined cantilever lengths of 5, 10 and 15mm. The study concluded that increase in the posterior cantilever length influenced the load distribution to the peri-implant bone, and recommended that cantilever lengths less than 15 mm led to a more

favourable stress distribution for mandibular ISPs. Also, the alloy used to fabricate the framework had an effect on the biomechanical behaviour and load transmission; this report indicated that the Co-Cr alloy exhibited greater compression values than the Pd-Ag alloy at the same cantilever lengths.[45]

Li et al (2016), evaluated the effect of partial reinforcement of glass or carbon fibre in the All-on-Four provisional prosthesis and its effect on the flexural properties of the material. The 3% glass or carbon fibres were woven together and tightened in a figure-of-eight pattern between the two abutments. For the three-point loading test, four different types of specimens were created; following which the interface was evaluated using scanning electron microscope. Results demonstrated that partial reinforcement of glass or carbon fibre in the provisional resin, increased the flexural strength and modulus substantially. Also, SEM analysis demonstrated that the fibres and acrylic resin were in reasonably constant contact. Therefore, glass or carbon fibres reinforced in the All-on-Four provisional prosthesis may be clinically helpful in preventing prosthesis fracture and may offer various clinical advantages.[46]

Menini et al (2017), investigated the mechanical characteristics and biocompatibility of dental implant frameworks fabricated from carbon fiber reinforced composite (CFRC), and compared it with the gold alloy framework. The CFRC framework exhibited optimal biological and mechanical properties comparable to the gold alloy framework. The gold alloy framework exhibited more plastic behaviour than the CFRC framework, also the gold alloy framework did not completely regain its previous shape after the load was removed. The results of the present study concluded that, CFRC showed excellent biological and mechanical properties and appears to be a suitable alternative for fabrication of full arch FFP.[24]

Pera et al (2017), compared the carbon fiber reinforced (CFRC) and metal framework in immediately loaded full arch ISPs. The study was divided into 2 subgroups; group 1 constituted of 42 participants with a total of 170 implants supporting a immediately loaded screw retained CFRC framework as per the columbus bridge protocol, whereas the Group 2 (control group) constituted of 34 participants with a total of 163 implants rehabilitated with immediately loaded full-arch prostheses reinforced with metal framework. Results demonstrated that 10 implants (6.1% of the total) failed in the control group; whereas no failure was denoted in the test group. Also, the mean peri-implant bone loss seen in the control group was 1mm , which was significantly greater than in the test group i.e. 0.8 mm. The CFRC framework resulted in less marginal bone resorption and demonstrated a higher implant survival rate as compared to the metal frameworks. Within the confines of this study, CFRC framework can be considered a suitable substitute for traditional metal frameworks in full arch ISPs.[47]

Menini et al (2018), analysed the failure pattern and shear bond strength (SBS) of CFRC and veneering materials in a total of 20 fabricated samples. Group A constituted of 10 CFRC samples veneered using polymethylmethacrylate, and Group B constituted of 10 CFRC samples veneered using composite resin. The SBS of samples in Group A i.e. veneered using polymethylmethacrylate was 7.39 ± 0.24 MPa, and that of Group B i.e. veneered using composite resin was 5.68 ± 0.29 MPa. In both the assessed groups, microscopic examination revealed an adhesive fracture at the interface between CFRC and veneering material, however the difference between the groups was not significant. Therefore, adhesion of CFRC with veneering material is consistent and reliable, though a precise protocol for improving adhesion must be implemented.[48]

Taşın et al (2019), investigated the misfit and strain distribution in fixed complete dentures (FCDs), as well as their correlation with the fabrication procedure for the Co-Cr metal framework. An edentulous epoxy resin model was fabricated with 4 implants placed in the interforaminal region of the model. The Co-Cr frameworks were fabricated using computer aided design and computer aided manufacturing (CAD-CAM) milling using soft blocks, hard blocks, and using direct metal laser sintering (DMLS). The misfit at the abutment-implant interface was observed using digital microscope, and the torque values were evaluated using strain-gauge analysis. The results showed that the manufacturing technique for the Co-Cr frameworks had a significant effect on the passive fit. Among the fabrication techniques evaluated, the CAD CAM milling from hard blocks proved to have higher precision with lower misfit values for the FCD Co-Cr framework.[49]

MATERIALS AND METHODS

SOURCE OF DATA

This in-vitro study was carried out in the Department of Prosthodontics and Crown and Bridge, KAHER KLE Vishwanath Katti Institute of Dental Sciences, Belagavi, and Department of Mechanical Engineering, K. L. S. Gogte Institute of Technology, Belagavi.

SAMPLE SIZE:

Two photoelastic models of an edentulous mandible were fabricated with two implants placed vertically in the anterior region and two placed at an angulation of 30° in the posterior region. Following which, two identical implant-supported frameworks with bilateral cantilever extension of 20mm, one with CFRC and other one with Co-Cr were fabricated. The framework had graduated markings at different cantilever lengths i.e. no cantilever extension (0mm), 5mm, 10mm, 15mm, and 20mm. The stresses were assessed by 5 different repetitions at the marked cantilever lengths, and the principal stresses were calculated using the mean maximum fringe order of 5 repetition stresses.

INCLUSION CRITERIA:

Models free of porosity and without residual stress when observed under circular polariscope. And Co-Cr and CFRC frameworks with passive fit.

EXCLUSION CRITERIA:

Models with greater than 0.5 fringe order of residual stress and model with surface defects and deformities were excluded.

TABLE 1: MATERIALS UTILIZED IN THE STUDY:

MATERIAL	DESCRIPTION	MANUFACTURER
Modelling Wax	Type II baseplate wax	(Pyrax, Uttarakhand)
Silicone material	Duplicating silicone	Doublident, WP Dental (Germany)
Epoxy resin	Adhesive CY 230 and Hardener HY 951	Araldite, Araldite casting system (Hunstman Corporation)
Dental Implant	4.2 * 13 mm internal hexagon cylindrical implant (CFI)	GDT Implants, Israel
Abutment	Straight abutment (SA7), 30 degree Multi unit abutment (MU-30-2)	GDT Implants, Israel

TABLE 2: ARMAMENTARIUM USED IN THE STUDY:

MATERIAL	DESCRIPTION	MANUFACTURER
Digital weighing balance	Model No. UW6200H	Uni Bloc UP series
Vacuum mixer	Model No: 26090	EasyMix BEGO
All-on-4 surgical guide	-	Custom made
Hex driver	Hand driver 1.25mm	Noris Dental Implant Systems
Torque driver and Torque wrench	-	Noris Dental Implant Systems
Circular polariscope	Model No. HP 12-02	Eternal Engineering Equipment Pvt Ltd.
Digital camera	6000 alpha	Sony

METHOD:

FABRICATION OF PHOTOELASTIC MODEL (Figure 5 to 12) :

For fabrication of photoelastic model, a wax model following the morphology of edentulous mandible was fabricated **(figure 5)**. The model was devoid of the land area, limiting structures and tongue space; which could interfere with the photoelastic stress analysis. A custom made All-on-4 surgical guide was fabricated, to aid in correct positioning and angulation of implants at predetermined location **(figure 6)**. The custom made guide had 2 anterior markings, 7mm apart from the midline for positioning of anterior implants, whereas 2 markings at the distal end for positioning of posterior implants (the anteroposterior distance between the anterior marking and distal marking was 15mm); also the guide had angulation markings of 17, 30 and 45 degrees.

This custom made guide was inserted in the fabricated wax model maintaining the midline **(figure 7)**. For fabrication of photoelastic test models, GDT 4.2 * 13 mm internal hexagon cylindrical implants were used **(figure 8)**. Two anterior implants were inserted parallel to each other and two posterior implants were placed at 30° distal inclination in accordance with the marks on the custom-made guide with the AP spread of 15 mm **(figure 9A & 9B)**. The wax model was duplicated using duplicating silicone (Doublident, WP Dental), maintaining an even thickness of the material. After complete setting of the material, de-waxing was carried out to eliminate any remaining wax residue. Thus, the desired silicone mould was obtained, with the implants positioned in the predetermined location and angulation **(figure 10)**.

Two Photoelastic models were fabricated using epoxy resin CY230 and hardener HY951 [Araldite, Araldite casting system (Hunstman Corporation)] using the same silicone mould. The resin and hardener were weighed in 10:1 ratio of parts by weight using digital weighing balance, followed by vacuum mixing of the material until a homogeneous and non-porous mix was obtained **(figure 11)**. The resin was gently poured into the silicone mould, and allowed to set for 24 hours at room temperature (following the manufacturer's instructions). During the pouring and curing stages, the silicone mould was maintained in an ice bath to reduce incorporation of residual stresses and minimize the exothermic heat produced at the time of setting. The obtained models were finished and polished using fine grits of sandpaper and pumice, to obtain a clear model for observation of fringes **(figure 12)**. The models were analysed in the circular polariscope for absence of more than 0.5 fringe order of residual stresses.

FABRICATION OF FRAMEWORK (Figure 13 to 18):

The finished photoelastic models were scanned using extraoral scanner, and obtained stereolithographic (STL) files were imported into the exocad designing software. Two identical ISPs bar framework, one with CFRC and other one with Co-Cr were designed in the exocad CAD designing software **(figure 13 & 16)**. Both the frameworks were identical, with a bilateral cantilever extension of 20 mm. After verification of html file of the designed frameworks, the frameworks were milled; one with CFRC and second with Co-Cr **(figure 14 & 17)**. The frameworks were verified for passive fit using the single screw test and the retaining screws were torqued to 20 Ncm. Graduated markings were made on both the frameworks at predetermined cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm and 20 mm **(figure 15 & 18)**.

PHOTOELASTIC STRESS ANALYSIS (figure 19-29):

The settings of the circular polariscope were adjusted to obtain bright field arrangement **(figure 4).** The polarizer and analyzer were placed parallel to each other, and 1st quarter wave plate and 2nd quarter wave plate were placed crossed for obtaining bright field isochromatics. After which, the model was placed in the loading frame, to analyze presence of residual stresses. Following that, the model was gradually loaded using a hydraulic load cell equipped with a digital load indicator for visualising the applied load. The load was increased gradually from 120 N until the load of 180 N with an interval of 20 N and the fringe orders were recorded against the load applied. The progressive load of 120 N-180 N was applied five times at 6 designated loading points:

A. Abutment of last tilted implant (i.e. at 0 mm cantilever extension),

B. On all four abutments at the same time using a resin platform,

C. At different cantilever lengths of 5 mm, 10 mm, 15 mm and 20 mm.

After the impact of the load, the presence of isochromatic fringes were observed and recorded using a digital camera. The stresses are quantified by counting the number of fringes. The higher the fringe order, more is the stress magnitude; and closer the fringes, more is the stress concentration. The zero order fringes are black and indicate no stresses, whereas pink and green order fringes indicate highest stresses.[50] The maximum fringe order for the calculation of principal stress was obtained by counting the number of fringes at each loading point (**figure 19-29**). After which, the model was gently unloaded and removed.

