A Novel Computational Analysis of Computer Milled Zirconium Implant Abutment Head Design under Reinforced Implant Supported Overdenture

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Abstract— During the past few decades, unalloyed titanium has been extensively used as a material of dental implant-supported restorations but it cause gingival discoloration and unnatural appearance of the surrounding soft tissue. Currently, yttrium oxide partially-stabilized zirconia (Y-TZP) is a ceramic of special interest because of its superior mechanical properties. This study was carried out with four one piece zirconium implants embedded on a standard acrylic resin mandibular edentulous model, the abutment of zirconium implant was classified into two designs and then laboratory test was applied with proposed biting force (sensor (BS) and a bidirectional transmit-receive module. Our study concluded that the use of one piece Zirconium implant with box or parallel shape abutment head in implant supported over-denture without a need of cement, screws or plastics or metal housing for attachment in other types of implant had a superior results and easier maintenance and repair of the prosthesis if any complications occur.

Keywords—3-D Finite Element; Box Shaped Implant; Computer Milled Zirconium.

I. INTRODUCTION

Different attachments are provided by a large number of manufacturers around the world for implant overdenture. [1, 2] Most of these are compatible with the majority of the implant systems currently available and are divided into two major categories: bar and stud attachments. The large number of attachments is rather confusing for the inexperienced clinician. This cause a big problem because the choice of attachment used is based basically on opinions and clinical experience rather than on real evidence and scientific findings. [3]

During the past few decades, unalloyed titanium has been extensively used as a material of dental implant-supported restorations but it cause gingival discoloration and unnatural appearance of the surrounding soft tissue which resulted in demands for esthetically improved and biocompatible materials. Currently, yttrium oxide partially-stabilized zirconia (Y-TZP) is a ceramic of special interest because of its : Superior mechanical properties which is similar to stainless steel , can tolerate well cyclical stresses , ethetic, opaque so very useful for marginal adaptation monitoring , no corrosion , no allergic reactions and not cytotoxic.[4,5]

Nowadays there is a greater interest in the CAD/CAM (computer-aided design computer-assisted manufacture) systems for implant-supported prosthesis as it decreased the costs of manpower and labor-intensive laboratory processes. Also allowed for the production of large and complex restorations with high accuracy and success rate. [6, 7]

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Implant overdentures were independently classified according to their manner of support. Misch (1999) suggested that implant overdentures can be either soft tissue-implant borne or implant-borne. [8] Mandez and Guerra (1995) provided slightly different terminology where they considered two types of implant overdentures. An implant-retained tissue borne overdenture was described as relying primarily on the residual alveolar ridge for support, while an implant retained implant-borne overdenture relies on implants to bear the full load of the occlusion. [9]

Overdenture construction necessitates sufficient room for the accommodation of the bar attachments between implants. Lack of space can result in fracture of the acrylic resin, or other technical problems. [10] Besides the necessary vertical space for the housing of the attachment for implant, sufficient horizontal space is also critical for the structural integrity of the prosthesis. [11] The most frequent fractures of resin denture bases occurred in area adjacent to implant abutment in overdenture due to greatest strain. So various methods have been investigated to improve acrylic denture materials and prevent fracture including mechanical reinforcement of acrylic with other materials, such as, carbon, nylon, rayon and glass fibers, [12] but glass fibers have gained popularity because of their good esthetics and good bonding to polymer. [13, 14] The select attachments for implant supported overdentures should have enough retentive properties to enhance the stability of the prosthesis. At the same time, the attachments should allow for an easy placement and removal of the prosthesis by the patient. [2]

The bite force (BF) is a useful indicator of the functional state of the masticatory system and the loading of the implant .It used to evaluate the therapeutic effect of prosthetic device and to provide reference values for studies on the biomechanics of prosthetic devices. [15]

