Original Article

Comparative evaluation of biting force and chewing efficiency of all-on-four treatment concept with other treatment modalities in completely edentulous individuals

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Abstract

Aim: To compare and evaluate biting force and chewing efficiency of all-on-four treatment concept, implant-supported overdenture, and conventional complete denture.

Settings and Design: Invivo – comparative study.

Materials and Methods: A total of 12 edentulous patients were included in the study and conventional complete dentures were fabricated. Patients were divided into two groups. In Group 1, complete dentures were replaced with implant-supported overdenture, and in Group 2, complete dentures were replaced with hybrid denture supported by all-on-four treatment concept. The biting force was assessed using a bite force sensor and electromyographic recordings were made by electromyogram for masticatory muscles when chewing three different consistencies of foods.

Statistical Analysis Used: The data was statistically analyzed using software SPSS version 22.0. Paired t-test was used for intra-group comparison and unpaired t-test was used for intergroup comparison.

Results: The difference in biting force and chewing efficiency for all-on-four treatment concept was statistically significant for overdenture and complete denture. The highest biting force and chewing efficiency were observed for all-on-four treatment concept, followed by implant-supported overdenture and complete denture.

Conclusion: The study concluded that the completely edentulous individuals with atrophic posterior alveolar ridges can be rehabilitated successfully with improved biting force and chewing efficiency by All-on-four treatment concept.

Keywords: All-on-four treatment concept, biting force, chewing efficiency, complete denture, overdenture

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INTRODUCTION

Tooth loss not only deteriorates oral function which includes mastication, swallowing, and speech but also adversely affects the self-esteem of individual by ruining esthetics.[1] Earlier complete denture was the only option available for rehabilitation of completely edentulous individuals, but over the period of time, treatment modalities have evolved.

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The rehabilitation of conventional complete denture wearers, no matter how perfectly done, could not completely solve their problems, either of functional and psychological. Complete denture wearer show a lower chewing efficiency in comparison to dentate controls.[2] The same functional impairment applies to maximum bite force, which was described to be 5–6 times lower than the dentate controls.[3] Complete denture wearers complained about the decreased retention, instability of prosthesis, decreased satisfaction, and reduced masticatory efficiency.[4]

With the evolution in dental advancement techniques, introduction of dental implants, together has revolutionalized the prosthodontics field. It has improved the overall oral function and solved the problem of denture instability. It has provided various options for the treatment of edentulous individuals from removable prosthesis to fixed prosthesis including implant-supported overdenture and ceramometal or hybrid prosthesis, respectively.

In highly resorbed ridges where adequate bone is available in the intraforaminal region of the mandible and in the premaxillary region of the maxilla, newer technique "All-on-Four" has been introduced by Malo *et al*.[5,6] This all-on-four treatment concept involves anteriorly placed two axially straight implants and posteriorly placed two tilted implants which are angled from 30° to 45° to retain a full-arch fixed prosthesis.[5,6]

Every treatment modality has its own specific clinical indication with different prognostic results. The results are defined by the masticatory performance, chewing efficiency, patient's satisfaction, and improvement in quality of life.[7-10] Various methods have been used to assess the efficiency of masticatory system, including the measurement of bite force and masticatory efficiency.[11] The results of some previous investigations showed a linear relationship between electromyographic activity potentials and direct bite force measurements.[12]

MATERIALS AND METHODS

This clinical study was undertaken in the Department of Prosthodontics, Crown and Bridge and Implantology, Faculty of Dental sciences, Varanasi, India. The approval for ethical clearance was obtained from the university ethical committee. ECR/Bhu/Inst/2013/Re-registeration-2017dt 31.01.2017. No. Dean/2018/EC/371.

Patient selection

A total of 12 patients were randomly selected, irrespective of gender, caste, religion, and creed for complete denture fabrication for the study following the inclusion and exclusion criteria. Six patients were selected in each group, where Group 1 included the patients with edentulous ridges and Group 2 included the edentulous patients with deficient bone in the posterior region. The adequate bone was present in the premaxilla region of the maxilla and the intraforaminal region of the mandible. In Group 1, edentulous patients were first rehabilitated with complete denture as baseline treatment, and after 1 month, bite force and electromyographic recordings were assessed and later complete dentures were replaced with implant-supported overdenture (2 implants are placed in the B and D region of the mandible, opposing complete denture in the maxillary arch). In Group 2, individuals were initially rehabilitated with conventional denture as baseline treatment, and after 1 month, bite force and electromyographic recordings were assessed and later complete dentures were replaced with all-on-four treatment. The average age of Group 1 was 55.83 years and Group 2 was 52.6 years.