The principal stresses produced were calculated using maximum fringe order and using formula :

Maximum principal stress = $\sigma_1 - \sigma_2 = \frac{N_{max} F\sigma}{h}$

Where, σ = principal stress

N_{max} = Maximum fringe order

F_σ = Material fringe value (constant)

and h = Thickness of the material

For calculating Material fringe value (F_σ) a graph of load versus fringe order was plotted. From which Slope (S) was determined by using formula, Slope(S) = $\Delta P/ \Delta N$; where ΔP is the load in Newton and ΔN is the fringe order.

The value of Slope (S) was substituted in formula, $F_\sigma = 8S/\pi D$; where S is the Slope, D is the diameter/height of the model and F_σ is the Material fringe value.

Fig 1. Duplicating silicone (Doublident, WP Dental)

Fig 2. Adhesive CY 230 and Hardener HY 951 (Araldite casting system)

Fig 3. Vacuum mixing of the material. EasyMix Bego.

Fig 4. Model placed in the Circular polariscope
(Model No. HP 12-02)

Fabrication of the Photoelastic models

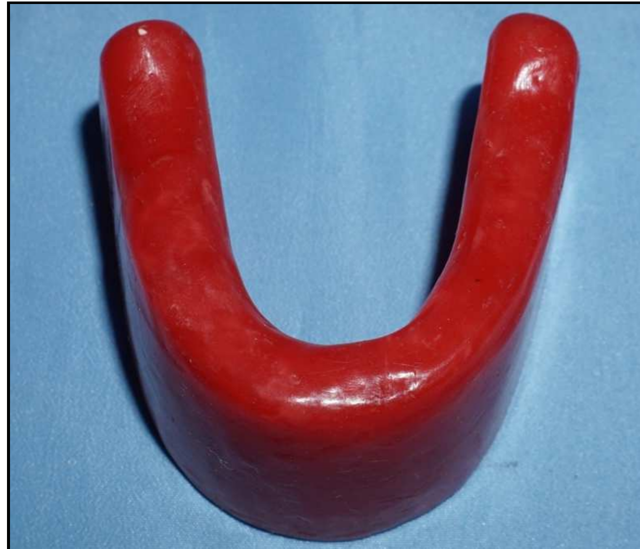


Fig 5. A wax model following the morphology of edentulous mandible

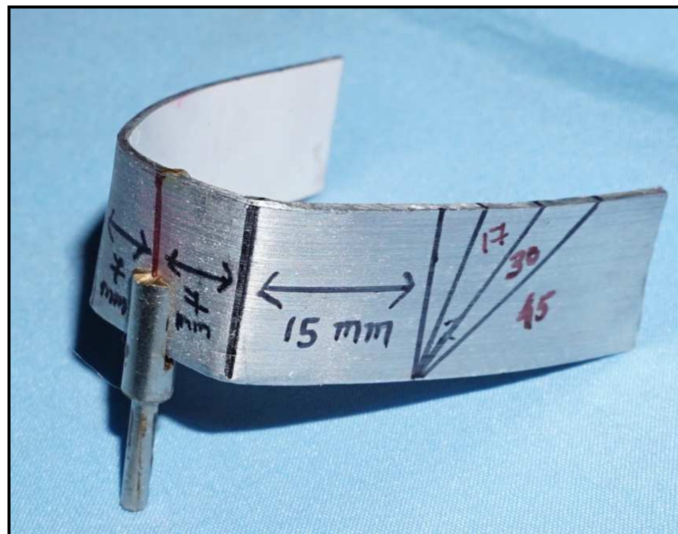


Fig 6. Custom made All-on-four surgical guide with designated implant position and angulation markings.

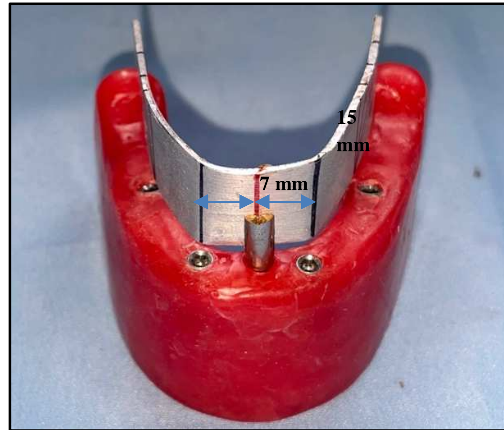
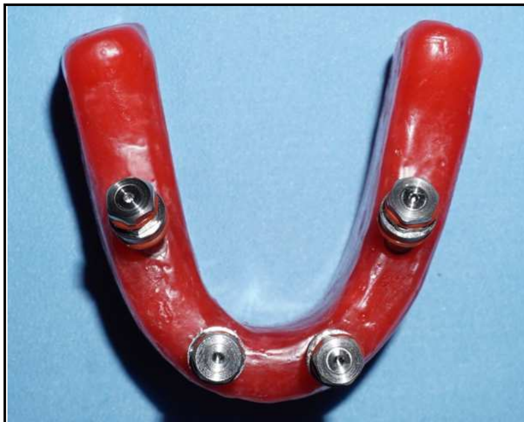


Fig 7. Placement of implants according to the custom guide

Fig 8. GDT 4.2 * 13 mm internal hexagon implant



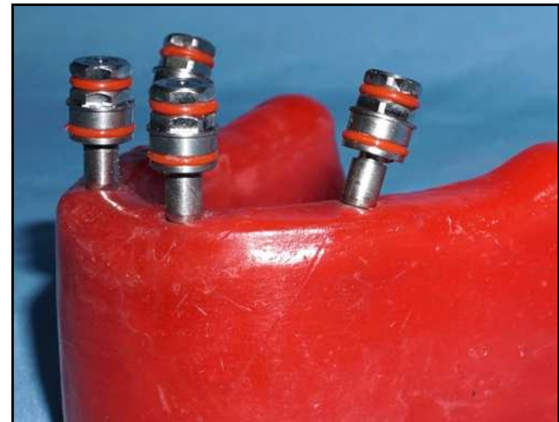


Fig 9A & 9B . Two anterior implants parallel, and two posterior implants placed at 30° distal inclination

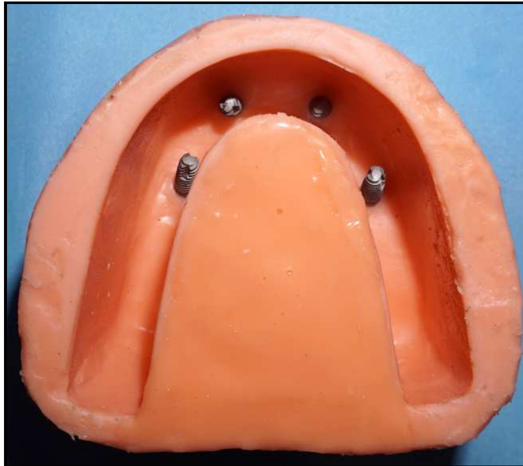


Fig 10. The desired silicone mould obtained

Fig 11. Vacuum mixing of the epoxy resin material CY230 and HY 951

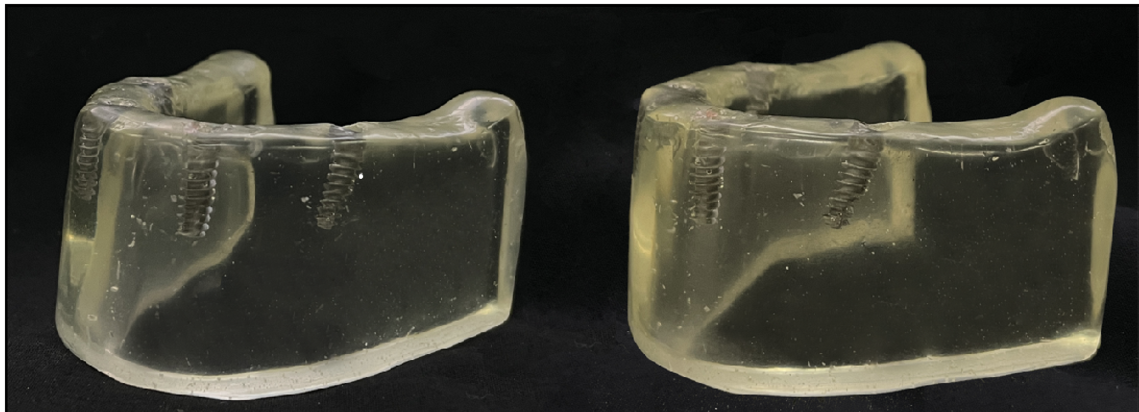


Fig 12. Two Photoelastic models fabricated following the "All-on-four" concept.