Literature review revealed several biting force devices, mentioned that the most commonly technique was strain gages. They offer many advantages over other techniques such as simple installation that can be carried out with little training, available circuitry to measure its linear output over a large range of forces, and because it is easy anticipate the magnitude of the gage output with little well defined calculations. However, the resistance strain gages have their limitations. One of the most important limitations is large size of the gauge applied to BF transducers. The large size of the gauges requires the height of the BF transducer to about 10 millimeters which causes a bite opening. The non-linearity of human Biting Force (BF) provides a non-accurate computational analysis results, whereas the force sensing resistor, surface material of the sensor, and the computational software are importance to increase the medical analysis accuracy. [16 – 19]

Therefore the aim of this study was carried out to use CAD/CAM macrodesign zirconia implant with reinforced glass fibers implant supported overdenture to solve the problem of fracture and analyzed the stress distributed on macrodesign zirconia implant abutment head under glass fiber reinforced implant supported overdenture using bite novel sensor (BS) and bidirectional transmit-receive module

II. MATERIALS AND METHODS

This study was carried out on a standard acrylic resin mandibular edentulous model.Transparent heat cured acrylic resin surgical guide stent was used for location of the implants.

Implant marks were drilled in the specified locations on the surgical guide stent and then drilled through the edentulous resin model. Four zirconium implants designed as one piece implant was embedded, two in the canine region and two in the posterior region with a diameter of 5mm and length of 10mm. The holes in the edentulous model for location of zirconium implant were wetted with resin monomer and the zirconium implant was screwed in the prepared sockets to ensure adequate bond to the resin model.

A. The procedure of fabrication of Zirconia Implants:

Two titanium implants was selected with diameter 5mm and length 10mm. The abutment of the titanium implant was prepared into two designs, one box shaped walls (Group I) and the other with parallel walls (solid) (Group II) as shown at figure 1.a and 1.b.

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Fig.1. One piece zirconium implant, a - with box shape abutment head, b- with parallel wall abutment head

- Titanium implants was fixed in the frame of the cercon machine (Degudent GmbH, Hanau-Wolfgang Dentsply International co., Germany) at one side and coated with Cercon Scan-Powder and Zirconium block was attached to the other side (3 mol Y- TZP,chemical composition of the block).(Fig.2) to fabricate zirconium implant similar to the titanium implant with the same dimension and preparation shapes for group I and group II.
- Press the start button to start scanning. The scanning procedure takes approximately 3 minutes. After rough milling and fine milling, the milled implants were cut with the carbide bur from the blank.(Fig.3)
- The milled zirconia implant was sintered in the cercon heat machine at 1350° C for 8 hours to achieve final density.

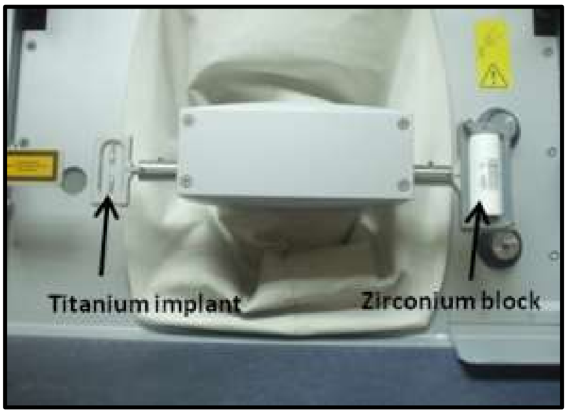

Fig.2. Titanium implants in the machine and zirconium block in the other side

Fig.3. Implant was cut.

B. Prosthetic phase :

Twenty reinforced glass fiber (Ever Sticktech. Co.,Ltd, Turku, Finland) implant supported overdentures were fabricated .Ten for each group .

The positions of the abutments heads were transferred to the bearing surface of the lower denture by marking the heads with an indelible pencil. An acrylic bur was used to grind this opening for the location of the abutment head on the denture (Fig.4). Separating medium was placed over abutment head. The glass fibres impregnated with silane, by immersing them for a ten minutes to obtain chemical bond between the fibres and the acrylic resin.

- Then they were cut in the blender to produce short woven filaments.
- The glass fibers with concentration (6% by weight) was mixed with the PMMA powder and monomer and applied in the dough stage over the opening of implant abutment head on the denture base of implant supported overdenture.
- The lower denture was then seated and stabilized until acrylic resin polymerized.
- The denture was removed, cleaned and finished.