Criteria for selection of cases

Inclusion criteria are shown in Table 1.

Exclusion criteria

1. History of metabolic or systemic disease affecting the osseointegration
2. Recent history of irradiation in the head and neck region
3. Smokers
4. Active infection, cyst, or tumor
5. Psychiatric disorders or unrealistic expectations.

Methodology

Each patient was explained in detail and written informed consent was obtained. As a standard protocol, initially, all patients received conventional complete denture with bilateral balanced occlusion as prosthesis for evaluation of biting force and electromyographic records. In Group 1 individuals, implant placement was done with respect to canine region bilaterally in the mandibular arch and implant-supported overdenture was installed as final prosthesis [Figure 1]. The biting force was assessed using

Table 1: Inclusion criteria

Overdenture	All-on-four
Completely edentulous patient	Completely edentulous patient
Absence of local infection	Absence of local infection
Absence of oral mucosal disease	Absence of oral mucosal disease
Medical fitness for surgery	Medical fitness for surgery
Controlled diabetes, no systemic disease	Controlled diabetes, no systemic disease
Written consent	Written consent
	Atrophic ridges posteriorly with adequate bone present in premaxillary region of maxilla and intraforaminal region of mandible

a bite force sensor (Bite Force Sensor, Hariom electronics, Vadodara, Gujarat, India) and masticatory muscle activity was measured using electromyogram. In Group 2, implant placement was done according to all-on-four treatment concept and hybrid denture as final definite prosthesis [Figure 2]. The biting force and electromyographic readings were recorded for final prosthesis, i.e., overdenture in Group 1 and hybrid denture in Group 2.

Biting force was measured using an electromechanical device which works on strain gauge-based Wheatstone bridge principle. The device consists of display unit and sensing probe [Figure 3]. The sensor is connected to the display unit which shows numerical values as a unit of measurement (Newton, KG or lb) set by the manufacturer. When sensing probes are placed between the occluding surfaces of dentition, deflections between the sensing probes of sensor give reading to the display unit which shows reading in mathematical units (Newton, Kg or lbs). The range of measurement of the device is 0–2500 Newton. The accuracy of bite force sensor used is ± 0.05% of its rated capacity.

The chewing efficiency was measured by an electromyographic study. The electromyographic study was conducted on masseter, temporalis, and anterior digastric muscle bilaterally, i.e., right and left side. The individuals were given food in three different consistencies which included soft-consistency food, medium-consistency food, and hard-consistency food as banana, apple, and peanuts, respectively. This device consists of electromyography (EMG) device, three electrodes, and one display unit [Figure 4], and two electrodes are positioned on the skin of the concerned muscle. The third electrode is the reference electrode placed on the forehead. The display unit displays recordings in waveform.

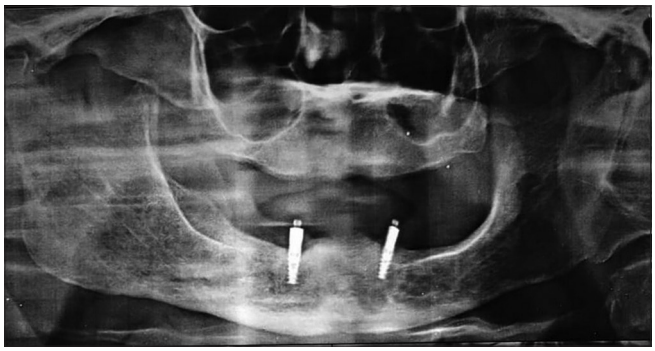


Figure 1: Orthopantomogram (overdenture)

Figure 3: Bite force measuring device

Bite force measurement

The patient was asked to sit in the upright position with no headrest. Disposable sheet was wrapped on the sensing probes which were covered with 1-mm sponge sheet by double-sided adhesive tapes and the patient was instructed to bite right and left side thrice with maximum force at an interval of 2 min. Biting force was recorded by placing probes in between the occluding surfaces of maxillary and mandibular molars and the patient was asked to bite voluntarily with maximum force. The biting force was displayed in Newton on the display unit [Figure 5]. The biting force was recorded bilaterally, i.e., right side and left side separately. Three readings were recorded at an interval of 2 min and their average was calculated.