Fabrication of the frameworks

1. Co-Cr framework

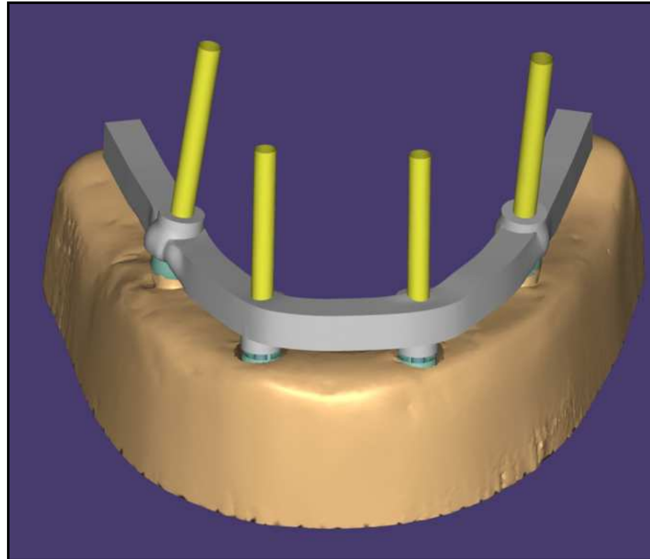


Fig 13. HTML file of the Co-Cr framework designed in the exocad software

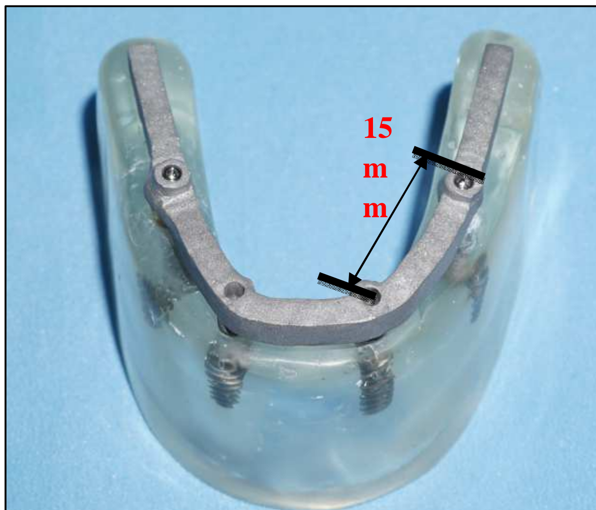


Fig 14. Fabricated Co-Cr All-on-four framework

Fig 15. Markings at cantilever length of 5mm, 10mm, 15mm in the Co-Cr framework

2. CFRC framework

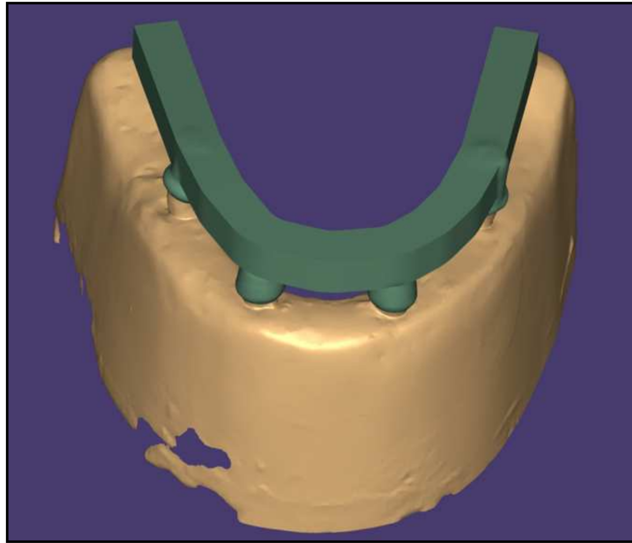
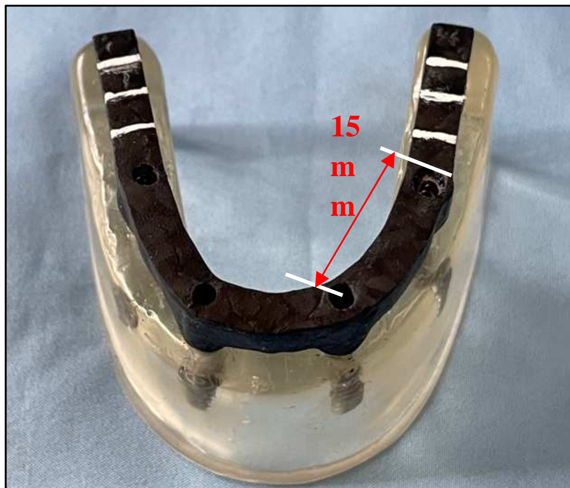


Fig 16. HTML file of the CFRC framework designed in the exocad software



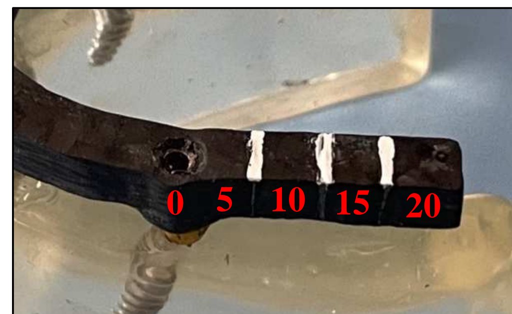


Fig 17. Fabricated CFRC All-on-four framework

Fig 18. Markings at cantilever length of 5mm, 10mm, 15mm in the CFRC framework

PHOTOELASTIC STRESS

Fig 19 (A to D): INTERPRETATION OF THE FRINGE ORDERS

Fig 19A. 1st order fringe

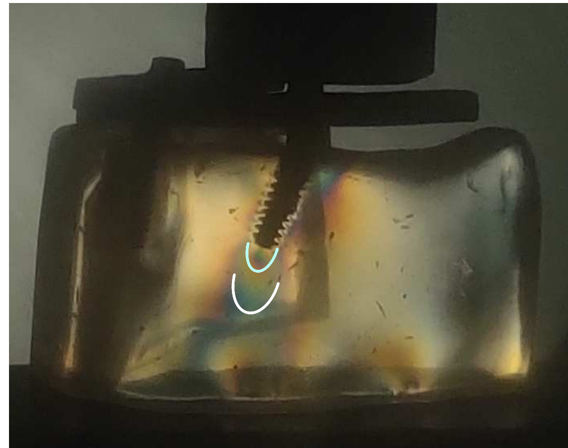


Fig 19B. 2nd order fringe

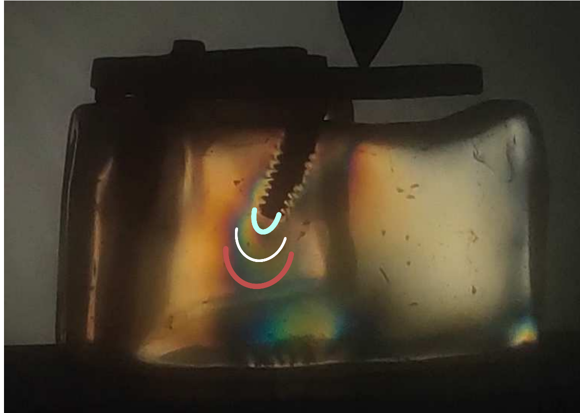


Fig 19C. 3rd order fringe

Fig 19D. 4th order fringe

1. Co-Cr Framework

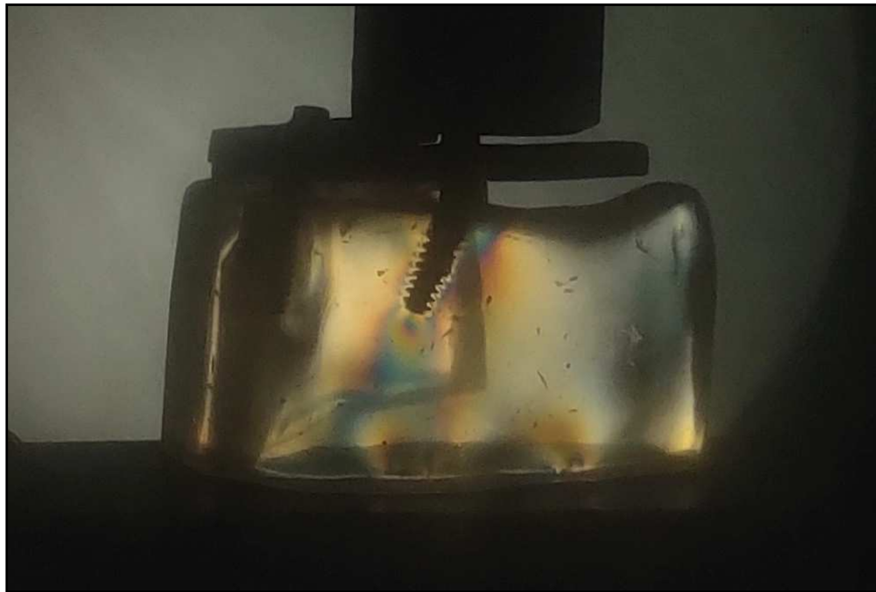


Fig 20. 2nd order fringe seen at application of 120 N load on abutment of last tilted implant (No cantilever extension)

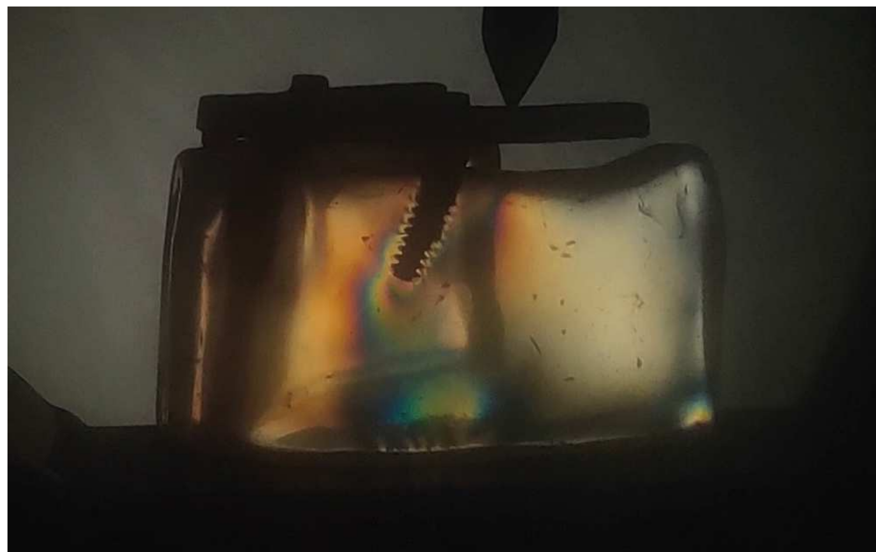


Fig 21. 3rd order fringe at application of 120 N load on 5mm cantilever

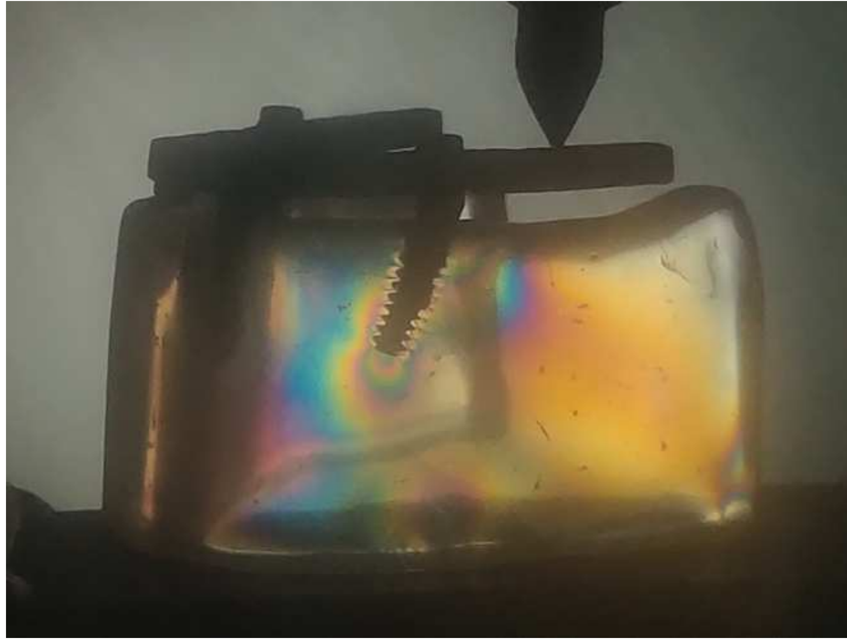


Fig 22. 4th order fringe along with the crestal fringe, at application of 180 N load at 10 mm cantilever length.

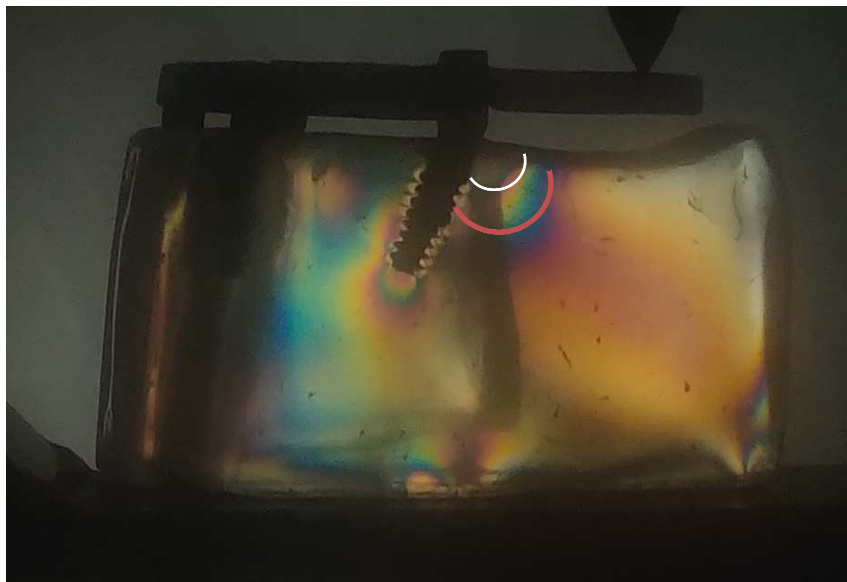


Fig 23. 4th order fringe **along with high crestal stresses**, at application of 180 N load on 15 mm cantilever length (Fringes merged due to higher stress concentration).