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Fig.4. Finished denture filled with glass fibers

C. Loading and Measurements:

1-Measurement of fracture resistance

Each experimental model with zirconium Implant and overdenture was loaded in a universal testing machine (Comenten Industries, inc. st. Petersburg, Florida ,USA. Model NO.942 D 10-20) at a crosshead speed of 1mm.min-1. A stainless steel indenter with a surface area of 4 mm2 was chosen to load the restoration. The base of attachment unit was aligned so that each restoration was loaded above the abutment until the denture was broken. Readings were taken at the peak value.

2-Stress analysis:

A Novel sensor [18] was used to measure the amount of force on the zirconium implant supported overdenture. The sensor had been designed and encapsulated into a conventional safe bite guard .It had three major components: an inner sensor, an intermediate activator and an outer surface. The inner sensor was made of a circular conductive polymer pressure- sensing resistor. It had two sheets were separated by a spacer that increased the peripheral thickness of the sensor to 0.5mm. Its basic characteristics were piezoresistive i.e. its resistance decreased with increasing normal pressure the thermoplastic sheets also insulated the sensor. The sensor bite force were calibrated and measured the different values of perpendicular forces against a universal testing machine (Instron Type 3382, German) shown in fig5 (a,b). The output signal from the load cell was conditioned, amplified and then recorded in a software program (Bluehill2).

In order to biomechanically evaluate the zirconiun implant the stability and viability, different occlusal perpendicular forces were measured against a universal testing machine

The testing model was secured to the solid base of the universal testing measuring device. Two identical novel BF sensors are fixed on the occlusal surface of the implant supported denture at the posterior implant abutment area and then at anterior implant area. Vertical downward static load was applied on the specimen at an increment of 10 N starting from zero loads up to 200 N. The sensor was connected to microcontrolled electronic measuring circuit this sensor produced frequency modulation. The output signals from the load cell were conditioned and amplified and then recorded in a software program (Biuehill2). The correlation between the force recorded by Bluehill program according to the load cell and readout frequencies were recorded and plotted to calculate the linear equation between them.(Fig. 6)

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Fig.5 Universal Testing machine (Instron Type 3382)

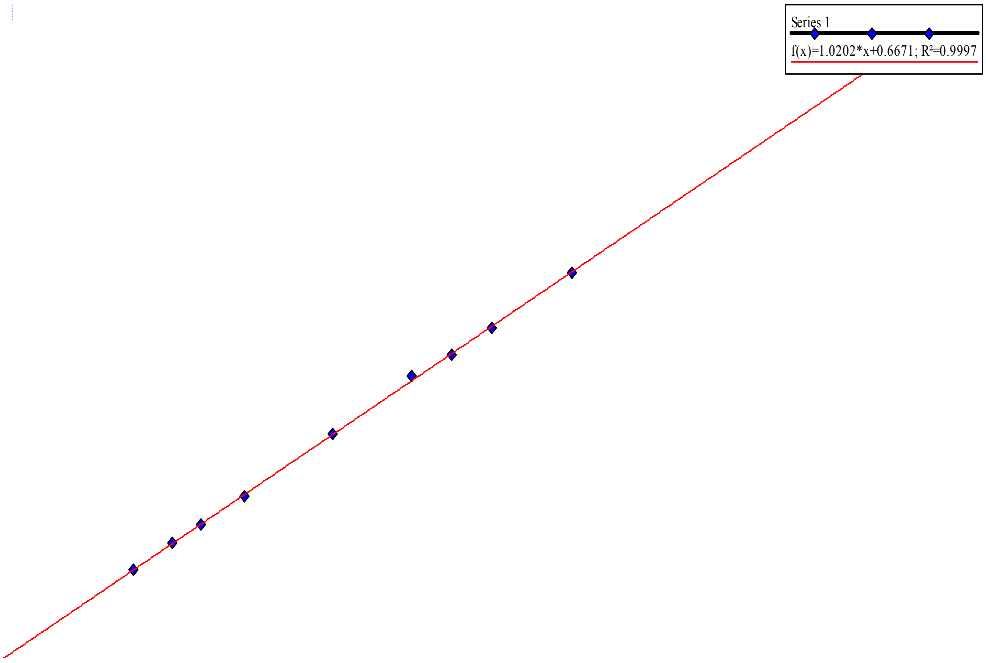

Fig.6. the plotted calibration curve was linear and the measurement were repeatable, it exhibited a linear relationship between the output frequency circuit and the resultant of programmed microcontroller

