RESEARCH ARTICLE

ASSESSMENT OF BITE FORCE AND MASTICATORY PERFORMANCE IN TOOTH-SUPPORTED OVERDENTURE REHABILITATION PATIENTS

Md Jawed Ali Khan[1], Gautam Bagchi[2], Pankaj Kumar Singh[3], Vipin Bhatnagar[4], Anuj Garg[5] ,Alka Singh[6]
1.Post Graduate Student, Department of Prosthodontics and Crown & Bridge, Dental College Azamgarh, Uttar Pradesh, India
2.Professor, Department of Prosthodontics and Crown & Bridge, Dental College Azamgarh, Uttar Pradesh, India
3.Reader, Department of Prosthodontics and Crown & Bridge, Dental College Azamgarh, Uttar Pradesh, India
4.Professor and Head, Department of Prosthodontics and Crown & Bridge, Dental College Azamgarh, Uttar Pradesh, India
5.Professor and Head, Department of Oral Pathology, Dental College Azamgarh, Uttar Pradesh, India
6.Research Scientist, Department of Orthopaedics KGMU, Lucknow

ABSTRACT

The transition to complete dentures following tooth extraction presents various challenges for patients, including adaptation to altered oral function and potential psychological effects. Tooth-supported overdentures offer an alternative, providing enhanced stability and comfort through attachment systems. This study compared the bite force and masticatory performance of patients with ball-cap and bar-clip attachment retained tooth-supported overdentures to conventional complete denture wearers, with natural dentate subjects as controls. Sixteen subjects were categorized into four groups based on their oral condition and restorative procedure. Bite force and masticatory performance were evaluated and statistically analyzed. Results showed significantly higher bite force in patients with tooth-supported overdentures compared to conventional complete denture wearers, with no significant difference between attachment designs. Natural dentition subjects exhibited the highest bite force. Masticatory performance was superior in tooth-supported overdenture wearers compared to conventional complete denture wearers, though lower than natural dentate subjects. The study concludes that tooth-supported overdentures, aided by attachments, improve oral function compared to complete dentures, though not to the level of natural dentition.

Keywords: Prosthodontics, Bite force, Tooth-supported Overdentures, Masticatory performance and edentulism.

INTRODUCTION:

Edentulism, the condition of tooth loss, not only results in functional impairment but also leads to significant aesthetic and psychological changes in individuals [1]. Conventional complete dentures, while commonly used for prosthodontic rehabilitation, present challenges in terms of adaptation and functional performance, often requiring a complex learning process influenced by both somatic and psychological factors [2]. Moreover, the loss of teeth initiates a cascade of alveolar bone loss, independent of overall skeletal health, further complicating the rehabilitation process [3].

Corresponding Author: Dr Pankaj Kumar Singh Email: pankaj.pankaj.singh2@gmail.com

To address the limitations of conventional complete dentures, alternative therapeutic approaches have been explored, with overdentures emerging as a promising option [4]. Overdentures, supported by teeth, tooth roots, or implants, offer benefits such as improved stability and chewing performance, along with preserving residual ridge integrity and periodontal feedback mechanisms [5]. The overdenture concept revolves around a preventive prosthodontic approach, aiming to conserve remaining natural teeth and mitigate further alveolar bone loss through effective endodontic treatment and optimized occlusal forces transfer [6].

Despite the theoretical advantages of overdentures, empirical evidence regarding their functional outcomes compared to conventional complete dentures remains limited[7]. Objective measures of masticatory function are crucial for evaluating treatment success and enhancing patient satisfaction. Therefore, this study aims to assess the functionality of tooth-supported overdentures by objectively measuring bite force and masticatory performance. By evaluating these parameters, we seek to contribute to a better understanding of prosthodontic outcomes in edentulous patients and improve treatment strategies for dental prostheses.

MATERIALS AND METHODS:

Study Design: This clinical study was performed to compare, quantitatively, the oral function, namely the maximal bite force and masticatory performance of three groups of subjects with (a) complete dentures (b) overdentures with ball and cap attachment and (c) overdentures with bar and clip attachment. Furthermore, correlations between maximum bite forces and chewing efficiency were investigated. A group of subjects with complete- natural dentition were taken up for this study to compare the bite force and masticatory efficiency with complete denture and overdenture wearers.

The Following Materials and Equipment's Were Used to Conduct the Study:

Armamentarium for Clinical Examination:

1. Kidney Tray
2. Mouth mirror
3. Periodontal probe
4. Cheek retractor
5. Disposable gloves and mask

Armamentarium for Tooth Preparation:

1. Airotor handpiece

2. Coarse and Fine Diamond points – flat-end tapering, round-end tapering, flame shape
3. Gates glidden Drill – sizes 1 to 6
4. Peeso reamer – sizes 1 to 6

Armamentarium for Fabrication of Complete Denture

1. Alginate – Chromalgin
2. Maxillary and Mandibular stock trays
3. Type III dental stone (Kalstone)
4. Type II Dental plaster
5. Green stick compound (Samit)
6. Putty addition silicone impression material (Ivoclar, Vivadent)
7. Light body addition silicone impression material (Ivoclar, Vivadent)
8. Tray adhesive (Ivoclar, vivadent)
9. Type IV dental stone (Ultrarock)
10. Dentatus face bow and Articulator
11. Acryrock Teeth set
12. DPI Heat cure

Armamentarium for Fabricating Attachment Retained Overdentures:

1. Castable pivots for canal impressions (normal - 2.5 mm, micro – 1.8 mm)
2. Castable spheres (normal – 2.5 mm and micro – 1.8 mm)
3. OT CAP retentive caps – white, pink, yellow, green and black caps (for lab use)- normal and micro size
4. Castable OT BOX CLASSIC (normal and micro size)
5. Castable OT BOX Connectors
6. Plastic Positioning rings (normal and micro size)
7. Castable bars
8. Retentive clips – pink and yellow
9. Parallelometer and its keys for OT CAP and OT BAR MULTIUSE
10. Insertion tool for OT CAP (normal and micro size)

Armamentarium for Evaluating the Bite Force:

1. Bite force meter – strain gauge transducer
2. Mouth prop
3. Surgical Gloves
4. Surgical spirit

Armamentarium for Evaluating the Masticatory Performance:

1. Paraffin wax test food
2. Die for preparing the test food, made of mild steel
3. Canon EOS 5D Mark II: 21Mega Pixels with macro lens
4. Ring Flash
5. Adobe Photoshop

6. Auto CADD software

Methodology:

1. Subject selection:
2. Preparing study models and diagnostic mounting
3. Selection of abutments and attachments
4. Tooth preparation and making secondary impression
5. Jaw relation recording and wax try-in
6. Fabrication of attachments and denture insertion
7. Evaluation of bite force using strain gauge transducer
8. Evaluation of masticatory efficiency using wax test food
9. Method of statistical analysis

S.No	Name (Commercial Name)	Form Of The Material	Manufacturer Details
1.	Vignette chromatic alginate impression material	Irreversible hydrocolloid impression material	Dentsply, India
2.	Jabbar trays	Stock tray	Jabbar &co, India
3.	Kalstone	Type III Dental stone	Kalabhai, India
4.	Virtual Tray Adhesive	Tray adhesive	adhesive Ivoclar Vivadent,USA
5.	Virtual Putty and light body	Putty and light body addition silicone impression material	Ivoclar Vivadent,USA
6.	Ultrarock	Type IV dental stone	Kalabhai, India
7.	Acralyn H High	heat cure resin	Asian Acrylates, India
8.	Bite force meter - Strain gauge transducer	Strain gauge transducer	Transducer Indigenously designed Hitech equipments, Bangalore
9.	Ball - cap attachments	Castable components	Rhein 83, Bologna, Italy
10.	Bar -clip attachments	Castable components	Rhein 83, Bologna, Italy

Subject selection: Study participants were selected from among the out patients at Department of Prosthodontics, Dental College Azamgarh. The patients selected for this study were categorized into 4 groups based on the oral condition and the restorative procedure.