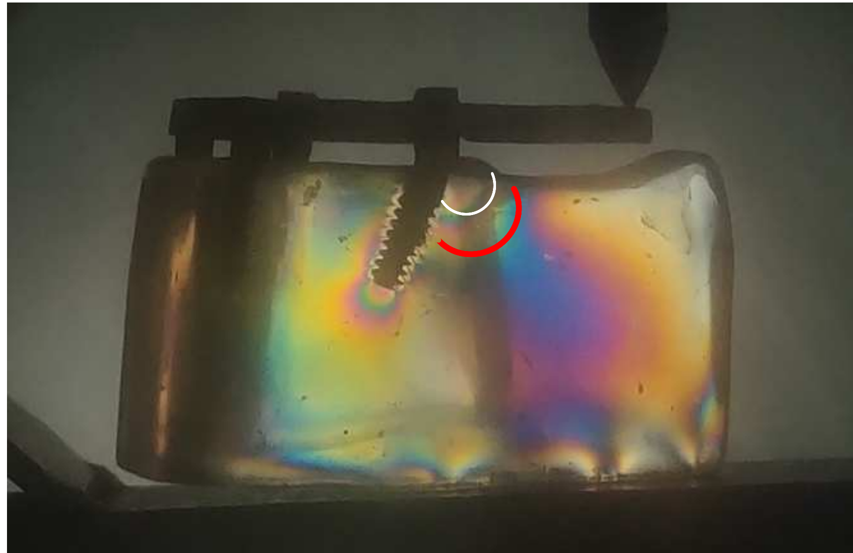


Fig 24. 4th order fringe **along with high crestal and apical stresses** seen, at application of 180 N load on 20 mm distal cantilever.

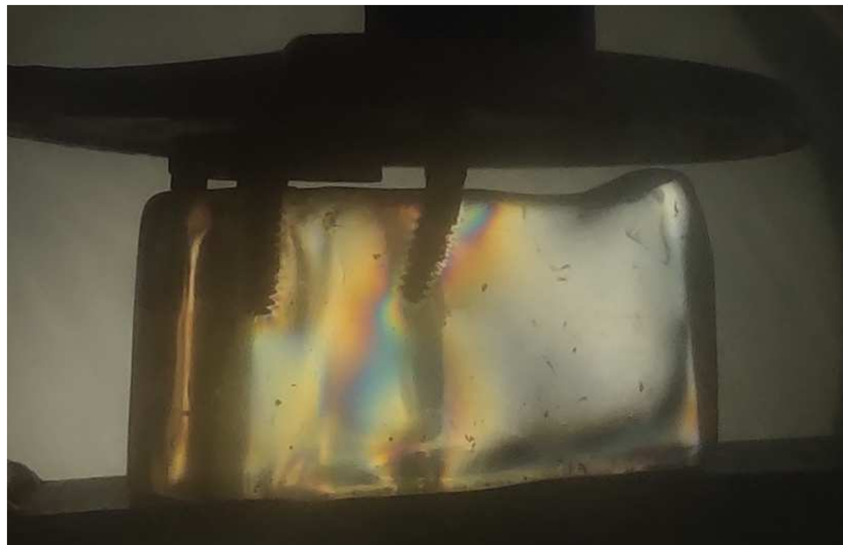


Fig 25. 2nd order fringe at 120 N when all the abutments were loaded simultaneously

2. CFRC Framework

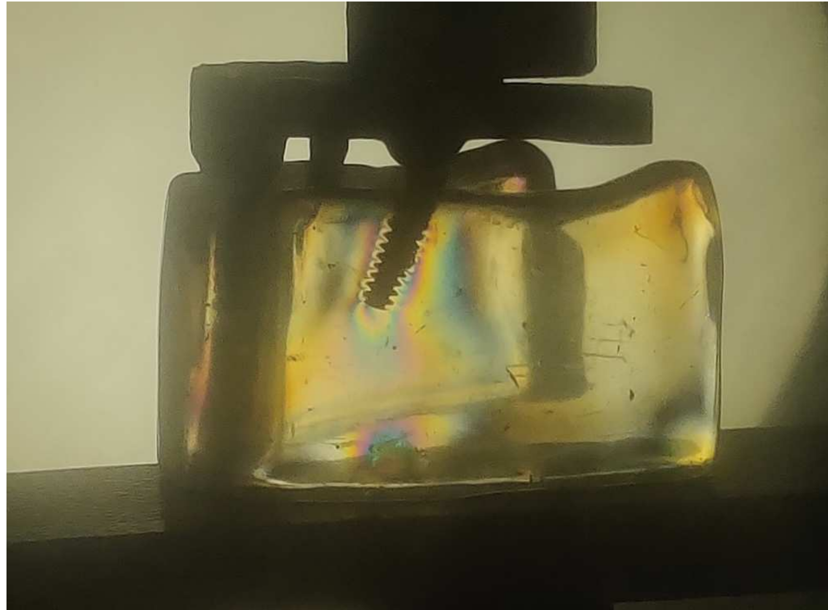


Fig 26. 2nd order fringe at application of 140 N load on abutment of last tilted implant

Fig 27. 3rd order fringe at application of 180 N load on 5 mm cantilever length.

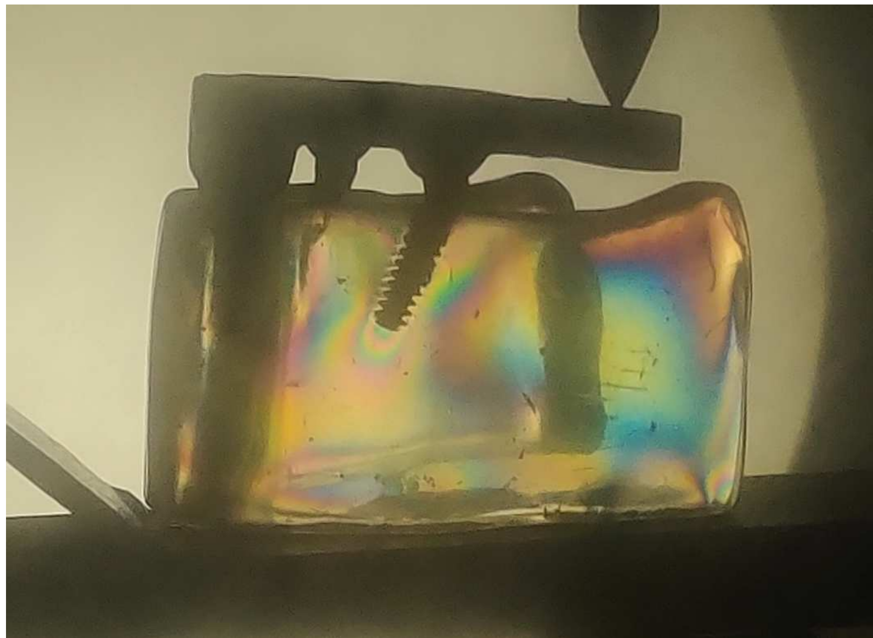


Fig 28. 4th order fringe at application of 160 N load on 15 mm cantilever length **(Note the homogeneous load distribution and absence of crestal stresses)**

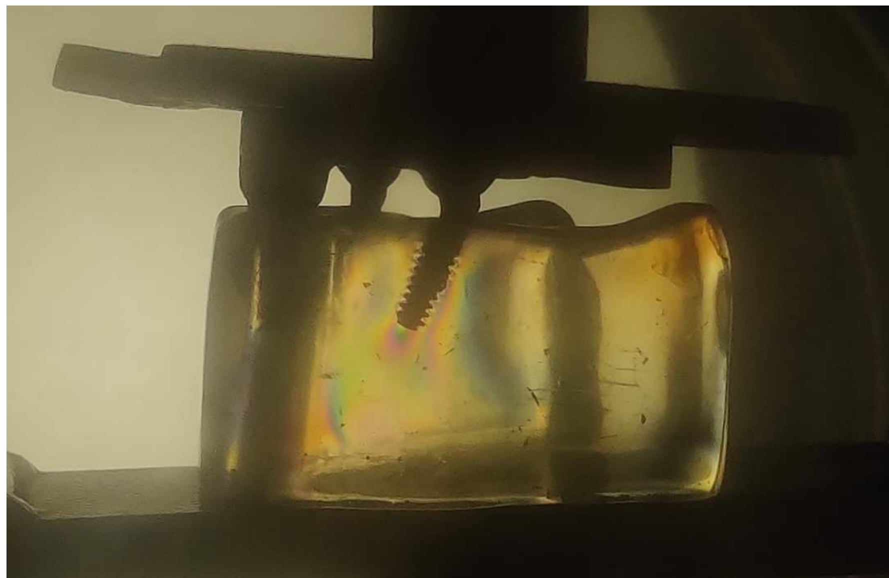


Fig 29. 1st order fringe at application of 140 N load on all the abutments simultaneously

RESULTS

The results derived from this in-vitro study were analysed to evaluate and compare the stresses between two implant-supported All-on-4 frameworks i.e. Co-Cr framework and CFRC framework, tested at different cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm, 20 mm and all 4 abutments respectively under progressive loading.