III.RESULTS

Table (1) showed the mean value of fracture resistance for group I was 321.60 ± 16.56 while group II was 256.0 ± 10.46. Highly significant difference was observed between group I box wall shape and group II parallel wall shape abutment (P= 0.004).

TABLE I
FRACTURE RESISTANCE ABOVE THE ABUTMENTS IN THE STUDIED GROUPS

	Group I (Box Wall)	**Group II (Parallel Wall)**
Mean ± SD	**321.60 ± 16.56**	**256.0 ± 10.46**
p	**0.004***	

p:p value for Student t-test
*: Statistically significant at $p \leq 0.05$

In vitro loading forces at a constant speed and static loading trials of zirconium abutments was applied for solid and box shaped abutment in both posterior and anterior region as shown in(Fig.7,8)

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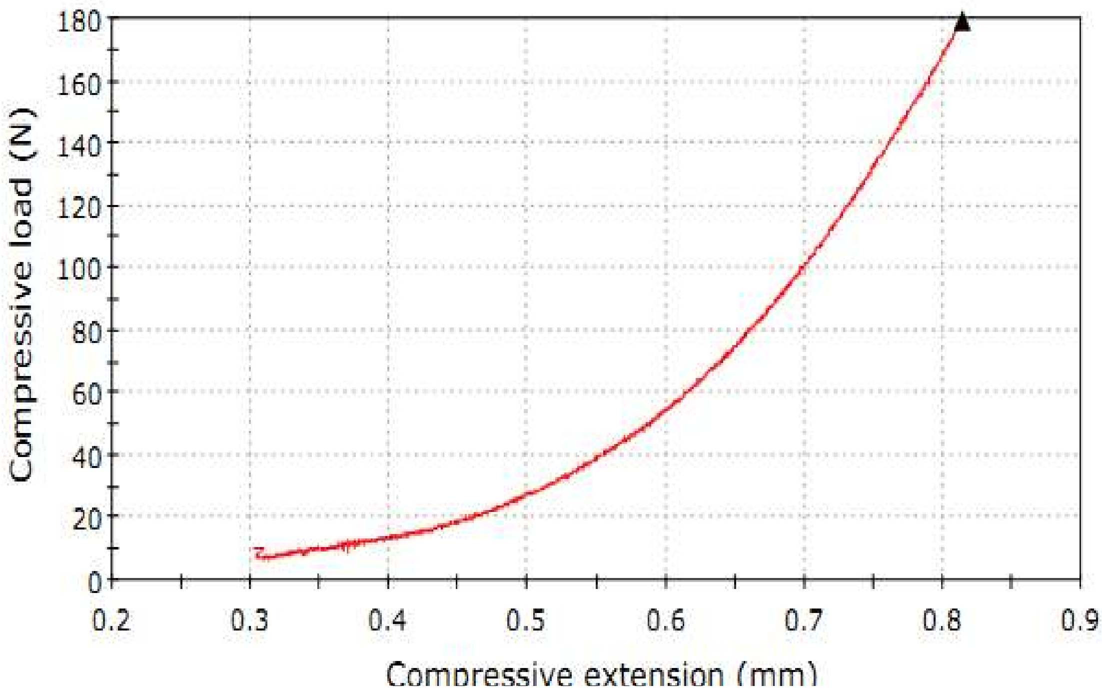
1. **<u>Group I (Solid shaped abutment)</u>**

(a)-Reinforced implant supported overdenture on solid parallel head implant abutment in the posterior region:



(b)-Reinforced implant supported overdenture on solid parallel head wall implant abutment in the anterior region