Group 1- Complete natural dentition, **Group 2** - Completely edentulous, **Group 3** – With four or less retainable teeth in the

mandibular and maxillary arch - Overdentures fabricated with ball and cap attachment, **Group 4** – With four or less retainable teeth in the mandibular and maxillary arch - Overdentures fabricated with bar and clip attachment.

The study participants with few teeth remaining having minimum bone support of 7 mm, which are indicated for total extraction were selected for over denture therapy. All the patients were similar in terms of age between 45 – 60 years. The dentate group was recruited as those healthy subjects with 28 teeth, without any restorations, and with normal occlusion. All the patients were informed about the purpose and methods of the study and signed the written consensus.

The inclusion criteria for entry into the trial were: Medically fit enough to undergo the treatment procedure like extraction and endodontic treatment; Healthy oral mucosa, Class I jaw relation, Adequate denture space, Suitable abutment teeth, Good oral hygiene, Co-operative attitude and motivation.

The exclusion criteria were: Presence of temporomandibular disorder, Bruxism, Systemic and/or neurological disorders, Smoking habits, Highly resorbed ridge, Soft tissue disorders, Chronic tissue trauma, poor tissue support for dentures, Those who could not chew with their dentures.

Diagnosis and Treatment Planning: All the patients underwent the stomatological examination and the following pathologies were observed: periodontitis, stomatitis, root caries and increased mobility of some abutments. Oral hygiene maintenance was checked and patients with poor oral hygiene were obliged and motivated to improve their hygienic habits.

Investigations: orthopantomogram and periapical radiographs were taken for assessment of bone support and endodontic evaluation.

Clinical steps involved:

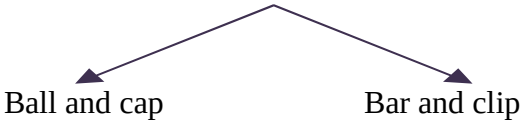
Preparation of study models: Maxillary and mandibular arch impressions were recorded with irreversible hydrocolloid and casts poured with type III dental stone. Bite registration was done with aluwax and mounted in mean value articulator. Diagnostic casts were mounted, for selection of abutments, positioning of teeth, jaw relationship, available denture space, tissue undercuts.

Selection of Abutment Teeth:

Periodontal Considerations:

- Minimum of 7mm of alveolar bone support should be present radiographically
- Periodontal disease of individual tooth is classified based on the guidance proposed by **Lindhe and Nyman (1975)**[C1]**,** according to which the periodontal status is classified into gingivitis (G), early periodontitis (P1), moderate periodontitis (P2), and severe periodontitis (P3).
- Mobility of teeth is classified into Grade I,II ,III, & IV .Abutment with severe periodontitis (P3) and grade III & grade IV mobility are advised for extraction and not included in the study
- Probing depth of not more than 3 mm around the abutment teeth
- Adequate zone of attached gingiva is needed for the periodontal health of the abutments, about 3mm is the minimal requirement
- **Endodontic Considerations:**
- Endodontic status of the abutments was assessed using intra oral radio graph. Abutment teeth with periapical pathology like perapical abcess, perapical granuloma, perapical cyst were advised for extraction and not included in the study.
- Endodontic therapy was performed on all abutment teeth in order to obtain a more favourable clinical crown – root ratio.
- Abutments that are fit both endontically and periodontally were selected and root canal therapy was done at the Department of Operative Dentistry and Endodontics, Dental College Azamgarh.
- Diagnostic casts which were mounted in mean value articulator was assessed for selection of attachments. Fabrication of an over denture with attachments requires minimum of 20 to 30 mm of interarch space.

Selection of attachments: The two attachments that were used in this study are the commercially available Rhein'83 precision attachments.



The attachments were selected based on the periodontal status and the crown – root ratio of the two abutment teeth. If one tooth is weak, the ball and cap attachment allows independent movement and the stronger tooth can serve as the

fulcrum point for movement of the weaker tooth in the prosthesis. Whereas the bar and clip has a splinting effect and rigidly fixates the prosthesis, therefore all or none of the teeth movement occurs under functional load.

Fabrication of attachment retained overdentures:

Ball and cap attachment retained overdenture

Preparation of post space and impression technique: Preliminary impression of maxillary arch was recorded with impression compound using edentulous stock tray. Preliminary impression of mandibular arch with the abutment for overdenture was recorded with irreversible hydrocolloid using dentulous stock tray, cast was poured with type III dental stone. Custom tray was fabricated with autopolymerising acrylic resin, border molding of maxillary arch was made with tracing stick and impression was made with zinc oxide eugenol.

Border molding of mandibular arch was done with addition silicone of putty consistency. Clinical crown of the abutment tooth was reduced to the level of the gingival margin, leaving 2-3 mm of tooth structure above the gingiva, with a chamfer finish line, incorporating cervical ferrule and antirotation groove. Guttapercha (GP) was removed from the root canal using H files leaving the apical third intact and IOPA was taken to confirm the presence of GP at the apical region. Coronal orifice was enlarged using gates gliden drill (available in sizes 1 to 6) and post space was prepared using peeso reamer (available in sizes 1 to 6) **(Fig. 1)**.

Prefabricated Impression post was used to record the impression of the post space. The prefabricated posts are available in two different sizes - micro (diameter of the sphere - 1.8 mm) and macro (2.5 mm diameter) and different lengths (7, 9,10,12,14 mm for macro and 7, 9, 10 mm for micro).

Addition silicone of light body consistency was coated in to the post space using lentilospiral, the impression post was coated with tray adhesive and placed into the post space, the border molded custom tray was loaded with light body and placed in to the mouth and allowed to set. The impression post placed in the post space was picked up by the impression. The impression was boxed and two casts were poured, one was poured in Type III dental stone, for processing the denture and other was poured in type IV dental stone, to make the wax pattern for Richmond crown.

Jaw relation recording and Wax try in: Maxillary and mandibular record bases were made with autopolymerising acrylic resin and occlusal rims were prepared using modeling wax. Orientation jaw relation was done with arbitrary face bow and the maxillary cast was transferred to the semi adjustable articulator (Dentatus). Vertical jaw relation was established, horizontal jaw relation was done by gothic arch tracing and centric and protrusive records were made using Type II Gypsum product. Teeth were arranged in balanced occlusion and tried in the patient's mouth.

Fabrication of wax pattern for Richmond crown: The prefabricated castable sphere (Rhein 83) was used to make the Richmond crown. They are available in two sizes, normal (2.5 mm diameter) and micro (1.8 mm diameter), also colour coded as green and red respectively.

The castable sphere has a leveled head which provides space between the retentive cap and the sphere and also reduces the stresses during vertical flexion (Fig. 2)

This ball and cap attachment provides retention by elastic means and allows movement of the denture, thereby resulting in a prosthesis which is resilient and shock absorbing. The prefabricated attachments are placed over the wax pattern using the Parallelometer with the respective keys for normal and micro sizes. Parallelometer is a mini surveyor used to find the correct horizontal position on the stone model using the swiveled base. The attachment mandrel was locked in place inserting it onto the notch on the movable extension arm and the locking screw tightened. The movement of the extension arm was monitored and the rear locking screw tightened. Parallelometer keys of normal and micro size were used to hold the attachment and orient it to the wax pattern.