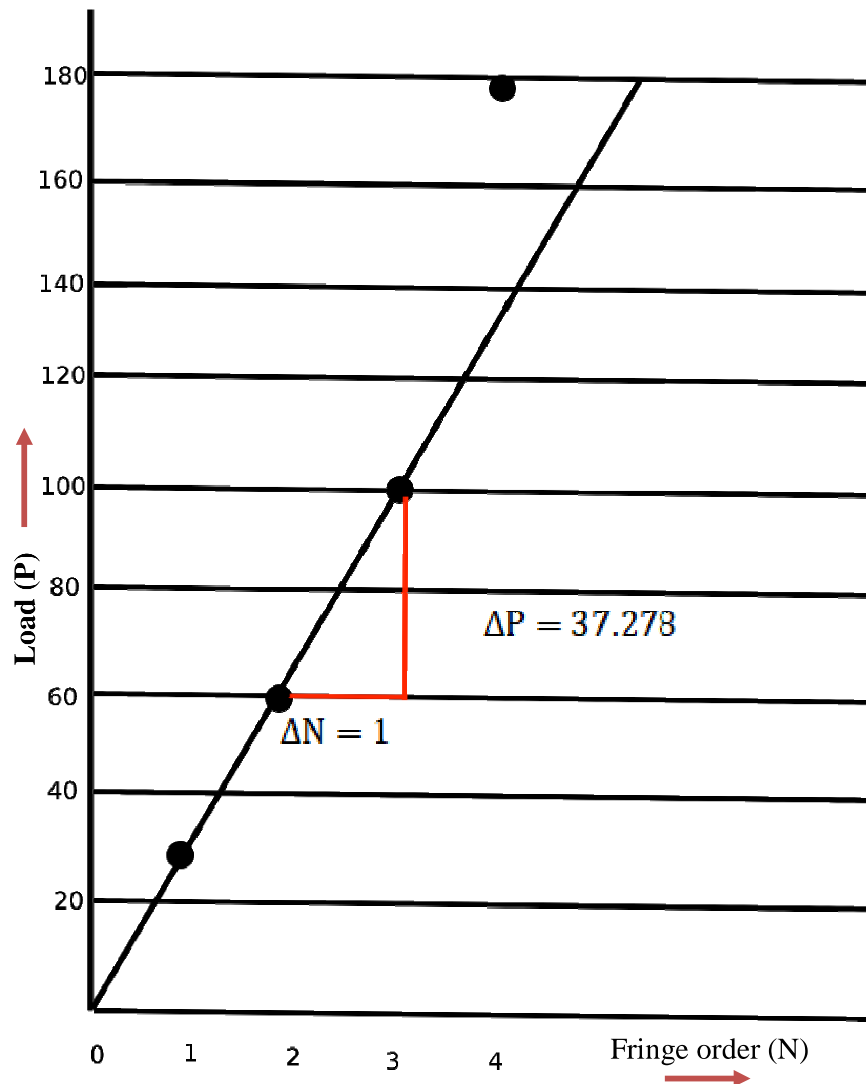
The models were subjected to progressive loading, by applying loads of 120N, 140N, 160N and 180N; to simulate the natural masticatory force. The loads of 120 N-180 N were applied five times at 6 designated loading points. The results were obtained using the mean of maximum fringe order obtained from 5 repetition stresses, and by using formula for calculating maximum principal stress (σ). The values obtained, representing the magnitude of stresses transferred were in Megapascal (MPa) or N/mm^2.

Descriptive statistical measures such as mean, median and standard deviation were computed and measured for all loading points for both the frameworks. To compare the mean of the loading points in the same framework, Kruskal Wallis test was used; whereas Mann-Whitney U test was used for comparing loading points between two different frameworks.

Calculations for determining maximum principal stresses (σ):

1. The material fringe value (F_{σ}) was determined by plotting a graph of load versus fringe order; where y-axis corresponds to the load applied in Newton (N), and x-axis corresponds to the fringe order (N) **(Graph 1).**

Graph 1 : Graph of load application versus fringe order for 5 mm cantilever length in Co-Cr framework



Graphical representation 1: A load-fringe order graph was plotted for a 5 mm cantilever length tested for the Co-Cr framework. Slope (S) was calculated using the formula, Slope(S) = ΔP/ΔN = 37.278/1 = 37.278 N/fringe. Following which, The **material fringe value (F_σ)** was calculated using equation, F_σ = 8S/πD = 8*37.278/3.141*30 = **3.165 N/mm fringe (constant).**

2. The Maximum principal stress (***σ***) were calculated by using formula, $\boldsymbol{\sigma} = \frac{N_{max} F\sigma}{h}$

Example,

The principal stress (***σ***) at abutment of last tilted implant in Co-Cr framework, when subjected to a load to 180 N; leading to an observation of 3rd order fringe. $\boldsymbol{\sigma} = N_{max}F\sigma/h = 3*3.165/10 = 0.9495$ MPa or N/mm^2.

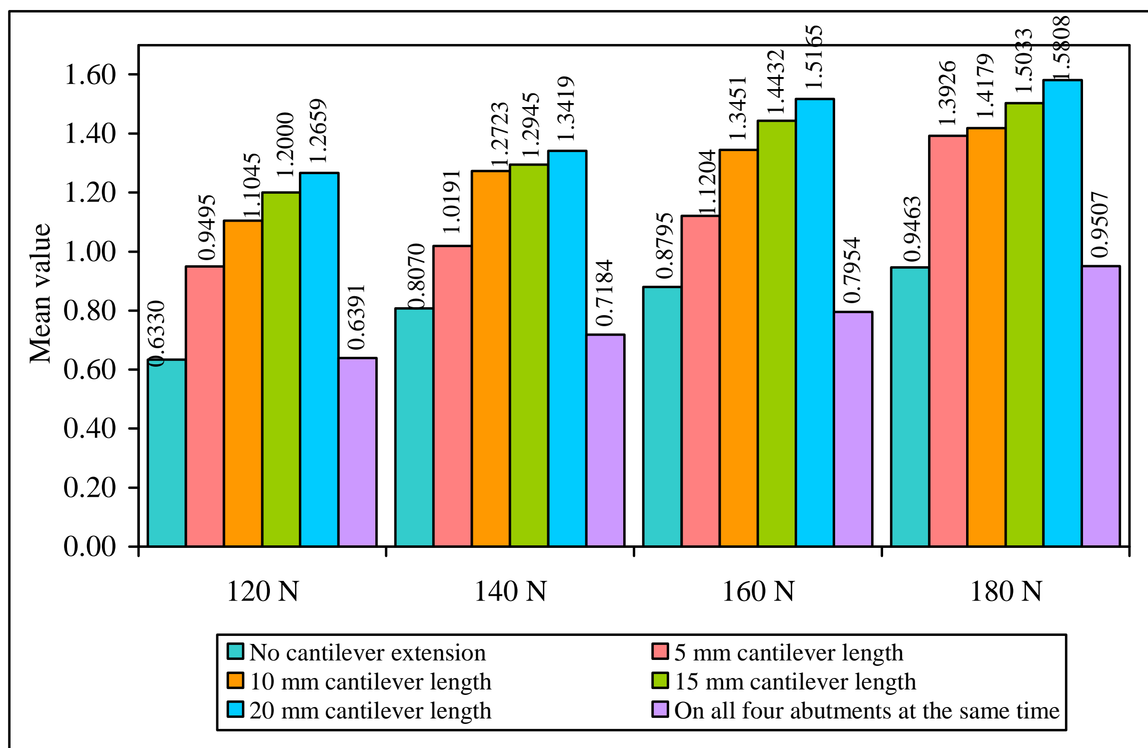
The principal stress (***σ***) at cantilever length of 5 mm in CFRC framework, when subjected to a load to 120 N; leading to an observation of 2nd order fringe. $\boldsymbol{\sigma} = N_{max}F\sigma/h = 2*3.165/10= 0.663$ MPa or N/mm^2.

The principal stress (***σ***) at cantilever length of 20 mm in Co-Cr framework, when subjected to a load to 120 N; leading to an observation of 4th order fringe. $\boldsymbol{\sigma} = N_{max}F\sigma/h = 4*3.165/10 = 1.266$ MPa or N/mm^2.

The principal stress (***σ***) at 15 mm cantilever in CFRC framework at 160 N load; exhibiting 4th fringe order. $\boldsymbol{\sigma} = N_{max}F\sigma/h = 4*3.165/10 = 1.266$ MPa or N/mm^2.

CO-CR FRAMEWORK

Graph 2: Stresses developed in Co-Cr framework when load is applied at below mentioned loading points under progressive load (Values are in MPa).



Graphical representation 2:

The results obtained pertaining to the principal stresses (**σ**) observed at different cantilever lengths in Co-Cr framework demonstrated that; the principal stresses increased with the increase in the posterior cantilever, also the increase in the progressive loading from 120N to 180 N, lead to an increase in the stress values (MPa). The obtained mean values show that, highest mean value (1.5808 MPa) was observed at the cantilever length of 20 mm when subjected to a load of 180 N; whereas the lowest mean value (0.6330 MPa) was observed at the abutment of last tilted implant (with 0 mm cantilever extension), when subjected to a load of 120 N.

Table 3: Comparison of loading points at 120N load in Co–Cr framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.5697	0.6963	0.6330	0.0500	0.6330
5 mm cantilever length	0.8862	1.0128	0.9495	0.0448	0.9495
10 mm cantilever length	1.0444	1.1868	1.1045	0.0529	1.1077
15 mm cantilever length	1.1550	1.2340	1.2000	0.0284	1.2027
20 mm cantilever length	1.2343	1.2970	1.2659	0.0222	1.2660
On all four abutments at the same time	0.6013	0.6640	0.6391	0.0262	0.6330
Total	0.5697	1.2970	0.9653	0.2591	1.0286
H-value	27.3880				
P-value	0.0001*				

*p<0.05

The table summarizes the mean, median, standard deviation, minimum and maximum values of the principal stress (MPa) at different loading points in Co–Cr framework at 120N load. When subjected to Kruskal Wallis test, there was a significant difference between the six loading points (p - 0.0001*). The highest mean value (1.2659 MPa) was observed at the cantilever length of 20 mm, whereas the lowest mean value (0.6330 MPa) was observed at the abutment of last tilted implant (with no cantilever extension) **(Table 3)**.

Table 4: Comparison of loading points at 140N load in Co–Cr framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.7596	0.8545	0.8070	0.0388	0.7912
5 mm cantilever length	0.9495	1.1077	1.0191	0.0598	1.0286
10 mm cantilever length	1.2660	1.2976	1.2723	0.0141	1.2660
15 mm cantilever length	1.2660	1.3451	1.2945	0.0324	1.2976
20 mm cantilever length	1.3293	1.3609	1.3419	0.0132	1.3451
On all four abutments at the same time	0.6804	0.7596	0.7184	0.0328	0.7121
Total	0.6804	1.3609	1.0755	0.2514	1.1869
H-value	27.3490				
P-value	0.0001*				

*p<0.05

While comparing the loading points at 140 N load in **Co–Cr framework,** Kruskal Wallis test demonstrated significant differences between the mean principal stresses (***σ***) at 6 loading points (p - 0.0001*). The highest mean value (1.3419 MPa) was observed at the cantilever length of 20 mm, whereas the lowest mean value (0.7184 MPa) was observed when load was applied on all the abutments at the same time using a platform **(Table 4)**.

Table 5: Comparison of loading points at 160N load in Co–Cr framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.8545	0.9170	0.8795	0.0238	0.8700
5 mm cantilever length	1.0761	1.1710	1.1204	0.0361	1.1077
10 mm cantilever length	1.2976	1.3767	1.3451	0.0296	1.3451
15 mm cantilever length	1.3926	1.4875	1.4432	0.0361	1.4559
20 mm cantilever length	1.4870	1.5350	1.5165	0.0177	1.5192
On all four abutments at the same time	0.7342	0.8545	0.7954	0.0510	0.7900
Total	0.7342	1.5350	1.1834	0.2807	1.2343
H-value	28.0760				
P-value	0.0001*				

*p<0.05

Table 5, demonstrates comparison of loading points in Co–Cr framework when subjected to a load of 160N by Kruskal Wallis test. Significant differences were observed in the mean stresses (p - 0.0001*); with 20mm cantilever length exhibiting the highest mean stresses (1.5165 MPa), and simultaneous application of load on all four showed the lowest mean value (0.7954 MPa).