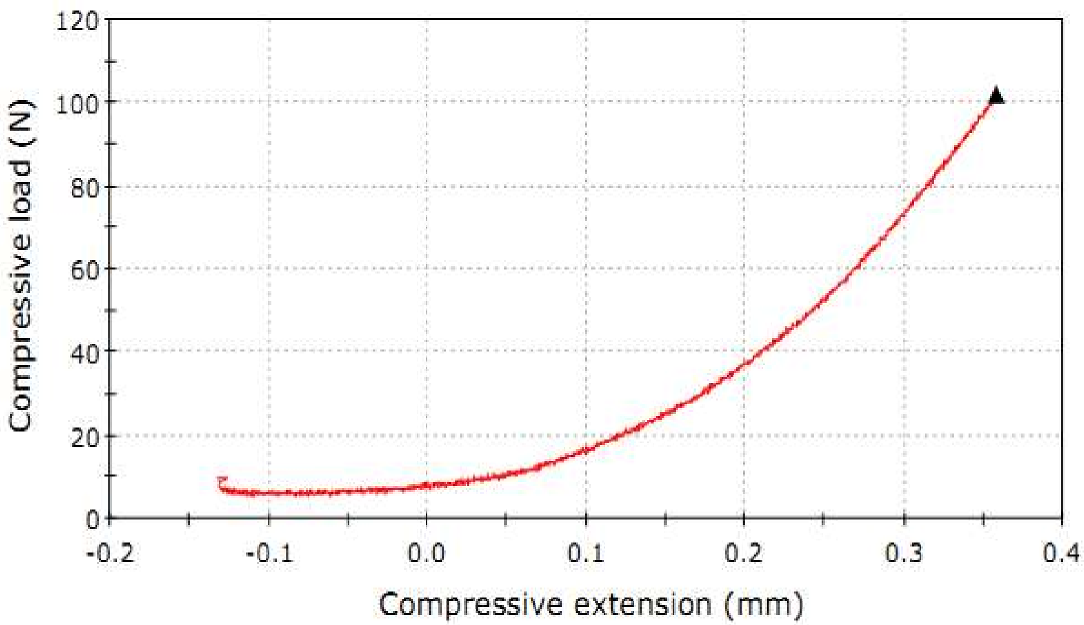
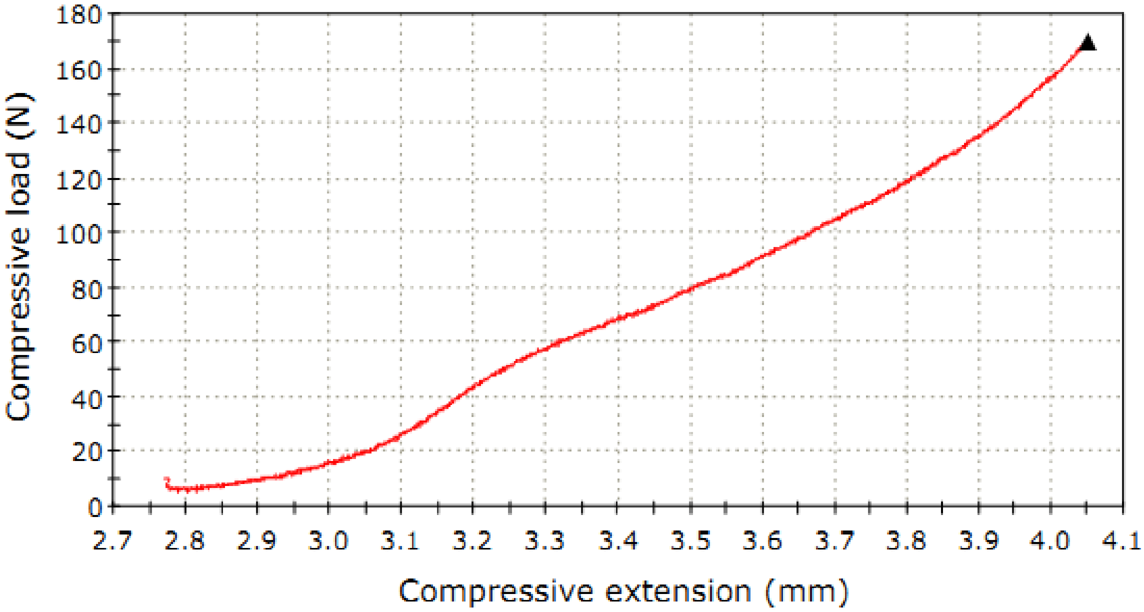