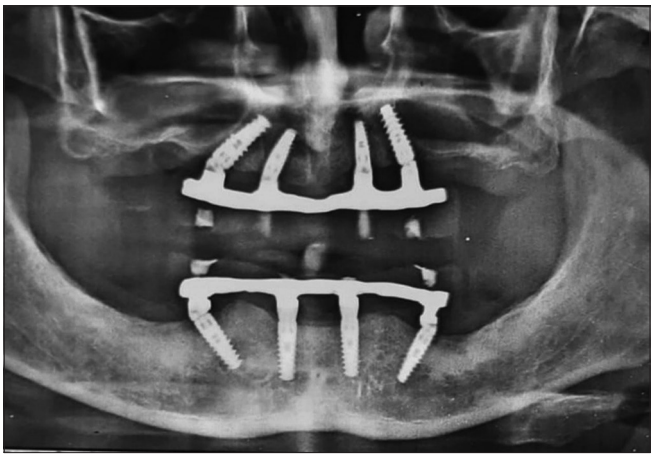


Figure 2: Orthopantomogram (all-on-four)

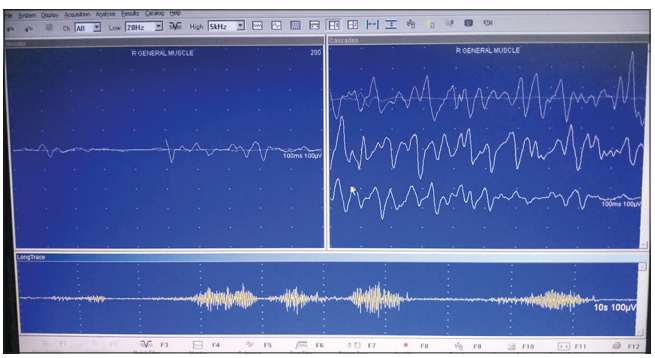


Figure 4: Electromyographic presentation

Electromyographic recordings

The EMG was recorded using computerized surface EMG (Synergy EMG-System, Arena medical care private limited, New Delhi, India).

The patient was asked to sit in the upright position with no headrest. EMG recording was conducted in a calm and silent room. Electromyogram was used to perform surface electromyographic study of masseter, temporalis, and anterior digastric muscle. The patient's skin was wiped with 70% alcohol to reduce the impedance between the skin and the electrode. The electrode gel was applied on electrodes before placing on the skin and fixed there by using white tape. The three electrodes were used. The two electrodes were placed 2–3 mm away from each other along the muscle length. The surface electrodes were positioned in the direction of the fiber bundles of masseter, temporalis, and anterior digastric muscles. The third electrode was placed as the reference electrode on patient's forehead. The patient was given food materials: banana as soft-consistency food, apple as medium-consistency food, and peanuts as hard-consistency food. The recordings were made with right and left masseter, temporalis, and digastric muscles, respectively. The recordings were displayed on monitor in waveform. The maximum amplitude was calculated by counting peaks in microvolts [Figure 6].

Statistical analysis

All the data obtained were statistically analyzed using Statistical Package for the Social Sciences version 22.0. Intragroup comparison of biting force and chewing efficiency of masticatory muscles for the right and left side for Group 1 (complete denture and overdenture individuals) and Group 2 (complete denture and all-on-four individuals) was analyzed using paired *t*-test. Intergroup comparison of biting force and chewing efficiency of masticatory muscles for the right and left side between Group 1 (complete denture and overdenture individuals) and Group 2 (complete denture and all-on-four individuals) was analyzed using unpaired *t*-test.

RESULTS AND OBSERVATIONS

The biting force of hybrid denture supported by all-on-four treatment concept was significantly highest followed by overdenture and complete denture, respectively [Tables 2-4 and Graphs 1-3].