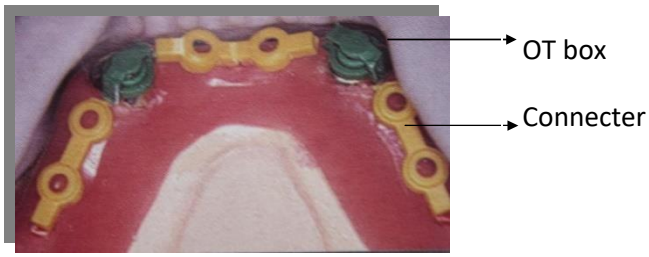
The teeth set up of mandibular trial denture was transferred to the second cast which was made in Type IV dental stone and placed on the parallelometer. The swiveled base locking nut was released so that the locking attachment for the mandrel could be moved up and down, front and back. The parallelism between the occlusal plane and the swiveled base was established such that the arm of the mandrel touched the acrylic teeth of both sides at the same time. The corresponding position of the swiveled table was locked and the cast removed from the table. Impression post which was used to record the post space were placed into the post space. Abutment teeth on the cast were lubricated, wax pattern made over the post and transferred to the parallelometer which was locked in a position parallel to the teeth set up. The attachment was locked in the

key and placed over the wax pattern and luted with wax. The locking key was released and the wax pattern with the post, core and ball attachment on the top (Richmond crown) was made.

Sprue of 2 mm diameter was attached, invested and cast with cobalt chromium alloy in centrifugal casting machine. The cast Richmond crown was sand blasted and trimmed with care without damaging the attachment. The attachment was glass blasted and polished with rubber wheels and rouge. The polished crown was placed on the cast and the fit verified. Then, fabrication of reinforcement frame work was carried out. Positioner ring of the corresponding size (normal or micro) of the attachment was placed over the Richmond crowns (Fig. 3).

Castable housing (OT box mono - micro or normal) was placed over the positioner ring, mesial and distal parts of the castable housing were connected by castable connector using pattern resin. The entire frame work was lifted from the cast, the positioner ring being retained on the Richmond crown. The frame work was sprued with 4mm diameter sprue and cast with cobalt chromium alloy (Fig. 4).

The elastic caps are available with different retention degrees, in different sizes and are colour coded. Black color for laboratory



purpose, yellow color for very elastic retention (normal size - 500 to 550 g, Micro size - 450 to 500 g), pink cap offers elastic retention (normal size - 800 to 950 g, micro size - 750 to 850 g), white cap offers standard retention (normal size - 1200 to 1300 g, micro size - 1000 to 1100 g). The black elastic cap was inserted into the cast frame work using the insertion tool provided from the manufacturer and seated on the Richmond crown and the fit was verified over the cast one. The teeth set up of the mandibular trial denture was indexed with laboratory putty, teeth were removed from the set up and positioned over the index.

The entire assembly of putty index and teeth was placed on the cast which is having the Richmond crown with reinforcement frame work. Acrylic teeth were trimmed to provide space for the acrylic resin, wax up was done and occlusion checked with the opposing trial denture. Flasking and dewaxing was done, light body addition silicone was coated in to the post space in the cast two, Richmond crown along with the frame work was stabilized over the cast

to prevent the movement of the prosthesis. Acrylic resin was packed in to the mold and polymerized. Denture was removed from the flask, trimmed and polished well. The maxillary and reinforced mandibular dentures along with the Richmond crowns were ready for insertion.

Insertion of Richmond crown and Denture: The black cap on the frame work was removed and a retentive cap other than the black was inserted in to the housing. Richmond crown was placed in the prepared tooth and the fit was verified, the lower denture with the retentive cap was placed over the Richmond crown, occlusion was checked with maxillary denture in place. The mandibular denture was removed from the mouth along with the Richmond crown being picked up. Zinc phosphate luting cement was mixed, post space and the Richmond crown were coated at the same time, the entire assembly was placed in the mouth, maxillary denture was inserted and the occlusion assessed. Patient was instructed not to remove the lower denture for 24 hrs and asked to come for review. On review, when the maxillary and mandibular dentures were removed, the Richmond crowns would be fixed to the prepared abutment teeth and the retentive caps are present in the impression surface of the mandibular denture. In cases, where the inter arch distance was less than 25 mm, mandibular overdentures without reinforcement were made. Laboratory steps for making the denture were similar to the fabrication of denture with reinforcement. The black cap in the denture was removed from the processed denture and a hole was made correspondingly. Richmond crowns were placed in the mouth, retentive caps placed over the crown and the denture seated in the mouth. The cap was seen through the hole and the occlusion was checked with the opposing maxillary denture. Retentive caps were placed over the Richmond crowns and lower denture was inserted, autopolymerizing acrylic resin was mixed and placed in to the hole and allowed to set. On removal, the Richmond crown was picked up along with the mandibular denture. The crown was removed from the denture, excess acrylic resin was trimmed, crown was seated in the denture and again occlusion was checked. Zinc phosphate cement was mixed and coated on the post space and crown simultaneously and the entire assembly was placed in the mouth. The patient was advised not to remove the lower denture for 24 hrs and recalled for review. The mandibular denture was removed and the excess cement cleaned and instructions given.

Fabrication of bar and clip retained over denture

Preparation of the abutment: The periodontal and the endodontic status of the abutment teeth were assessed as per the guidelines discussed earlier, intentional endodontic treatment was done for the abutment teeth. Preliminary impression of the mandibular arch was recorded with irreversible hydrocolloid using dentulous stock tray. Custom tray was fabricated using autopolymerising resin.

The abutment tooth was reduced and prepared with chamfer finish line, with an occluso-gingival height of minimum 3 to 4 mm to provide resistance and retention form. The custom tray was seated in the patient's mouth, extensions were checked, border molding done with addition silicone of putty consistency and final impression made with light body consistency of addition silicone. Two casts were poured using the impression, first cast was poured with type III dental stone for processing the over denture, second cast was poured with type IV dental stone for making the wax pattern of castable bar .

Jaw relation recording and Wax try in: The procedures of jaw relation and wax try in were performed in a usual manner.

Fabrication of wax pattern for the Castable bar: Castable bar (RHEIN 83) was used in the fabrication of bar and clip retained over denture. The bar is convex on one side and flat on the other side. Convex side when placed up and flat side placed facing the alveolar ridge (version A) offers rigid retention whereas flat side facing up and the convex side towards the residual ridge (version B) offers resilient retention. Special key for parallelometer is available to orientate the bar to the wax patterns on the abutment teeth. Version A, rigid retention mode was used for all the cases in this study.

The trial denture from the first cast was transferred to the second cast and the parallelism was established using the parallelometer as it was described for the ball and cap attachment procedure. The key for the parallelometer was used to fix the bar to the wax pattern, 2mm sprue was attached and casting done in cobalt chromium alloy. Trimming and polishing was done as per the earlier procedure.

The retentive clip is available in two colors pink (soft retention) and yellow (medium retention). The bar with the retentive clip was placed over the first cast, space for the acrylic resin was assessed and acrylic teeth were trimmed using the putty index as discussed earlier. The dentures were processed and the mandibular denture with the cast bar was ready for insertion.