Fig.7. (a&b): Solid abutment loading simulations curve

2- <u>Group II (Box shaped abutment)</u>

<u>(c)-Reinforced implant supported overdenture on box shaped implant abutment head in the posterior region:</u>



<u>(d)-Reinforced implant supported overdenture on box shaped implant abutment head in the anterior region</u>

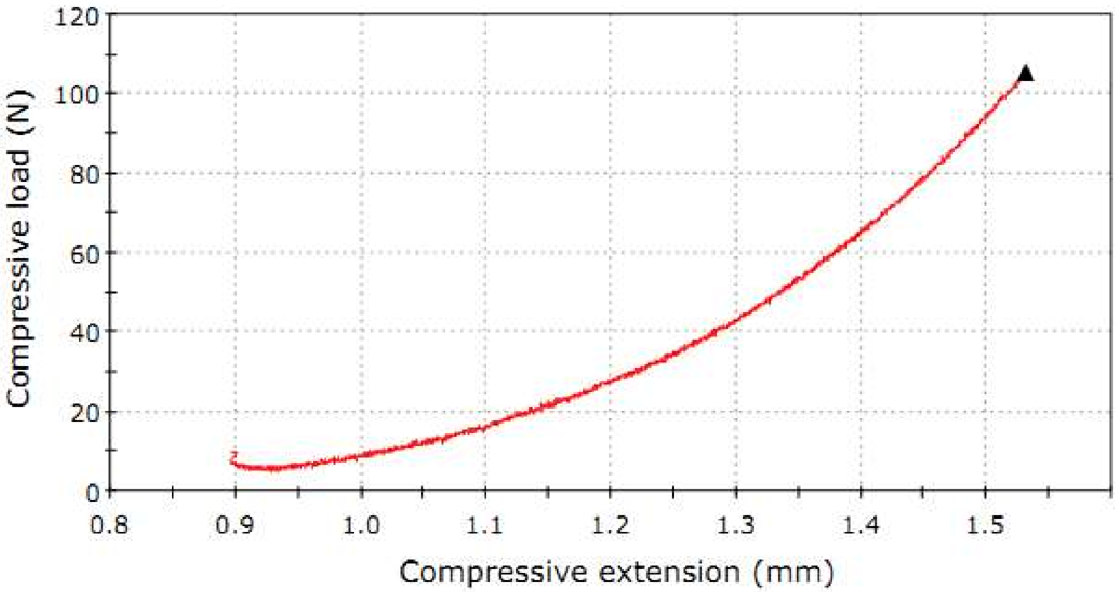
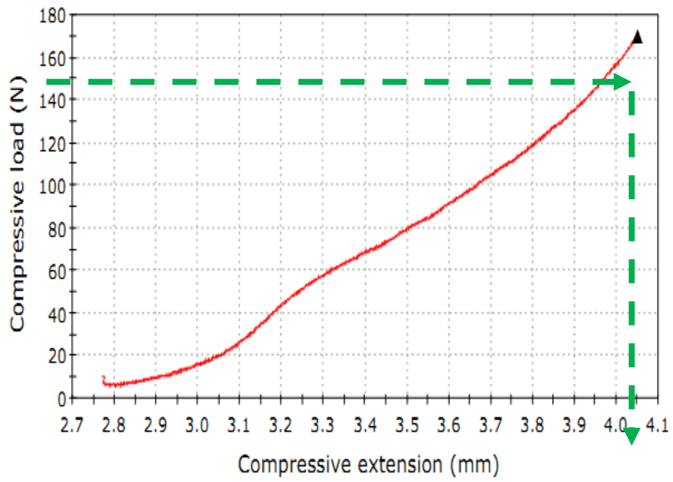
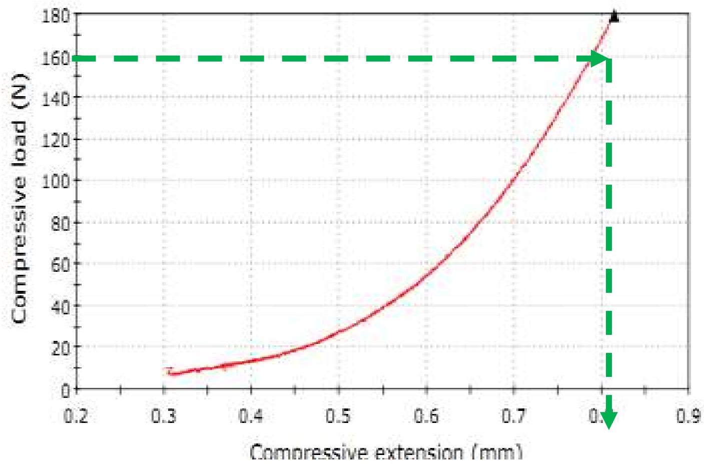