The chewing efficiency was significantly highest for hybrid denture supported by all-on-four treatment concept followed by overdenture and complete denture,

Table 2: Intragroup comparison of biting force within Group 1

Side	Prosthesis	Mean±SD (Newton)	*P*
Right	Complete denture	25.00±14.18	0.001
	Overdenture	78.50±12.15	
Left	Complete denture	25.33±12.40	0.001
	Overdenture	82.00±23.97	

SD: Standard deviation

Table 3: Intragroup comparison of biting force within Group 2

Side	Prosthesis	Mean±SD (Newton)	*P*
Right	Complete denture	51.17±24.57	0.008
	All-on-four	219.17±117.35	
Left	Complete denture	55.67±28.66	0.002
	All-on-four	209.33±84.80	

SD: Standard deviation

Table 4: Intergroup comparison of biting force for Group 1 and Group 2

Side	Prosthesis	Mean±SD (Newton)	*P*
Right	Overdenture	78.50±22.15	0.016
	All-on-four	219.16±117.35	
Left	Overdenture	82.00±23.97	0.005
	All-on-four	209.33±84.80	

SD: Standard deviation

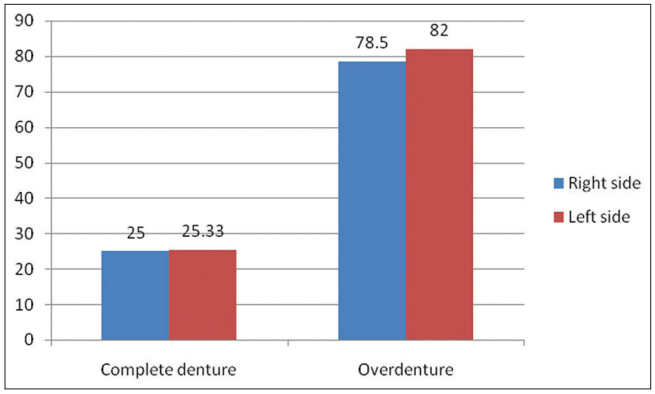
Figure 5: Bite force recording

Figure 6: Electromyographic recording

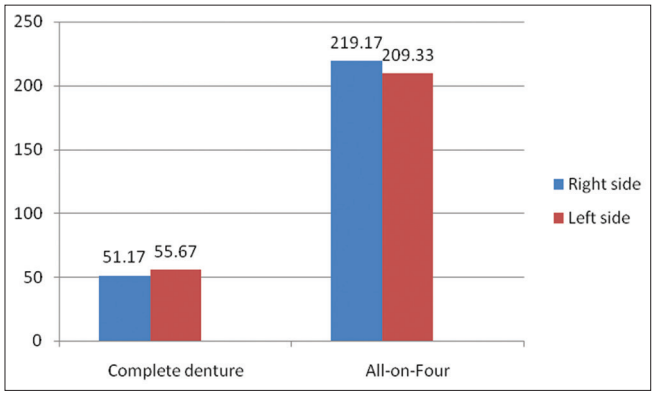
respectively [Tables 5-7 and Graphs 4-6]. The study has shown the highest chewing efficiency for masseter muscles compared to temporalis and digastric muscles. The higher chewing efficiency was observed in hard-consistency food as compared to medium- and soft-consistency food.

DISCUSSION

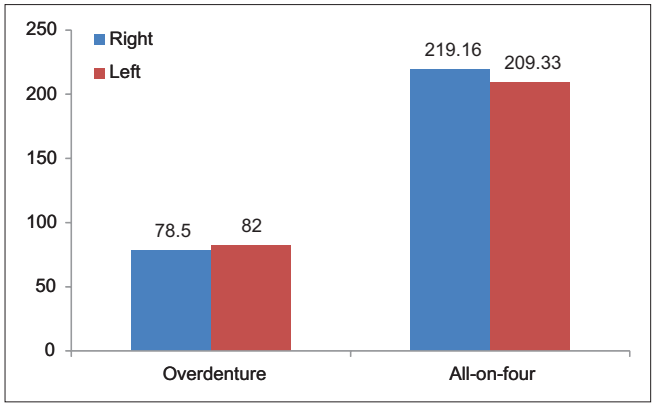
The present study was conducted to compare and evaluate bite force and chewing efficiency of all-on-four treatment with overdenture and complete denture. Extensive