Table 6: Comparison of loading points at 180N load in Co–Cr framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.8700	1.0128	0.9463	0.0507	0.9495
5 mm cantilever length	1.2660	1.4559	1.3926	0.0775	1.3926
10 mm cantilever length	1.3609	1.4559	1.4179	0.0347	1.4242
15 mm cantilever length	1.4875	1.5192	1.5033	0.0112	1.5033
20 mm cantilever length	1.5761	1.5820	1.5808	0.0026	1.5820
On all four abutments at the same time	0.9178	0.9874	0.9507	0.0247	0.9495
Total	0.8700	1.5820	1.2986	0.2620	1.4242
H-value	28.0760				
P-value	0.0001*				

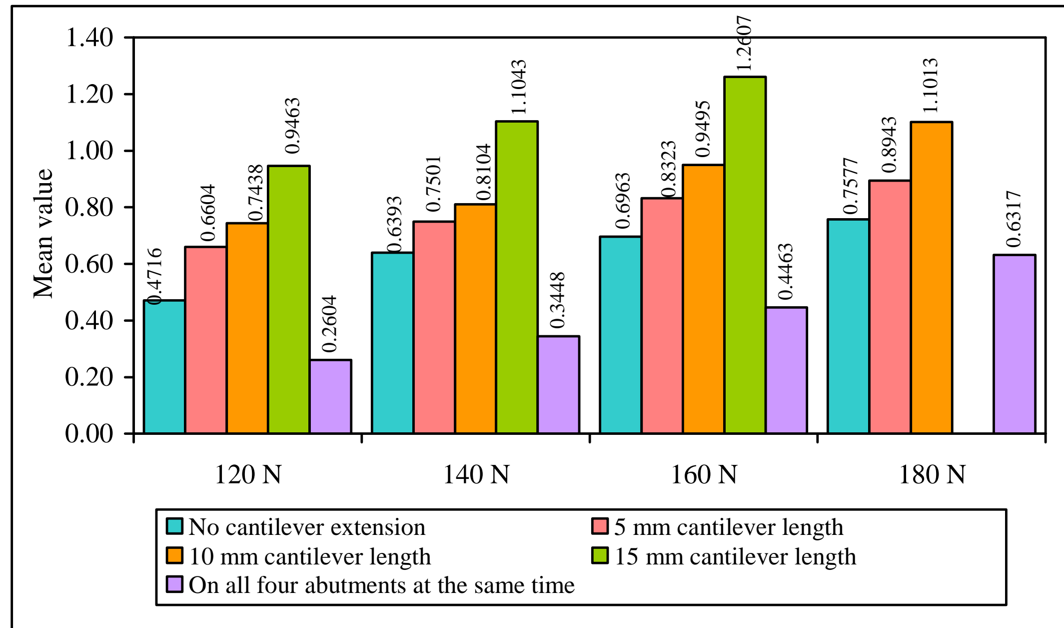
*p<0.05

The results of 180 N load application in Co-Cr framework, showed significant difference between the 6 loading points (p - 0.0001*). The mean value of principal stresses ($\boldsymbol{\sigma}$) at 20 mm cantilever length is higher as compared to the mean values at 0mm, 5mm, 10mm, 15mm cantilever, and simultaneous loading on all abutments **(Table 6)**.

The pair wise comparison was done between the loading points under different loads for Co-Cr framework using Mann-Whitney U test. The pair wise comparison showed significant differences between the cantilever lengths i.e. 0mm, 5mm, 10mm, 15mm, 20mm and simultaneous loading on all abutments. However, the pair wise comparison between 0 mm cantilever (No cantilever) and application of load on all the 4 abutments was not significant for 120 N and 180 N load, also the pair wise comparison of 15 mm and 20 mm cantilever was not significant at 140 N load ($p<0.05$).

CFRC FRAMEWORK

Graph 3: Stresses developed in CFRC framework when load is applied at below mentioned loading points under progressive load (Values are in MPa).



Graphical representation 3:

The graph demonstrates the principal stresses (***σ***) observed at different cantilever lengths in the CFRC framework. The principal stresses increased with the increase in the posterior cantilever from 0 to 15 mm, and also with the increase in the progressive loading from 120N to 180 N. **The cantilever length of 20 mm showed bending movement** and deformation of the framework at application of load of 40 N, so principal stress values could not be obtained for 20mm cantilever; also **15 mm cantilever showed bending movement at 180 N**, therefore could not be included in the analysis. The obtained mean values show that, highest mean value (1.2607 MPa) was observed at 15mm cantilever on 160 N load application; whereas the lowest mean value (0.2604 MPa) was observed when all the abutments were loaded simultaneously at 120 N.

Table 7: Comparison of loading points at 120N load in CFRC framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.4431	0.5064	0.4716	0.0235	0.4747
5 mm cantilever length	0.5850	0.7279	0.6604	0.0506	0.6630
10 mm cantilever length	0.6963	0.7754	0.7438	0.0317	0.7596
15 mm cantilever length	0.8387	1.0128	0.9463	0.0656	0.9495
20 mm cantilever length	-	-	-	-	-
On all four abutments at the same time	0.1899	0.3481	0.2604	0.0600	0.2532
Total	0.1899	1.0128	0.6165	0.2434	0.6630
H-value	22.8870				
P-value	0.0001*				

*p<0.05

Table 7 summarizes the mean, median, standard deviation, minimum and maximum values of the principal stress (MPa) for the CFRC framework at 120 N load. Comparison of 5 loading points using Kruskal Wallis test demonstrated significant difference between the mean values (p - 0.0001*). The mean principal stress value of 15 mm (0.9463 MPa) cantilever is higher in comparison to other cantilever lengths (i.e. 0 mm, 5 mm and 10 mm) and loading of all four abutments.

Table 8 : Comparison of loading points at 140N load in CFRC framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.6013	0.6963	0.6393	0.0347	0.6330
5 mm cantilever length	0.6804	0.8070	0.7501	0.0483	0.7596
10 mm cantilever length	0.7912	0.8290	0.8104	0.0180	0.8177
15 mm cantilever length	0.9811	1.1860	1.1043	0.0760	1.1077
20 mm cantilever length	-	-	-	-	-
On all four abutments at the same time	0.2840	0.3798	0.3448	0.0364	0.3481
Total	0.2840	1.1860	0.7298	0.2551	0.7596
H-value	22.6060				
P-value	0.0001*				

*p<0.05

When the loading points in the CFRC framework at 140 N load were compared using the Kruskal Wallis test, a significant difference in the mean values (MPa) of 5 loading points was observed (p - 0.0001*). A cantilever length of 15 mm (1.1043 MPa) produced the highest mean stress value, whereas simultaneous loading of all four abutments (0.3448) produced the lowest mean stress value (**Table 8**).

Table 9: Comparison of loading points at 160N load in CFRC framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.6646	0.7279	0.6963	0.0250	0.6963
5 mm cantilever length	0.7912	0.8703	0.8323	0.0307	0.8229
10 mm cantilever length	0.8862	1.0128	0.9495	0.0448	0.9495
15 mm cantilever length	1.1390	1.3350	1.2607	0.0737	1.2660
20 mm cantilever length	-	-	-	-	-
On all four abutments at the same time	0.3798	0.5064	0.4463	0.0453	0.4431
Total	0.3798	1.3350	0.8370	0.2790	0.8229
H-value	23.1390				
P-value	0.0001*				

*p<0.05

The results of 160 N load application for the CFRC framework demonstrate significant difference between the 5 loading locations (p - 0.0001*). The mean principal stress values at 15 mm cantilever (1.2607 MPa) are greater than the mean values at 0mm, 5mm, 10mm cantilever and loading of all four abutments **(Table 9).**

Table 10: Comparison of loading points at 180N load in CFRC framework by Kruskal Wallis test (Values are in MPa)

Loading points	Min	Max	Mean	SD	Median
No cantilever extension	0.7279	0.7912	0.7577	0.0268	0.7596
5 mm cantilever length	0.8540	0.9241	0.8943	0.0290	0.8862
10 mm cantilever length	0.9811	1.1710	1.1013	0.0721	1.1077
15 mm cantilever length	-	-	-	-	-
20 mm cantilever length	-	-	-	-	-
On all four abutments at the same time	0.5380	0.7216	0.6317	0.0649	0.6330
Total	0.5380	1.1710	0.8462	0.1850	0.8226
H-value	17.9380				
P-value	0.0001*				

*p<0.05

Table 10 summarizes and compares the mean stress values (σ) in CFRC framework, when subjected to a load of 180N. Due to bending movement and deformation of the framework, the stress values could not be analysed at 15 mm and 20 mm cantilever. However, comparison of the remaining 4 loading points showed significant difference.

The pairwise comparisons of loading points under various loads were made for CFRC framework using Mann-Whitney U test. The pairwise comparison revealed significant differences between the cantilever lengths of 0 mm, 5 mm, 10 mm, and 15 mm, and loading of all the abutments simultaneously.

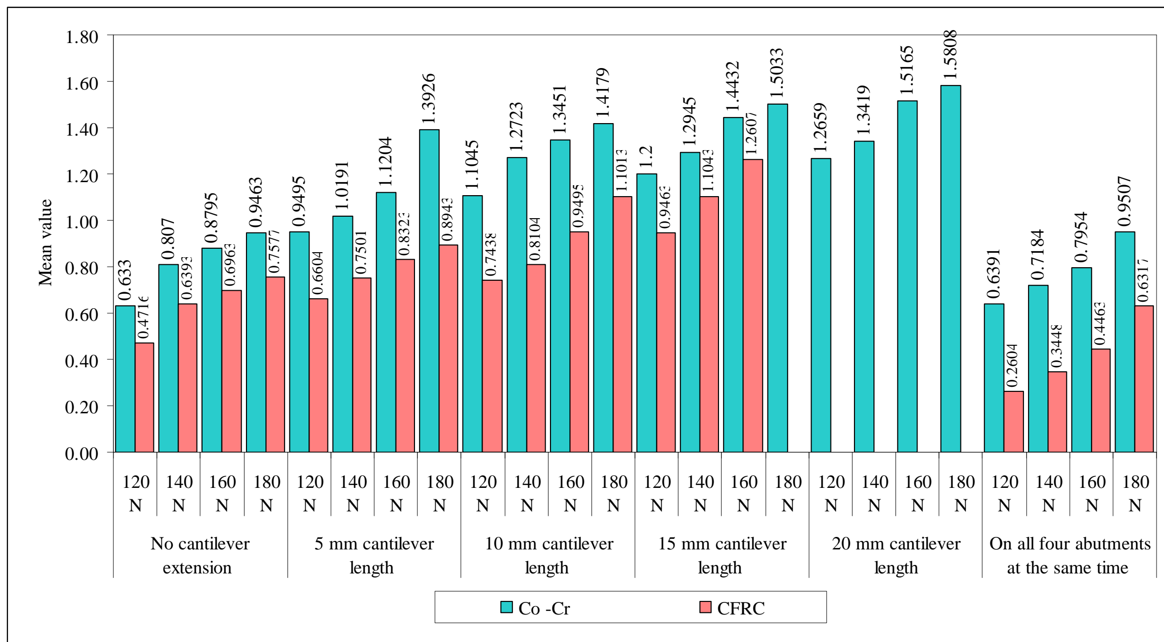
Table 11: Comparison of Co-Cr and CFRC frameworks at different loading points with 120, 140, 160 and 180N load by Mann-Whitney U test