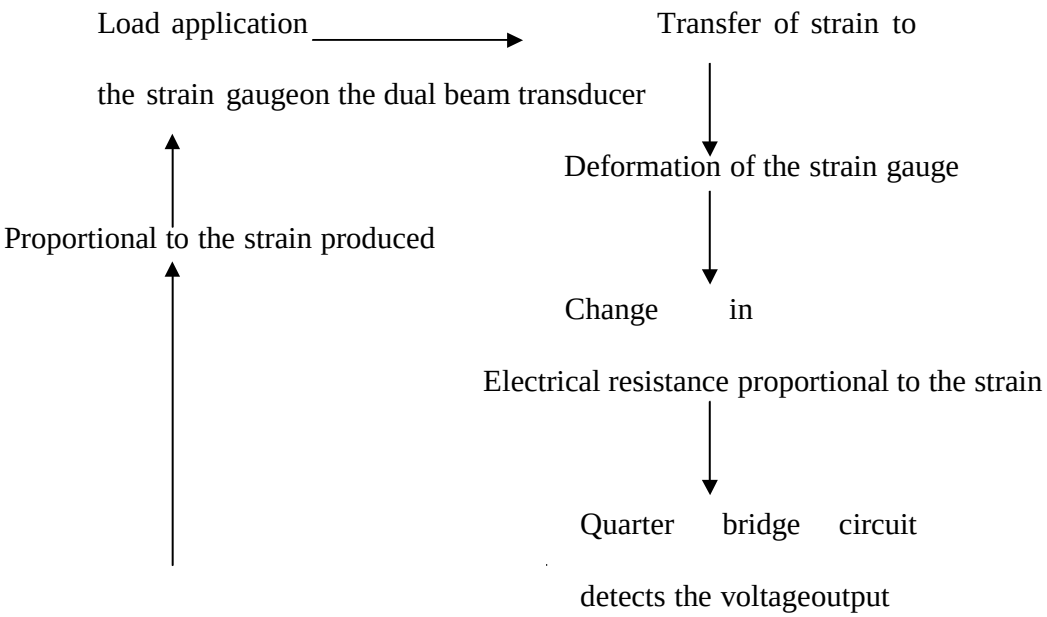
Insertion of the Denture and Coping with Bar: The coping with the bar was placed on

the prepared tooth and the fit verified. The mandibular and maxillary dentures were inserted and occlusion assessed. The coping along with the bar was cemented using glass ionomer cement and the patient was recalled after 24 hrs. Retentive clip was placed over the bar, auto polymerizing acrylic resin was used to fix the clip, it was allowed to set and the denture removed from the mouth. The retentive clip placed on the bar would be picked up by the denture. Post insertion maintenance and instructions were given to the patient.

Evaluation of Bite Force: Bite force is measured by determining the strain which is the degree of deformation due to the stress or load applied to the strain gauge. When a material is compressed, the force used generates a corresponding stress which in turn generates a proportional compressive strain which deforms the material by L +/- ^L, where L is the original length of the material and the ratio of ^L to L is called strain. The strain gauges consist of a semi- conductor material and measure the resultant strain to the corresponding electrical resistance changes in the strain gauge material, on application of external load.

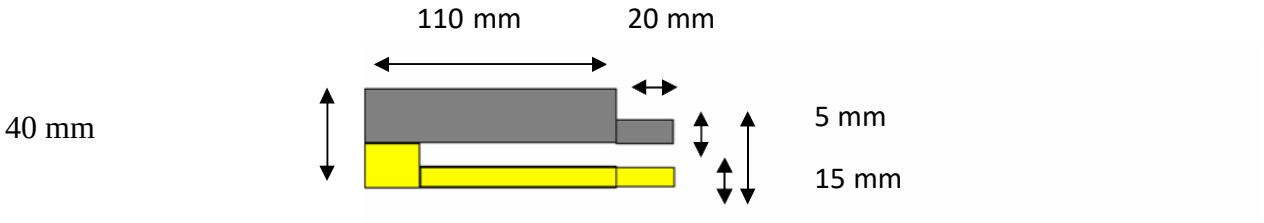
Strain gauge Configuration: In this study, the stain gauge transducer was constructed by bonding a fine electric resistance wire i.e. paralleled vinyl lead wire of 15mm long, laid in a zigzag manner, to a compensating material – Aluminium 2024-T4, which is an electric insulation base. Epoxy resin was used as bonding material and 3 mm thick butyl rubber was coated as a protective layer. The gauge has a length of 15mm, width of 3 mm, resistance of 350 ohms, and gauge factor 2.14%. The strain gauge transducer was sensitive upto a maximum force of 400 N. Self-temperature compensated gauges were used to minimize the gauge thermal output when bonded to the dual beam transducer, made of Aluminium, that has a specific linear co-efficient of thermal expansion in the specified temperature range. The strain limit i.e. the allowable elongation percent was 150% more than the maximum force it could withstand. The number of repeated cycles that the gauge can endure (fatigue life) was 1×10^5 cycles.

The theory of strain gauges was based on the fact that elongating a metal element such as a wire will change in resistance. When strain was generated in the dual beam transducer, it was relayed via the gauge base (electrical insulation) to the resistance wire in the gauge. As a result, the fine wire experienced a variation in electrical resistance, which was exactly proportional to the strain. Since this resistance change was very small, a Wheatstone bridge circuit was required to convert it to voltage output.

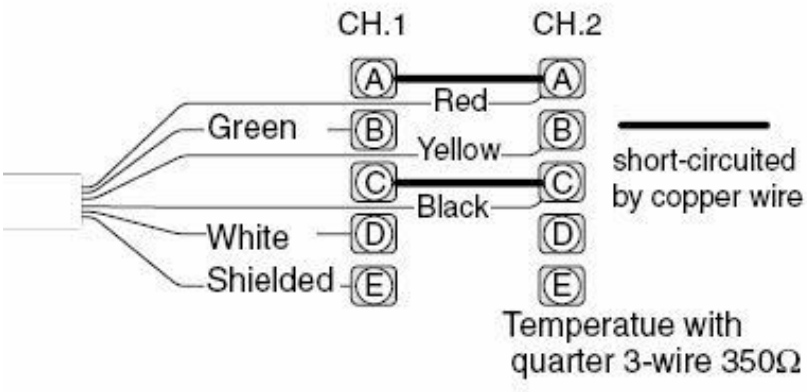


The strain gauge was connected to a static strainmeter, which provided the Wheatstone bridge circuit and exciting input voltage. The strain (E) was measured on the digital display.

Dimensions of dual beam transducer:

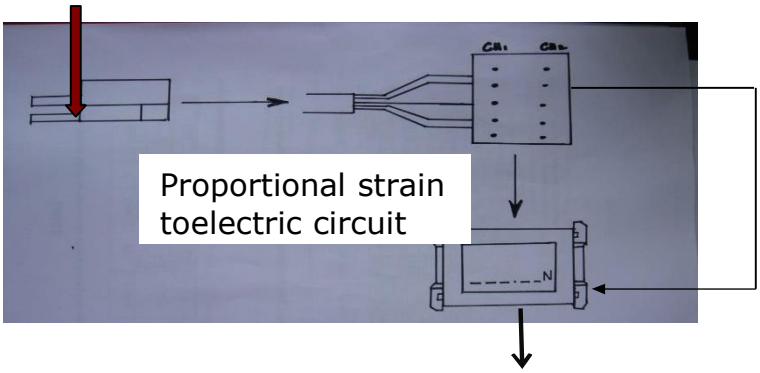


Electric circuit of strainmeter:



Schematic representation of bite force measurement:

Biting Force



Force in Newtons

Methodology for measuring the Unilateral maximum bite force:

Patient preparation: The bite force was measured in the subjects after a period of 1 month, so that the patients were used to the dentures. Patient was seated in upright position in dental chair, keeping the maxillary occlusal plane approximately parallel to the floor. The dual beam transducer was also maintained parallel to the maxillary denture and evaluated intraorally for proper position and comfort. Patients were trained before test to create confidence and instructed to bite on the bite force meter with their maximum force.