Graph 1: Intragroup comparison of biting force within Group 1



Graph 2: Intragroup comparison of biting force within Group 2



Graph 3: Intergroup comparison of biting force for Group 1 and Group 2

Table 5: Intragroup comparison of chewing efficiency for Group 1

Food consistency	Prosthesis	Right temporalis		Left temporalis		Right masseter		Left masseter		Right digastric		Left digastric	
		Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*
Soft	Complete denture	141.67±20.41	0.004	116.67±25.81	0.005	208.33±86.12	0.002	225.00±75.82	0.007	125.00±52.44	0.004	158.33±49.15	0.027
	Over denture	225.00±27.38		233.3±75.27		383.33±25.81		433.33±51.63		250.00±54.77		266.67±68.31	
Medium	Complete denture	175.00±27.38	0.018	166.67±40.82	0.003	291.67±97.03	0.003	241.67±58.45	0.001	166.67±0.82	0.009	183.33±60.55	0.014
	Over denture	275.00±61.23		275.00±52.44		441.67±37.63		508.33±49.15		283.33±75.27		313.33±45.46	
Hard	Complete denture	233.33±25.81	0.001	208.33±37.63	0.004	358.33±111.43	0.012	283.33±68.31	0.001	200.00±54.77	0.010	216.67±40.82	0.017
	Over denture	320.83±40.05		333.33±51.63		504.17±33.22		575.00±52.44		341.66±73.59		333.33±60.55	

SD: Standard deviation

Table 6: Intragroup comparison of chewing efficiency for Group 2

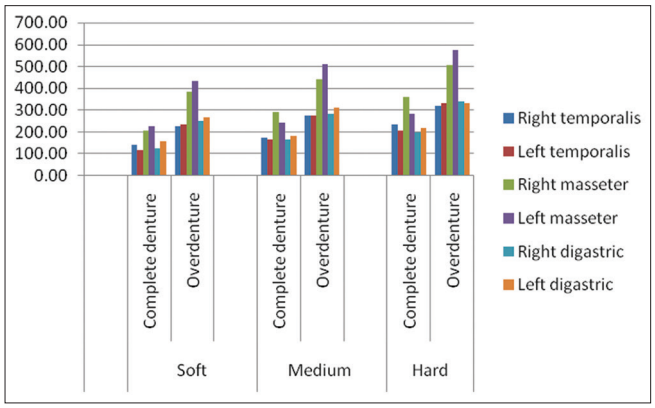
Food consistency	Prosthesis	Right temporalis		Left temporalis		Right masseter		Left masseter		Right digastric		Left digastric	
		Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*
Soft	Complete denture	141.67±49.15	0.002	116.67±40.82	0.001	208.33±49.15	0.003	191.67±73.50	0.004	150.00±44.72	0.002	133.33±51.63	0.005
	All-on-four	325.00±27.38		333.33±25.81		604.17±212.37		608.33±201.03		350.00±70.71		325.00±103.68	
Medium	Complete denture	208.33±20.41	0.001	175.00±27.38	0.001	266.67±93.09	0.011	216.67±68.31	0.002	158.33±20.41	0.004	175.00±61.23	0.003
	All-on-four	408.33±97.03		379.16±67.85		683.33±244.26		666.67±218.32		375.00±121.44		408.33±115.83	
Hard	Complete denture	241.67±20.41	0.004	200.00±31.62	0.001	308.33±106.84	0.016	266.67±68.31	0.002	175.00±41.83	0.001	200.00±44.72	0.002
	All-on-four	475.00±112.91		458.33±97.09		779.17±291.72		808.33±251.82		566.67±116.90		558.33±124.16	

SD: Standard deviation

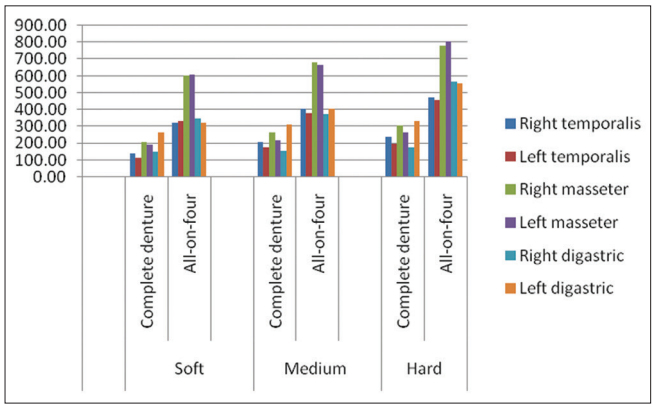
Table 7: Intergroup comparison of chewing efficiency for Group 1 and Group 2