Loading points	Loads	Co -Cr			CFRC			Z-value	p-value
		Mean	SD	Mean rank	Mean	SD	Mean rank		
No cantilever extension	120 N	0.6330	0.0500	8.00	0.4716	0.0235	3.00	2.5143	0.0109*
	140 N	0.8070	0.0388	8.00	0.6393	0.0347	3.00	2.5456	0.0109*
	160 N	0.8795	0.0238	8.00	0.6963	0.0250	3.00	2.5143	0.0119*
	180 N	0.9463	0.0507	8.00	0.7577	0.0268	3.00	2.5377	0.0112*
5 mm cantilever length	120 N	0.9495	0.0448	8.00	0.6604	0.0506	3.00	2.5698	0.0102*
	140 N	1.0191	0.0598	8.00	0.7501	0.0483	3.00	2.5143	0.0119*
	160 N	1.1204	0.0361	8.00	0.8323	0.0307	3.00	2.5221	0.0117*
	180 N	1.3926	0.0775	8.00	0.8943	0.0290	3.00	2.5298	0.0114*
10 mm cantilever length	120 N	1.1045	0.0529	8.00	0.7438	0.0317	3.00	2.5221	0.0117*
	140 N	1.2723	0.0141	8.00	0.8104	0.0180	3.00	2.5947	0.0095*
	160 N	1.3451	0.0296	8.00	0.9495	0.0448	3.00	2.5456	0.0109*
	180 N	1.4179	0.0347	8.00	1.1013	0.0721	3.00	2.5456	0.0109*
15 mm cantilever length	120 N	1.2000	0.0284	8.00	0.9463	0.0656	3.00	2.5221	0.0117*
	140 N	1.2945	0.0324	8.00	1.1043	0.0760	3.00	2.5298	0.0114*
	160 N	1.4432	0.0361	8.00	1.2607	0.0737	3.00	2.5221	0.0117*
	180 N	1.5033	0.0112	-	-	-	-	-	-
20 mm cantilever length	120 N	1.2659	0.0222	-	-	-	-	-	-
	140 N	1.3419	0.0132	-	-	-	-	-	-
	160 N	1.5165	0.0177	-	-	-	-	-	-
	180 N	1.5808	0.0026	-	-	-	-	-	-

On all four abutments at the same time	120 N	0.6391	0.0262	8.00	0.2604	0.0600	3.00	2.5221	0.0117*
	140 N	0.7184	0.0328	8.00	0.3448	0.0364	3.00	2.5143	0.0119*
	160 N	0.7954	0.0510	8.00	0.4463	0.0453	3.00	2.5143	0.0119*
	180 N	0.9507	0.0247	8.00	0.6317	0.0649	3.00	2.5698	0.0102*

*p<0.05

Graph 4: Comparison of Co-Cr and CFRC framework at different loading points with 120, 140, 160 and 180N applied load



The above graph and table compares the mean principal stress (σ) values between the Co-Cr framework and CFRC framework by using Mann-Whitney U test. The comparison of different loading points at 120, 140, 160 and 180N load showed significant differences between both the frameworks (p<0.05*). The mean principal stress values and mean rank for CFRC framework was significantly lower as compared to the Co-Cr framework at all the loading points.

Table 12: Summary of mean values of fringe order observed in both the frameworks at below mentioned loading points under progressive load

Loading points	Loads	Co -Cr (Mean values)	CFRC(Mean values)
		Fringe Order	**Fringe Order**
No cantilever extension	120 N	2	1.5
	140 N	2.5	2
	160 N	2.75	2.2
	180 N	3	2.4
5 mm cantilever length	120 N	3	2
	140 N	3. 25	2.4
	160 N	3.5	2.6
	180 N	4.4	2.8
10 mm cantilever length	120 N	3.5	2.4
	140 N	4	2.6
	160 N	4.25	3
	180 N	4.5	3.5
15 mm cantilever length	120 N	3.8	3
	140 N	4.1	3.5
	160 N	4.6	4
	180 N	4.75	-

20 mm cantilever length	120 N	4	-
	140 N	4.25	-
	160 N	4.8	-
	180 N	5	-
On all four abutments at the same time	120 N	2	0.8
	140 N	2.25	1.1
	160 N	2.5	1.4
	180 N	3	2

The above table summarizes the mean fringe order values for the Co-Cr and CFRC framework. It demonstrates increase in the fringe order with the increase in the posterior cantilever, and also with the increase in the progressive loading from 120N to 180 N for both the frameworks. The CFRC framework demonstrated mean fringe order values lower than the Co-Cr framework under all loading conditions.

DISCUSSION

Paulo Malo and the Malo Clinic team developed the "All-on-four" treatment approach to rehabilitate edentulous patients with immediately loaded full arch restorations supported by only four implants in each arch.[5] The “All-on-four” approach was proposed to rehabilitate atrophic jaws by maximizing the use of remnant bone, whilst avoiding the extensive surgical procedures.[6]

Soto-Peñaloza et al, in an systematic review on the “All-on-four” concept indicated an implant survival rate of 99.8% for more than 24 months, stating that the “All-on-four” approach gave predictable results for rehabilitation of atrophic jaws, in patients who did not want regenerative therapies.[7]

The consensus agreement and clinical guidelines on the “All-on-4” standard treatment issued at the 9th Ticare Conference in Spain, stated that four implants are sufficient for immediate loading in the treatment of atrophic jaws for full-arch implant supported prosthesis (ISPs); even when adequate bone exists between the mental foramina or maxillary sinuses. Also, they recommended evaluation of newer materials for “All-on-4” prosthesis.[51]

However, various factors affect the longevity of implant supported FDPs such as bone density, implant number and location, implant diameter and length, thread design, implant abutment connection and angulation, anteroposterior spread, posterior cantilever length, and the biomaterial used for framework. The above factors affect the prognosis and longevity of full arch FDPs and play a key role in the treatment planning.

The selection and accuracy of frameworks for implant supported FDP are essential prerequisites for the osseointegration of dental implants in immediately loaded prosthesis.[17, 52] Additionally, in immediate loading protocols, it is crucial to control the implant micromovements in order to ensure osseointegration, which can be accomplished by rigidly splinting the implants together with a stiff substructure framework.[24, 53]

Traditionally, for the above mentioned reasons metal frameworks have been used in full arch FFPs to rigidly splint the implants together. However, due to the limitations associated with the metal framework fabrication like technique sensitivity, casting shrinkage and inaccuracies associated with the fabrication process. The recent advances and improvements in fiber reinforced materials, has now made it possible to fabricate metal free ISPs using fiber reinforced composite frameworks.[24, 49]

Among the fiber reinforced composite materials, studies done by Menini et al[24], Li et al[44], Pera et al[47], and Menini et al [16, 48] have demonstrated that CFRC exhibits excellent mechanical and biological properties, as well as good adhesion with the veneering materials, and appears to be promising alterative for fabrication of full arch ISPs.

Additionally, Rangert et al.[54] stated that the impact of inter-implant distance, anterior-posterior spread (AP spread), and cantilever length are critical parameters concerning the stress transfer to the underlying bone. Bilaterally cantilevered frameworks are required to replace the posterior occlusion; when implants are placed in between the mandibular mental foramina or maxillary sinuses, to avoid the invasive surgical procedures.[55] However, the posterior cantilever length has demonstrated to

have an direct clinical impact on the marginal bone loss, as it directly influences the forces transmitted to the implants and thereby to the bone.[26]

Different authors have given different recommendations for cantilever lengths. Branemark[55] advised cantilever length equivalent to the length of 2 to 3 premolars. Zarb and Schmitt[56] recommended to work within the limit of 20-mm distal cantilever. Whereas, Taylor and Bergman[57] indicated that the maximum cantilever extension should be 20 mm when five to six abutments are involved, and 15 mm when four abutments are involved. Rangert et at.[54] recommended cantilever extension of 15 to 20 mm for the mandible, and upto 10mm for the maxilla. The 9th Ticare consensus agreement on the "All-on-four" standard treatment, recommends placement of 10 to 12 teeth in the "All-on-four" implant supported FDP, depending on the emergence of the implant in the second premolar or the first molar area.[51] Also, Rangert and English provided guidelines for calculating cantilever length based on the AP Spread ("The AP spread is the distance between centre of the two most anterior implants and the distal aspect of the two most posterior implants"). Rangert stated that cantilever length can be 2 times the A-P spread; whereas English stated that cantilever length can be 1.5 times the AP spread.[58]

From the literature the recommended cantilever lengths for the full arch mandibular ISPs are; 20 mm[59,60], not greater than 20mm[61-64], less than 15mm[65], 18-20mm,[66] 15-20mm[54], and equal to the width of two teeth positioned distal to the posterior most abutment.[67]

A statement from the report of Dutch Consensus on the guidelines recommended for FFP superstructures on endosseous implants placed in the edentulous mandible quotes that "The forces on the cantilever must be limited.

Therefore, the length of the level arm must be kept as short as possible. Centring the chewing and other forces directly on the implants as much as possible."[68]

Therefore, different authors have given different recommendations for cantilever length, but the optimal cantilever length as a function of framework material has not been established. So, the present study compared the stresses in the recently introduced CFRC framework and the conventional Co-Cr framework at varying cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm and 20 mm for the All-on-4 framework. These tested cantilever lengths are in accordance with those recommended by Zarb and Schmitt[56], Rangert et at.[54] and English[58]. Also, according to the recommendations given by English, the maximum posterior cantilever length of the tested frameworks were kept at 20mm; considering the anteroposterior spread of 15 mm in the model, which would allow posterior cantilever of 22.5mm (1.5x AP spread).

The progressive load of 120 N to 180 N was chosen in the present study to simulate the intraoral loading conditions. This is in accordance with the study done by Melo et al, which demonstrated the mean maximum bite force of 150.04 N in 124 individuals rehabilitated with fixed ISPs in the mandibular arch at a follow-up period of 3 to 5 years.[69]

From the results obtained in the present study, the null hypothesis stating there is no difference in stress distribution between All-on-four implant-supported Co-Cr framework and CFRC framework at different cantilever lengths was rejected.

The results obtained from the present study demonstrated that for both the frameworks (i.e. the Co-Cr framework and CFRC framework); the principal stresses

increased significantly with the increase in the posterior cantilever length, and also with the increase in the progressive loading from 120N to 180 N.