Micro strain recording: The experiment started with no load, where strain value was nil. The dual beam transducer was positioned at the first molar and second premolar region and the patient was instructed to clench hard for 2 seconds. Once the load was completely applied, readings of the strain gauges were taken in micro strain units from the digital multi-channel strain indicator. The measurements were repeated once with a one-minute rest and the highest of the two readings were noted down for each patient. The maximum bite force was tabulated for right and left sides separately.

A mouth prop of the same height as that of the dual beam transducer was placed on the opposite side for occlusal stability of the maxillary complete denture. The same procedure was repeated on the other side by interchanging the dual beam transducer with the mouth prop.

For the dentate groups, the teeth were protected by covering on both the sides of the transducer with 1.5- mm-thick putty addition silicone bonded by tray adhesive. The dual beam transducer was covered with surgical glove while inserting it in the patient's mouth as a part of sterilization and

also cleaned with ethyl alcohol, after each use.

Evaluation of Masticatory Performance:

Preparation of Test Food: Food grade fully refined paraffin wax (Sasolwax 7835) with melting range of 56 – 74 ^{o}C was used along with 20% of liquid paraffin so as to make it softer and less brittle. They were melted together and divided into equal halves. Red and green food colorants were added and stored at 37 ^{oC}.

Preparation of Test Cubes: A die was made of mild steel (MS) with a mould space of dimension 2 x 2 x 10 mm. The die had three parts, with holes and pins to approximate them correctly, each time after pouring the wax into the mould space.

Small cuboids having the identical dimensions of 2 x 2 x 10 mm were made from the molten paraffin wax which is dyed either red or green. The red cuboids and green ones were put together side by side to produce a sheet of 10 x 10 x 2 mm with only different colour cuboids touching each other. Five identical sheets were stacked together so that a standard cube of 10 x 10 x 10 mm was obtained with alternating colors. The paraffin cubes were stored at 37 ^{o}C till just before the tests were performed. Therefore, the cubes maintained their constant properties and also not very hard for the patient to chew.

Masticatory Performance test: The subjects were instructed to chew the test food well either on the right side or on the left or on both, as preferred by the subject (habitual chewing) for 10 strokes and to expectorate the bolus of masticated test food from their mouths on a sheet of gauze as thoroughly as possible. The collected paraffin wax was washed with running water for 30 seconds to remove the saliva. The temperature of the water was also 37 ^{o}C, to prevent the contraction of the paraffin wax.

After chewing the paraffin cube, a deformation of cube, i.e. a chewed test cube was obtained. The chewed test cubes were treated as samples for evaluating the masticatory performance. The samples were managed by means of digital image processing. From the images, the information of colour mixing and the shape of the sample were acquired.

Digital image analysis: Digital images of the samples were captured using a Canon Digital EOS 5D – 21 Mega pixels with high performance DIGIC 4 series to produce accurate white balance, thereby improved image quality. The Canon EF 100mm f/2.8 USM (Ultra sonic motor lens) Macro Lens was used so as to get an image of magnification 1:1 (i.e. nil magnification). The images were taken under the illumination of ring flash where the origin

of the light is very close to (and surrounds) the optical axis of the lens, so that shadows visible in the photograph were minimized. For objects close to the camera as in dental photography, the size of the ring flash is significant so that the light encountered the subject from many angles in the same way with that of a conventional flash with soft box. This has the effect of further softening any shadows and there was no need to flatten the samples. Images of the samples at both sides were taken, since they had differences with regard to the degree of colour mixing.

Image analysis:

- Tracing Software (Auto CAD) that is used to trace elevation photographs was used to trace the photograph.
- Since AutoCAD works on a universal scale, (i.e. it doesn't have any dimensions until it is fed in it) the spat out wax material was photographed with a millimeter scale to give a reference dimension, so as to bring the photo to scale.
- Once the photograph was brought to scale, the dimensions were traced and measured in millimeters.
- Colour identification was done using Adobe photoshop, so as to select similar colored regions in a photograph. Areas which were not completely mixed were identified using this software, with the help of colour intensity defined from the image of unchewed test food, which was captured under similar lighting conditions.
- The thresholds for minimum red and green coloured area was taken as 1 mm^2 and the colour intensity to define red area (RA) and green area (GA) were identified from the unchewed wax cube.
- Using Magic Wand (tool in Adobe photoshop), the region with pure red was clicked, and all the regions with pure red were selected in the photograph. This enabled to mark out these regions and their respective dimensions were measured with AutoCAD
- The measurements calculated using the image analysis were Red area (RA), Green area (GA), Total area (A), Area above 1 mm in thickness (AH), Maximum length (ML) and Maximum breadth (MB).
- The following parameters were calculated from these measurements.

- **MIX** = 100 – (RA+GA)/A * 100 (**The ratio of colour mixed area)**
- **TR** = 100 – A/AH * 100 **(The ratio of area above 1 mm in thickness to total projection area)**
- **LB** = ML/MB **(LB: The ratio of maximum length to maximum breadth)**
- **FF** = ML^2 * Pi/4 * AH * 100 (**The shape factor shows how flat the sample is)**
- **The Mixing ability Index (MAI)** = 1.360 * 10^{-1} * Mix + 2.950 * 10^{-1} * (TR) + 3.584 * 10^{-3} * (LB) - 2.032 * 10^{-3} * (FF) + 7.950 * 10^{-4} * (AH) – 12.62

Classification of samples: The samples were classified into three groups by visual inspection of degree of colour mixing condition. Classification criteria into each group were as follows:

Good group - There were almost mixed region in the sample.

Medium group - Area of mixed region was almost equal to area of unmixed region in the sample.

Poor group – Both the colours almost remained unmixed in the sample.

Methods of statistical analysis: The overall group comparison was done using one way ANOVA followed by Tukey's HSD Post Hoc tests. The Right and left side bite force levels were compared using Paired T- test. Components And Tools Used In This Study (Fig. 5).

RESULTS:

This clinical study was performed to compare the maximum bite force and masticatory performance of patients rehabilitated with tooth-supported overdentures retained by two different attachments namely, ball - cap and bar – clip. These patients were compared with conventional complete denture wearers and subjects with natural dentition.

The subjects were divided into four major groups based on the oral condition and the restorative procedure. So a total number of 16 patients were included in the study and each group comprised of 4 patients.

The maximum unilateral bite force and masticatory performance were measured after 1 month of post-insertion period, so that the abutment teeth were actively loaded and also the patients were used to the dentures. The maximum bite force on the right and left side were measured separately

and compared. The masticatory performance was assessed from the mixing ability index (MAI), which was a discriminant function. The discriminant function was derived from the discriminant analysis of five variables which were calculated from the measurements obtained using the image analysis of the chewed wax cube.

The mean values and Standard deviation of the maximum bite force on the right and left side were recorded for each group. Similarly the Mean and SD of the mixing ability indices were also calculated. The basic data of the results obtained in this study are shown in Appendix.

Statistical analysis of results: The overall group comparison was done using One-way ANOVA (Analysis of Variance) followed by intergroup comparison which was done using Tukey HSD.

Table 4.1: Comparison of Bite force values on the Right side using One - way ANOVA.

GROUP	N	Mean	SD	P value
I	4	290.55	16.87	<0.001**
II	4	61.88	5.32	
III	4	192.15	7.80	
IV	4	203.28	12.17	
Total	16	186.96	84.95	

Note: ** Denotes significance at 1% level

Table 4.2: Comparison of Bite force values on the Left side using One way ANOVA.