Food consistency	Prosthesis	Right temporalis		Left temporalis		Right masseter		Left masseter		Right digastric		Left digastric	
		Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*	Mean±SD (μV)	*P*
Soft	Overdenture	225±27.38	0.001	233.33±75.27	0.012	383.33±25.81	0.030	433.33±51.63	0.06	250.00±54.77	0.021	266.67±68.31	0.277
	All-on-four	325±27.38		333.33±25.81		604.17±212.37		608.33±201.03		350.00±70.71		325.00±103.68	
Medium	Overdenture	275.00±61.23	0.017	275.0±52.44	0.014	441.67±37.63	0.038	508.33±49.15	0.114	283.33±75.27	0.147	313.33±45.46	0.091
	All-on-four	408.33±97.03		379.16±67.85		683.33±244.26		666.67±218.32		375.00±121.44		408.33±115.83	
Hard	Overdenture	320.83±40.05	0.010	333.33±51.63	0.019	504.17±33.22	0.045	575.00±52.44	0.051	341.66±73.59	0.003	333.33±60.55	0.003
	All-on-four	475.00±112.91		458.33±97.09		779.17±291.72		808.33±251.82		566.66±116.90		558.33±124.16	

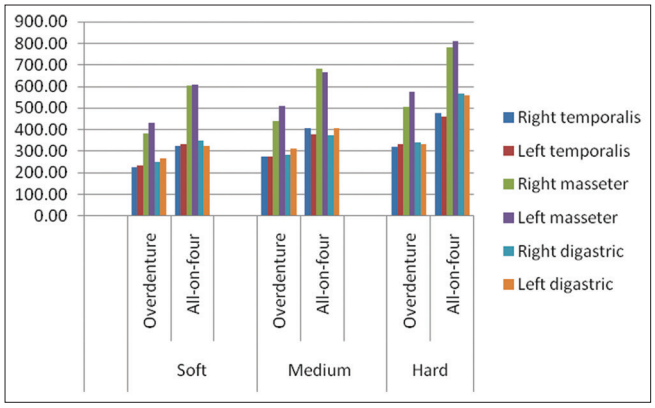
SD: Standard deviation



Graph 4: Intragroup comparison of chewing efficiency for Group 1



Graph 5: Intragroup comparison of chewing efficiency for Group 2



Graph 6: Intergroup comparison of chewing efficiency for Group 1 and Group 2

literature search revealed that no such study was conducted previously and this study is pioneer in comparing biting force and electromyographic activity of masticatory muscles among individuals rehabilitated with all-on-four treatment, implant-supported overdenture, and complete denture.

Previous studies were conducted using different methods to record bite force and masticatory efficiency by measuring masticatory forces, duration required to pulverize given food, strokes used to pulverize given food, electrical activity of masticatory muscles, and size of particles after a given number of strokes. In the present study, electromyogram and bite force sensor were used to evaluate masticatory muscle activity and biting force, respectively. The various factors that influence bite force are age, craniofacial morphology, gender, periodontal support of teeth, signs and symptoms of temporomandibular disorders and pain, the tooth loss and type of restoration, malocclusion, total area of teeth in contact, oral motor function, and salivary glands function. In addition to these biological factors, the mechanical determinants including different recording devices, position of recording devices in dental arch, unilateral or bilateral measurements, using acrylic splints and opening wide of mouth etc also influences the biting force measurement.[13] The present study recorded bite force at molar and incisor regions thrice and their average was calculated to measure bite force. Although the accuracy of the bite force sensor used in the present study was 0.05%. The previous studies reported accuracy (10 N) and precision (80%) with strain gauge device which recorded a wide range of force (50–800 N).[14] According to Lyons *et al*., strain gauge transducers have been provided an accurate method for maximum bite force measurements, and recording is still difficult because biting on the hard metal surfaces of the transducers causes discomfort and fear of breaking of edges of teeth and restorations. Although the protective covers have decreased the discomfort and fear but has not been completely overcome the associated problem.[15] Various materials such as gauze, gutta percha, polyvinyl chloride, and acrylic resin have been used to cover the transducers.[16] In present study, the metal surface of sensing probes was covered using 2-mm sponge sheet by a double-sided adhesive tape which was further wrapped by disposable sheet to prevent fear of fracture of tooth edges. The overall sensor thickness was approximately 16 mm. Paphangkorakit and Osborn in their study revealed that an incisal separation 14–28 mm is most favorable opening for bite force measurement.[17,18]

The present study showed that the biting force was significantly higher for all-on-four concept than overdenture followed by complete denture. Previous studies reported that bite force increases in implant-supported overdenture than complete dentures and bite force is positively correlated to muscular activity.[19-21] Carlsson and Lindquist conducted a study on 10 edentulous individuals initially rehabilitated with complete denture later replaced with fixed implant-retained prosthesis. The biting force has increased significantly from 80 N to 240 N.[22] van der Bilt *et al*. conducted a study to evaluate biting force and masticatory performance of complete denture and

implant-supported mandibular overdenture, which has showed a statistically significant increased biting force from 116 N to 200 N for complete denture and overdenture, respectively.[23]