These results are in accordance with studies done by White et al[26], Geremia et al[34], Sertgöz A and Güvener S[28], and Shackleton et al[27]. White et al[26], demonstrated the increase in the maximum stresses on the distal and second most distal implants in a non-linear fashion, with the increase in the cantilever length. Also, Sertgöz A and Güvener S[28], reported that increase in the cantilever length resulted in an increase in the stress value at the bone to implant interface. Geremia et al[34], demonstrated that with the increase in posterior cantilever from 10 to 20 mm, the axial force increased by approximately 50% and the sagittal bending moment increased by 70%. A clinical study done by Shackleton et al[27] demonstrated that prostheses with cantilever lengths of 15 mm or less survived significantly better than prostheses with cantilever lengths greater than 15 mm.

However, the results of the present study are in contrast with a study conducted by Malhotra et al[41]. Malhotra et al[41], analysed the effect of 4mm and 12mm cantilever length on the mandibular “All-on-four” prosthesis, and reported no significant differences between posterior cantilever lengths of 4 mm and 12 mm.

In the present study, the CFRC framework showed mean principal stress values and mean rank significantly lower as compared to the Co-Cr framework at all the loading points tested under 120N to 180N progressive load. Also, the CFRC framework showed a more homogeneous stress distribution, with the stresses transmitted apically and distributed more evenly throughout the model; with the absence of stress concentration at the crest of terminal implant.

These results are in accordance with the findings of the studies done by Bahajan et al[70] , Menini et al[16], and Pera et al[47]. In a study Bahajan et al[70], revealed that CFRC distributed the applied forces uniformly across the prosthetic framework, providing high strength and rigidity to the framework. This is because in CFRC, the polymeric matrix binding the fibres together, transfers the applied load evenly among them. Menini et al[16], in a study done to investigate stresses in an maxillary "All-on-4 model" supporting an FFP, stated that CFRC framework demonstrated rigidity and stiffness similar to the metal frameworks. A clinical study done by Pera et al[47], showed that the CFRC framework resulted in less marginal bone resorption and demonstrated a higher implant survival rate as compared to the metal frameworks.

A significant finding in the study was that, the lowest principal stresses were observed when all the abutments were loaded simultaneously in both the frameworks. Also, the stresses observed in the CFRC framework were significantly lower as compared to the Co-Cr framework (with an observation of 1st order fringe at 140 N load application in CFRC framework), due to the homogeneous load distribution by the polymeric matrix binding the fibres together. The simultaneous loading of the abutments is of clinical importance, because in an full arch ISPs with a splinted sub-structure framework; the entire arch is working in the load distribution and can reduce the effects of the posterior cantilever.

However in the present study, the CFRC framework showed bending movement and deformation of the framework at 20 mm cantilever length at the applied load of 40 N, also at the 15 mm cantilever length at 180 N load application. These results could not be compared with the literature available, because of the lack of studies evaluating the effect of cantilever length on the CFRC framework.

In the current study, the Co-Cr framework showed mean principal stress values higher than the CFRC framework at all tested loading points and applied load. Also, the Co-Cr framework did not show any signs of deformation at higher cantilever lengths i.e.15 mm and 20 mm, as seen in the CFRC framework. However, high crestal stresses (with the observation of pink and green order fringes indicating highest stresses) were observed at the distal/terminal implant in the Co-Cr framework at the cantilever lengths of 10 mm and more (i.e. 15 mm and 20 mm).

These findings correspond with the findings of the study done by white et al[26], which revealed that the maximum stresses were concentrated near the crest of the ridge of the distal implant with the increase in the cantilever lengths evaluated.

The cortical bone has been reported to have ultimate tensile and compressive strengths of 133 and 193 MPa, respectively. The principal stresses observed in the present study ranged from 0.2604 MPa (simultaneous loading of all the abutments in CFRC framework at 120 N load) to 1.5808 MPa (180 N load applied at 20 mm cantilever length in Co-Cr framework). Therefore, the maximal principal stresses recorded in the present study for both the frameworks were lower than these values, which indicated that no area was critically loaded with respect to mechanical stresses.[28]

Within the confines of this study, we can recommend that CFRC framework appears suitable for fabrication of framework for “All-on-four” prosthesis with a recommended short cantilever length of 10mm, as they demonstrated mean principal stress values and crestal stress significantly lower in comparison to the Co-Cr framework under all loading conditions. However, Co-Cr framework can be recommended in clinical scenarios, necessitating full arch ISPs requiring distal

cantilever greater than 10 mm due to high stiffness and yield strength of the material; also keeping in mind the high risk of failure associated with longer cantilevers.

The study and its findings have indicated that there was a statistically significant difference seen between the “All-on-four” implant-supported Co-Cr framework and CFRC framework, when evaluated at different cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm and 20 mm under 120-180N progressive loading. The study has its own limitations of not simulating the intraoral environmental conditions, the effect of multidirectional load applied intraorally, and the effect of the superstructure material on the stress distribution, however further studies with a few randomized control trails are required to draw definitive conclusions.

SCOPE OF THE STUDY

In this research the parameter under investigation was the CFRC and Co-Cr framework material for the "All-on-four" prothesis and it's correlation with the cantilever length.

1. Further research can be done by evaluating these frameworks for other implant configurations like All-on-five, All-on-six and newer concepts like Simpli5y.
2. Also, the effects of CFRC framework and Co-Cr framework can be evaluated for ISPs with different distal implant angulations, as small differences in implant angulations can considerably affect the stress transfer to the underlying bone.
3. The effect of occluso-gingival thickness of the framework material should be evaluated, as they could amplify the effect of the long cantilevers by acting as an vertical lever arm.
4. The frameworks can be tested in 3 dimensional dynamic loading conditions using FEA analysis to simulate the oral environment.
5. The CFRC framework should also be evaluated for fabrication of ISPs in the maxillary arch; along with assessing the effect of posterior cantilever, as it plays a pivotal role in the maxillary arch due to poor bone density.
6. Future well designed clinical studies can be conducted to evaluate the effect of the newer framework materials and it's clinical relevance.

LIMITATIONS OF THE STUDY

1. Photoelastic method is an in-vitro method based on the interpretation of isochromatic color fringes, and may not exactly simulate the clinical situation completely. It cannot reproduce the physical characteristics of the peri-implant tissues, which present different modulus of elasticity according to the region. Also, there is inability to differentiate between cortical and medullary bone.
2. The loads applied were vertical static loads, whereas multidirectional dynamic loading is seen intraorally, with more axial loads directed onto the implants and the prosthesis.
3. A state of optimum osseointegration was assumed between bone and implant in the present model this may not occur in all clinical scenarios.
4. Bone was assumed to be linearly elastic, isotropic and homogenous whereas natural bone is viscoelastic, anisotrophic and heterogenous material.
5. Only the effect of the posterior cantilever length on the framework was evaluated, however the effect of the occluso-gingival thickness of the framework was not evaluated.
6. Only the implant bar framework was considered in the present study, the effect of the hybrid superstructure material was not evaluated.
7. Due to the limitations pertaining to this study, further research needs to be combined with clinical evaluation.

CLINICAL IMPLICATION

1. The results of this study give clinical support that fixed ISPs with shorter cantilevers show less stress concentration on the implant and thereby to the bone, thereby leading to better survival rate than those with longer cantilevers.
2. Also, patients should be advised of the increased risk of failure associated with longer cantilevers over a period of time.
3. From the results of the present study, the use of 10 mm as an arbitrary cantilever length recommendation for the CFRC framework, and 15 mm for the Co-Cr framework seems reasonable.

CONCLUSION

The null hypothesis was rejected and the research hypothesis is accepted as there is a significant difference in stress distribution between the two framework materials. The study and its findings have indicated that there was a statistically significant difference seen between the "All-on-four" implant-supported Co-Cr framework and CFRC framework, when evaluated at different cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm and 20 mm under 120-180N progressive loading.

In view of the results of this study, the following conclusions are drawn:

1. The CFRC framework appears suitable for fabrication of framework for "All-on-four" prosthesis with a recommended short cantilever length of 10 mm, as they demonstrated mean principal stress values and crestal stress significantly lower in comparison to the Co-Cr framework under all loading conditions.
2. However, Co-Cr framework can be recommended in clinical scenarios, necessitating full arch ISPs requiring distal cantilever greater than 10 mm due to high stiffness and yield strength of the material; also keeping in mind the high risk of failure associated with longer cantilevers.
3. The CFRC framework showed a more homogeneous stress distribution, with the stresses transmitted apically and distributed more evenly throughout the model; with the absence of stress concentration at the crest of terminal implant.
4. High crestal stresses were observed at the distal/terminal implant in the Co-Cr framework at the cantilever lengths of 10 mm and more (i.e. 15 mm and 20 mm).

SUMMARY

The present study was conducted to evaluate and compare the stresses between two implant-supported All-on-4 frameworks i.e. Co-Cr framework and CFRC framework, tested at different cantilever lengths under progressive loading.

The models were subjected to progressive loading, by applying loads of 120N, 140N, 160N and 180N; to simulate the natural masticatory force. The loads of 120 N-180 N were applied five times at 6 designated loading points. The results were obtained using the mean maximum fringe order of 5 repetition stresses, and by using formula for calculating maximum principal stress ($\boldsymbol{\sigma}$). The values obtained, representing the magnitude of stresses transferred were in Megapascal (MPa) or N/mm^2. To compare the mean of the loading points in the same framework, Kruskal Wallis test was used; whereas Mann-Whitney U test was used for comparing loading points between two different frameworks.

The results obtained in the present study rejected the null hypothesis, that there is no difference in stress distribution between All-on-four implant-supported Co-Cr framework and CFRC framework at different cantilever lengths.

On analysing obtained data, the study and its findings have indicated that there was a statistically significant difference seen between the "All-on-four" implant-supported Co-Cr framework and CFRC framework, when evaluated at different cantilever lengths of 0 mm, 5 mm, 10 mm, 15 mm and 20 mm under 120-180N progressive loading.

The CFRC framework showed mean principal stress values significantly lower than the Co-Cr framework under all loading conditions, however deformation of the framework was observed at the cantilever lengths of 15 mm and 20 mm. Whereas, the Co-Cr framework showed mean principal stress values and crestal stress higher than the CFRC framework.

So, within the limitations of this study, the CFRC framework appears suitable for fabrication of framework for “All-on-four” prosthesis with a recommended short cantilever length of 10 mm.

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ANNEXURE – I – ETHICAL CLEARANCE LETTER

Research and Ethics Committee
KLE V K INSTITUTE OF DENTAL SCIENCES
KLE University

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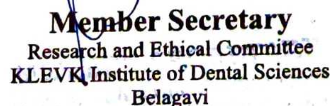
CERTIFICATE

This is to Certify that the synopsis titled COMPARATIVE PHOTOELASTIC STRESS ANALYSIS BETWEEN IMPLANT SUPPORTED ALL ON FOUR COBALT - CHROMIUM FRAMEWORK AND CARBON FIBER REINFORCED FRAMEWORK WITH VARYING CANTILEVER LENGTHS : AN IN-VITRO STUDY *Submitted by Dr.* RUTVI SHAH *P. G. Student / Staff, Guided by* DR. ANANDKUMAR G. PATIL *from Department of* PROSTHODONTICS & CROWN & BRIDGE *has been critically evaluated by committee members and granted ethical clearance to conduct the above mentioned study*

Date :



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