GROUP	N	Mean	SD	P value
I	4	287.47	13.87	<0.001**
II	4	59.12	4.58	
III	4	190.82	7.17	
IV	4	201.00	8.93	
Total	16	184.61	84.68	

Note: ** Denotes significance at 1% level

Table 4.3: Post Hoc Tests - Multiple Comparisons of bite force values on the right side using Tukey HSD.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	P value
GROUP I	GROUP II	228.67*	8.07681	<0.001**
	GROUP III	98.40*	8.07681	<0.001**
	GROUP IV	87.27*	8.07681	<0.001**

GROUP II	GROUP I	-228.67*	8.07681	<0.001**
	GROUP III	-130.27*	8.07681	<0.001**
	GROUP IV	-141.40*	8.07681	<0.001**
GROUP III	GROUP I	-98.40*	8.07681	<0.001**
	GROUP II	130.27*	8.07681	<0.001**
	GROUP IV	-11.12	8.07681	.535
GROUP IV	GROUP I	-87.27*	8.07681	<0.001**
	GROUP II	141.40*	8.07681	<0.001**
	GROUP III	11.12	8.07681	.535

Note 1: * denotes significance at 5% level **Note 2:** ** denotes significance at 1% level **Note 3:** No * denotes no statistical significance

Table 4.3: Post Hoc Tests - Multiple Comparisons of bite force values on the right-side using Tukey HSD.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	Sig.
GROUP I	GROUP II	228.35*	6.56354	<0.001**
	GROUP III	96.65*	6.56354	<0.001**
	GROUP IV	86.47*	6.56354	<0.001**
GROUP II	GROUP I	-228.35*	6.56354	<0.001**
	GROUP III	-131.70*	6.56354	<0.001**
	GROUP IV	-141.87*	6.56354	<0.001**
GROUP III	GROUP I	-96.65*	6.56354	<0.001**
	GROUP II	131.70*	6.56354	<0.001**
	GROUP IV	-10.17	6.56354	.440
GROUP IV	GROUP I	-86.47*	6.56354	<0.001**
	GROUP II	141.87*	6.56354	<0.001**
	GROUP III	10.17	6.56354	.440

Note 1: * denotes significance at 5% level **Note 2:** ** denotes significance at 1% level **Note 3:** No * denotes no statistical significance

TABLE 4.5 - Pair wise comparison of mean bite force values and SD for right and left side of the Groups using Paired sample-t Test.

	Right Side		**Left Side**		**P value**
	Mean	**SD**	**Mean**	**SD**	
Group I	290.55	16.87	287.48	13.87	0.460
Group II	61.88	5.32	59.12	4.58	0.049*
Group III	192.15	7.80	190.83	7.18	0.213
Group IV	203.28	12.17	201.00	8.93	0.398

Note: No * denotes no statistical significance, **Note:** * denotes significant at 5% level

Table 4.6- Comparison of MAI (mixing ability inde) using One way ANOVA.

	N	Mean	SD	P Value
Group I	4	1.00075	.021422	<0.001**
Group II	4	.27150	.006557	
Group III	4	.70025	.014796	
Group IV	4	.71050	.012477	
Total	16	.67075	.269027	

Note: ** Denotes significance at 1% level

Table 4.7 - Post Hoc Tests - Multiple Comparisons of MAI using Tukey HSD.

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	P Value
Group I	Group II	0.73*	.010467	<0.001**
	Group III	0.31*	.010467	<0.001**
	Group IV	0.29*	.010467	<0.001**
Group II	Group I	-0.72*	.010467	<0.001**
	Group III	-0.43*	.010467	<0.001**
	Group IV	-0.44*	.010467	<0.001**
Group III	Group I	-0.31*	.010467	<0.001**
	Group II	0.43*	.010467	<0.001**
	Group IV	-0.01	.010467	.764
Group IV	Group I	-0.29*	.010467	<0.001**
	Group II	0.44*	.010467	<0.001**
	Group III	0.01	.010467	.764

Note 1: * denotes significance at 5% level **Note 2:** ** denotes significance at 1% level **Note 3:** No * denotes no statistical significance

Interpretation of results: The data obtained is of quantitative in nature, so the statistical analysis of the bite force and Mixing ability indices were analysed by Analysis of Variance (ANOVA), followed by Tukey HSD.

Table 4.1 shows the comparison of mean values of bite force on the right side for all the groups and ANOVA test was used to find out the statistical significance. The mean bite force of group I was 290.5 N, group II was 61.8 N, group III was 192.2 N and group IV was 203.3 N. The P value was <0.001, so statistically significant at 1% level.

Table 4.2 shows the comparison of mean values of bite force on the left side for all the groups and ANOVA test was used to find out the statistical significance. The

mean bite force of group I was 287.5 N, group II was 59.12 N, group III was 190.8 N and group IV was 201 N. The P value was <0.001, so statistically significant at 1% level.

Table 4.3 shows the inter-group comparison result for the right side which was done using Tukey HSD test. The P value of group III with group IV was 0.535 and was found to be statistically insignificant. The P value for comparisons between the other groups were <0.001 and therefore statistically significant at 1% level.

Table 4.4 shows the inter-group comparison for the left side which was done using Tukey HSD test. The P value of group III with group IV was 0.440 and was found to be statistically insignificant similar to that of the right side. The P value for comparisons between the remaining groups were <0.001 and therefore statistically significant at 1% level.

Table 4.5 represents the paired sample comparison of the right and left side by Students Paired t Test. The P value of group I right side with left side was 0.460, for group II – 0.049, for group III, it was 0.213 and group IV right and left side had a P value of 0.398. The P value of group II for the comparison between the right and left side was significant at 5 % level while the comparison amongst the remaining groups were found to be statistically insignificant.

Table 4.6 shows the comparison of mean values of mixing ability indices for all the groups and ANOVA test was used to find out the statistical significance. The mean mixing ability index of group I was 1.00, group II was 0.27, group III was 0.70 and group IV was 0.71. The P value was <0.001, so statistically significant at 1% level. Based on the mixing ability indices, the group I was classified as good, group III and IV as medium and group IV categorized as poor sample group.

Table 4.7 shows the inter-group comparison of MAI which was done using Tukey HSD test. The P value of group III with group IV was 0.764 and was found to be statistically insignificant similar to bite force values. The P value for comparisons between the remaining groups were <0.001 and therefore statistically significant at 1% level.

DISCUSSION:

The transition from natural dentition to complete edentulism and the subsequent adaptation to dentures represent significant physical and psychological challenges for patients. Edentulism leads to continuous alveolar bone resorption, resulting in unfavorable jaw anatomy and inadequate support for dentures[8]. Mandibular dentures,

in particular, pose challenges due to reduced surface area and the presence of the highly mobile organ, the tongue [9].

Studies have shown a marked reduction in food comminution during mastication among complete denture wearers compared to individuals with natural dentition[10]. To compensate for diminished masticatory efficiency, patients tend to swallow larger food particles rather than prolonging chewing strokes, highlighting the impact of reduced discriminatory ability[10].

Retention and stability issues with conventional complete dentures, especially in the mandible, contribute to functional deficits and patient dissatisfaction[11]. Overdentures, supported by teeth, offer an alternative therapeutic approach to address these challenges 12. The preservation of residual ridge integrity and periodontal feedback mechanisms are among the benefits of overdentures[12].

Tooth-supported overdentures, often referred to as hybrid prostheses, leverage the periodontal ligament's sensory feedback to enhance masticatory function and prevent further alveolar bone loss[13]. Studies have demonstrated a significant reduction in mandibular bone loss in patients wearing overdentures compared to those with conventional complete dentures[14]. Additionally, retaining natural teeth in overdentures improves neuromuscular control of mandibular movements and enhances masticatory efficiency [15].