Fig.8(c&d): Box abutment loading simulations curves

Generally comparing the compression extension occurred to the box and solid abutment showed a higher compression extension occurred in box shape abutment compared to solid abutment. Thus it reaches 4.05 mm at applied force equal to 170 N in solid shape but in box abutment, the maximum displacement reaches 0.82 mm at 180 N as shown in Fig 9(a) and (b)

IV. DISCUSSION





The magnitude of stress to the macrodesign implant abutment head under implant overdenture was considered a major problem confronting the prosthodontists .These problems included the transimittion of biting force. The bite force gauge measuring device was sensitive, large in size and resultant in inaccurate measurement and non linear behavior of resistance force response.

Measuring of the actual biting force on each implant would be beneficial for accurate study of stress-strain distribution of force along bone –implant interface.

Our work was performed invitro to avoid many variables in the different mouth with different general physical condition of the patients .The study was carried out with novel BF sensor to determine the magnitude of force transmitted to implant abutment under reinforced implant overdenture , using two different macrodesign abutment abutment head , groupI (box shape) and group II (solid parallel wall shaped)

Four zirconium one piece implants fabricated in this study with CAD/CAM milling concept has reduced use of the metal casting procedure. The fit of CAD/CAM has been well documented to be as good as and better than that of restoration fabricated by hand. [20, 21]

The length and size of the implant was selected in this study because the increased implant diameter better dissipated the simulated masticatory force and decreased the stress around the implant neck [22,23] A review of the literature revealed that implants shorter than 10mm showed a higher failure rate than longer implants. These complications may be related to an increase in crown height, higher bite forces in the posterior regions, and less bone density. The area of forces applied to the prosthesis may be increased by increasing the implant number, increasing the implant diameter and increasing the implant design surface area, all these biomechanical methods leads to decrease stress. [24, 25]

Reinforcement of overdentures with glass fibers plus using of silane coupling agents technique may be a useful approach to strengthening denture bases beyond their normal limits. Hence, glass fibers are strongly recommended in patients with heavy occlusal load. This method of reinforcement is uncomplicated, relatively inexpensive to accomplish and can be used routinely with all implant-supported mandibular overdentures to improve chemical bonding between fibers and resin matrix. [26, 27]

The fracture resistance measured by the universal testing machine showed a positive effect with the use of box shape implant with glass fiber reinforced acrylic resin in test specimens above the implant overdenture abutment. This might be due to the increased acrylic thickness which filled in the grooves in the box shape. The higher fracture resistance of group I was due to the addition of glass fibers which increased the specimen's stiffness and rigidity against high loads. [28 – 30]

V. Conclusion

The process of restoring of lower edentulous ridge with one piece zirconium implant using glass fiber reinforced overdenture and CAD/CAM technology has been documented . Our study revealed that the use of one piece Zirconium implant with box or parallel shape(macrodesign) abutment head in implant supported overdenture without a need of cement, screws or plastics or metal housing for attachment in other types of implant had a superior results and easier maintenance and repair of the prosthesis if any complications occur.

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