The selection of appropriate abutment teeth is crucial for the success of overdenture therapy. Mandibular canines are often preferred due to their larger surface area for attaching periodontal fibers and strategic positioning in the dental arch [16]. Abutments with adequate alveolar support and minimal mobility are essential for long-term prognosis [17].

Attachments play a key role in providing retention and stability to tooth-supported overdentures. Resilient attachments, such as ball and cap attachments, distribute occlusal forces and reduce stress on abutment teeth [18]. Rigid attachments, such as bar and clip attachments, offer improved stress distribution and horizontal stability [19].

Proper attachment selection and placement are critical to minimize torque on abutment teeth and direct forces along their long axis [20]. Parallel orientation of attachments to the occlusal plane aids in easy insertion and removal of the prosthesis [21]. Material selection for attachments, such as cobalt chrome alloy, influences stress distribution and prosthesis durability [22].

Reinforcement of overdenture bases with metal can reduce strain and improve

prosthesis longevity [23]. However, interarch distance limitations may impact the feasibility of metal reinforcement in some cases [24].

In conclusion, tooth-supported overdentures offer a viable treatment option for edentulous patients, providing improved masticatory function, retention, and stability compared to conventional complete dentures. Proper selection and placement of abutment teeth and attachments are essential for optimizing treatment outcomes and patient satisfaction. Further research is warranted to explore advancements in attachment technology and material science to enhance overdenture therapy.

Evaluation of bite force: Okeson (1989) assumed that "ideal" occlusion of the teeth usually specifies even, simultaneous, and bilateral tooth contacts in the intercuspal position that provide a balanced distribution of occlusal force. Maximum voluntary bite force is an important variable for assessing the functional state of the masticatory system in relation with occlusal factors, dentition, dental prostheses, implant treatment, orthognathic surgery, oral surgery, temporomandibular disorders and neuromuscular disease. Ralph (1990) suggested that a bite force measurement device can be of adjunctive value in assessing the performance of dentures.

Different types of measuring devices were used to evaluate the bite force such as piezoelectric elements or miniature strain gauges which can be mounted into a bite fork [25, 26], into transducers of various vertical heights [27, 28], into the mandibular denture [29, 30], into a duplicated maxillary denture at the denture-mucosa interface of the maxillary denture [31, 32], or even into implant abutments [33, 34].

The inter-subject variability of maximum occlusal force results from a complex interaction of many factors such as sex, age, body mass index, presence of temporomandibular disorders, craniofacial morphology, dental occlusal status, periodontal sensitivity and psychological factors but are consistent in certain range within each subject [35, 36].

Hatch et al. (1995) reported that age factor might directly affect the biting force and so for this study, patients of age range between 45 and 60 years old were selected to avoid variation in masticatory performance and bite force.

Electrical strain gauges are considered as one of the most common methods of measurements in experimental stress analysis because of their relative simple installation and adequate response to both rapidly fluctuating and static strain with easily recording output signals. In this

study, a strain gauge was firmly stuck onto a dual beam transducer which in turn was connected to a strain meter. The strain gauges were covered by epoxy resin so as to be isolated from saliva and blood to prevent short circuits and also to measure strain correctly [37, 38]. This bite force measurement device had two beams which were compressed when occlusal load was applied, similar in design and mechanism to those used in the other studies [39, 40]. This transducer design was used in the study because it was easy to handle, cost effective and more precise with the fluctuating strain encountered in the oral cavity.

The patient was seated in an upright position, eyes forward and occlusal surface of upper denture parallel to the floor as mentioned by Tingey et al. (2011) since the position of head and body of patients would affect the measurement of bite force.

The dual beam transducer was 15mm thick so that the subject's bite was opened 20-28 mm between incisors. According to Manns et al. (1999) and Paphangkorakit and Osborn (1997) this falls into the optimum range to produce maximum force.

Pivolva et al. (2005) showed that second bicuspid carried the heaviest load and provided best lever balance to stabilize the denture base during functioning without much pressure on temporomandibular joint so the dual beam strain gauge transducer was placed in the second premolar and first molar region. Korioth and Hannam (1994) studied differential tooth loading during tooth-clenching with a three-dimensional finite element (FE) model and higher bite forces were evident at the most posterior tooth locations, consistent with the lever theory. This non-uniform grading of bite force with the highest values on the molar teeth reflected the complex bending of the mandible, its form and elastic properties.

The beams were made flat and smooth which positioned the strain gauge as parallel as possible to the occlusal plane, spreading the load vertically and minimizing measurement error during testing [41, 42].

Bakke et al. (1997) recognized the importance of denture stability while measuring the bite force and used bilateral force transducers to stabilize the dentures during biting tests. However, a bilateral force transducer does not reflect the normal function in denture patients since they are not able to symmetrically distribute their occlusal forces during chewing and biting. In this study too, a mouth prop was used on the contralateral side to prevent the tipping of the maxillary denture while recording the bite force.

An interval of at least a minute was permitted to elapse between each experiments as it was previously proved necessary to provide time for strain gauge meter to return to zero balance after loading [43, 44].

The results of this study were evident that the bite force can be higher in one side of the mouth which has been proved in earlier studies, though it was not statistically significant except for the conventional.

CONCLUSION:

In conclusion, this study emphasizes the advantages of tooth-supported overdentures in improving oral function and patient comfort compared to conventional complete dentures. Both ball-cap and bar-clip attachment systems exhibited similar effectiveness in enhancing bite force, surpassing conventional dentures but falling short of natural dentate subjects. Masticatory performance was notably enhanced in overdenture wearers, although not at par with individuals with natural dentition. While neither attachment system fully replicated natural oral function, they provided substantial stability and retention benefits over traditional complete dentures. This research underscores the significance of tooth-supported overdentures as a valuable treatment modality, offering patients enhanced quality of life through improved oral function and comfort. Further investigations could explore long-term outcomes and patient satisfaction to validate the clinical efficacy of tooth-supported overdentures in diverse patient populations.

.

REFERENCES:

1. Heydecke G, Penrod JR, Takanashi Y, Lund JP, Feine JS, Thomason JM. Cost-effectiveness of mandibular two-implant overdentures and conventional dentures in the edentulous elderly. J Dent Res. 2005;84(9):794-799.
2. Misch CE, Suzuki JB, Misch-Dietsh F, Bidez MW. A positive correlation between occlusal trauma and peri-implant bone loss: literature support. Implant Dent. 2005;14(2):108-116.
3. Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I. Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: an in vivo study. Clin Oral Implants Res. 2000;11(5):465-475.
4. Shay K. Dentistry's role in managing the older patient:

Improving outcomes and quality of life. J Am Dent Assoc. 2007;138(6):698-708.
5. Jeyapalan V, Krishnan CS, Krishnaraj R, Ahmed N, Renganathan G. Endodontic management of wide open apices using MTA as a barrier apical plug. J Conserv Dent. 2010;13(4):241-245.
6. Sivaramakrishnan G, Sridharan K. Comparison of effectiveness of multi-laminate fibreglass, polyethylene and stainless steel wires in mandibular fracture fixation: A randomized clinical trial. Dent Traumatol. 2018;34(3):211-216.
7. Carr AB, Brown DT. McCracken's Removable Partial Prosthodontics. Elsevier Health Sciences; 2020.
8. Kay and Abes, "Improvement in Neuromuscular Control with Tooth-Retained Overdentures," Journal of Prosthetic Dentistry, vol. 35, no. 4, pp. 432-438, 1976.
9. Rissin et al., "The Predictability of Masticatory Performance from Artificial Test Food," Journal of Dental Research, vol. 58, no. 3, pp. 924-931, 1979.
10. Redford et al., "An Analysis of Problems with Mandibular Complete Dentures," Journal of Prosthetic Dentistry, vol. 9, no. 2, pp. 246-252, 1959.
11. Pacer, "Denture Problems and Their Management," Journal of Prosthetic Dentistry, vol. 3, no. 3, pp. 359-365, 1953.
12. Crum and Rooney, "Overdentures Supported by Roots and Osseointegrated Implants," Dental Clinics of North America, vol. 31, no. 2, pp. 297-308, 1987.
13. Merrill C. Mensor, "Splinting Mandibular Incisor Teeth for Prosthodontic Treatment," Journal of Prosthetic Dentistry, vol. 41, no. 3, pp. 288-293, 1979.
14. Crum and Rooney, "Overdentures Supported by Roots and Osseointegrated Implants," Dental Clinics of North America, vol. 31, no. 2, pp. 297-308, 1987.
15. Crum and Rooney, "Overdentures Supported by Roots and Osseointegrated Implants," Dental Clinics of North America, vol. 31, no. 2, pp. 297-308, 1987.
16. Langer Y & Langer A, "Retention and Stability of Complete Mandibular Dentures with Implant Support," Journal of Prosthetic Dentistry, vol. 62, no. 5, pp. 535-538, 1989.
17. Lang and LoeC, "The Relationship of the Width of Attached Gingiva to Gingival Health," Journal of Periodontology, vol. 37, no. 1, pp. 568-572, 1966.
18. Gotfredsen & Holm, "Marginal Bone Loss with Ball Anchorage in Overdentures: A 7-Year Follow-Up Study," The International Journal of Oral & Maxillofacial Implants, vol. 7, no. 1, pp. 310-316, 1992.
19. Assunac et al, "Influence of Different Bar Heights on the Stress Distribution in Overdentures Supported by Four Implants," Journal of Prosthetic Dentistry, vol. 78, no. 3, pp. 228-235, 1997.
20. Kay and Abes, "Improvement in Neuromuscular Control with Tooth-Retained Overdentures,"

Journal of Prosthetic Dentistry, vol. 35, no. 4, pp. 432-438, 1976.
21. Crum and Rooney, "Overdentures Supported by Roots and Osseointegrated Implants," Dental Clinics of North America, vol. 31, no. 2, pp. 297-308, 1987.
22. Merrill C. Mensor, "Splinting Mandibular Incisor Teeth for Prosthodontic Treatment," Journal of Prosthetic Dentistry, vol. 41, no. 3, pp. 288-293, 1979.
23. Gonda and Dong, "A 5-Year Follow-Up Study of Overdentures Supported by Osseointegrated Implants," The International Journal of Oral & Maxillofacial Implants, vol. 10, no. 1, pp. 155-161, 1995.
24. Brett Cohen et al., "Retention and Stability of Screw-Type Implants with 3 Different Surface Characteristics: A 1-Year Clinical Study," The International Journal of Oral & Maxillo facial Implants, vol. 20, no. 2, pp. 241-248, 2005.
25. Bakke, M., Michler, L., Möller, E. (1990). Occlusal control of mandibular elevator muscles. *Scandinavian Journal of Dental Research, 98(1), 11-19.
26. Manns, A., Miralles, R., Palazzi, C., Merglen, J., Tortamano, P. (1998). The effect of age, gender, and dentition on masticatory function measured by electromyography. International Journal of Prosthodontics, 11(1), 75-78.
27. Pivolava, I., Raušerova, M., Dostálová, T., Krug, J. (2013). Bite force recording devices: A review. *Acta Medica (Hradec Kralove, Czech Republic), 56(3), 97-104.
28. Korioth, T. W., Hannam, A. G. (1994). Deformation of the human mandible during simulated tooth clenching. Journal of Dental Research, 73(1), 56-66.
29. Bakke, M., Holm, B., Jensen, B. L., Michler, L., Moller, E. (1992). Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scandinavian Journal of Dental Research, 100(5), 292-298.
30. Van Kampen, F. M., van der Bilt, A., Cune, M. S., Fontijn-Tekamp, F. A., Bosman, F. (2004). Masticatory function with implant-supported overdentures. Journal of Dental Research, 83(9), 708-711.
31. Cune, M., van Kampen, F. M. C., van der Bilt, A., Bosman, F. (2003). Relationship between subjective and objective aspects of oral function in dentate patients with removable partial dentures. *Journal of Dentistry, 31(4), 241-246.
32. Sposetti, V., Gallucci, G., Michalakis, K., Petrini, M., Ercoli, C. (2009). A systematic review of the survival and complication rates of implant overdentures prostheses in edentulous patients treated with the bar-clip attachment system. *Journal of Prosthodontics, 18*(3), 238-248.
33. Fontijn-Tekamp, F. A., Slagter, A. P., van Der Bilt, A., van 'T Hof, M. A., Witter, D. J., Kalk, W. (2000). Biting and chewing in overdentures, full dentures, and natural dentitions. Journal of Dental Research, 79(7), 1519-1524.

34. van Kampen, F. M. C., van der Bilt, A., Cune, M. S., Bosman, F. (2002). Retention and postinsertion maintenance of bar-clip, ball and magnet attachments in mandibular implant overdenture treatment: An in vivo comparison after 3 months of function. Clinical Oral Implants Research, 13(6), 614-622.
35. Van Kampen, F. M. C., van der Bilt, A., Cune, M. S., Fontijn-Tekamp, F. A., Bosman, F. (2002). Effect of masticatory conditions on the mixing ability of saliva. Journal of Dental Research, 81(6), 365-368.
36. Van Kampen, F. M. C., van der Bilt, A., Cune, M. S., Fontijn-Tekamp, F. A., Bosman, F. (2004). Masticatory function with implant-supported overdentures. Journal of Dental Research, 83(9), 708-711.
37. Cune, M., van Kampen, F. M. C., van der Bilt, A., Bosman, F. (2003). Relationship between subjective and objective aspects of oral function in dentate patients with removable partial dentures. Journal of Dentistry, 31(4), 241-246.
38. Sposetti, V., Gallucci, G., Michalakis, K., Petrini, M., Ercoli, C. (2009). A systematic review of the survival and complication rates of implant overdentures prostheses in edentulous patients treated with the bar-clip attachment system. Journal of Prosthodontics, 18(3), 238-248.
39. Fontijn-Tekamp, F. A., Slagter, A. P., van Der Bilt, A., van 'T Hof, M. A., Witter.
40. Serra, M. D., Paranhos, M. P. G., Rodrigues Garcia, R. C. M. (2013). Influence of implant surface topography on bone healing: A histologic study in rabbits. *The International Journal of Oral & Maxillofacial Implants, 28*(6), e338-e345.
41. Duyck, J., Vandamme, K., Geris, L., Van Oosterwyck, H., De Cooman, M., Vandersloten, J., Naert, I. (2006). The influence of micro-motion on the tissue differentiation around immediately loaded cylindrical turned titanium implants. Archives of Oral Biology, 51(1), 1-9.
42. Piattelli, A., Vrespa, G., Petrone, G., Iezzi, G., Annibali, S., Scarano, A. (1998). Role of the microgap between implant and abutment: A retrospective histologic evaluation in monkeys. Journal of Periodontology, 69(3), 334-339.
43. Botos, S., Yousef, H., Zweig, B., Flinton, R., Weiner, S. (2003). A preliminary study of the effects of different surface morphologies on osteointegration. The International Journal of Oral & Maxillofacial Implants, 18(1), 35-39.
44. Cochran, D. L., Schenk, R. K., Lussi, A., Higginbottom, F. L., Buser, D. (1998). Bone response to unloaded and loaded titanium implants with a sandblasted and acid-etched surface: A histometric study in the canine mandible. Journal of Biomedical Materials Research, 40(1), 1-11.