The surface EMG records were made to evaluate the masticatory activity of masseter, temporalis, and anterior digastric muscles. Electromyogram is a biomedical device which capture signals by measuring electrical activity during muscle contraction. It is a tool to assess muscle activity. Few studies revealed that there is a linear relationship between EMG activity potentials and direct bite force measurements.[24] EMG is used to assess the electrical activity of specific muscle. Thus, EMG determines that how the muscles function during chewing and the role of specific muscle to the extent it performs in mastication (i.e., which muscle play what role to what extent).

Our study showed a statistically significant difference in chewing efficiency in intragroup comparison of Group 1 (complete denture and implant-supported overdenture) and Group 2 (complete denture and hybrid denture supported by all-on-four treatment concept) individuals. The chewing efficiency of overdenture was significantly greater than conventional complete denture. Similarly, the chewing efficiency of hybrid denture was significantly greater than complete denture.

In addition, intergroup comparison (overdenture and all-on-four) also showed a statistically significant difference in chewing efficiency with few exceptions. The chewing efficiency was highest in hybrid denture supported by all-on-four treatment concept, followed by implant-supported overdenture and complete denture for all three masticatory muscles when chewing different consistencies of foods. There was an insignificant difference observed in chewing efficiency of hybrid denture and overdenture in left masseter and right and left digastric muscles when chewing medium-consistency food and in left digastric muscle when chewing soft-consistency food. The current study showed a higher EMG activity of masseter muscles among other muscles. The present study showed higher EMG activity for hard-consistency food followed by medium- and soft-consistency food.

However, Feine *et al*. in a cross-over study observed no statistically significant difference in patients' perception, electromyographic activity of overdenture, and implant-retained fixed prosthesis.[25-28] Ferrario *et al*. also showed similar results where they observed that overdentures and fixed implant-retained prosthesis were functionally equivalent. They conducted electromyographic study of masticatory muscles and concluded similar efficiency with implant-supported overdenture and fixed implant-supported prosthesis.[29] Apolinário *et al*. conducted a randomized controlled trial to evaluate masticatory function of complete denture and implant-supported dentures (fixed and overdenture).[30] Their study revealed a statistically significant difference for masticatory efficiency between conventional complete denture and implant-supported dentures (fixed and removable overdenture), but no significant difference was observed in masticatory efficiency of implant-supported overdenture and implant-retained fixed prosthesis.[30]

Heydecke *et al*. conducted a crossover trial to show contrary results where they compared maxillary implant-retained fixed prosthesis with implant-supported overdentures opposed by mandibular implant-supported overdenture. The study revealed that removable overdenture has significantly higher chewing ability and general satisfaction than fixed prosthesis.[31]

Previous studies revealed that EMG activity of masseter muscles was greater than the temporalis muscles. The masseter is considered as the strongest muscle, as it exerts higher pressure during mastication. Three different consistencies of food items were included in the study where banana as soft, apple without peel as medium, and peanut as hard-consistency food.[32]

The limitations of the study includes small sample size, short-span study, random patient distribution among groups, and lack of advanced instruments for bite force measurement and masticatory muscle activity recordings. The study did not include individuals with full-mouth conventional implant fixed prosthesis.

After eliminating the limitations of the current study, further researches and studies need to be conducted which are aimed for the enhancement of the quality of life of the edentulous individuals.

CONCLUSION

Within the limitations of the study, the present study conducted by us concludes that biting force and chewing efficiency improves with all-on-four treatment concept compared to implant-supported overdenture and conventional complete denture.

The biting force and chewing efficiency were higher in all-on-four subjects followed by implant-supported overdenture and conventional complete denture. Among

all three muscles, masseter muscle has showed higher electromyographic activity than temporalis and anterior digastric muscles. Among different consistencies of food, hard food has showed a higher electromyographic activity.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Awad MA, Lund JP, Shapiro SH, Locker D, Kle-Metti E, Chehade A, *et al*. Oral health status and treatment satisfaction with man-dibular implant overdentures and conventional dentures: A randomized clinical trial in a senior population. Int J Prosthodont 2003;16:390-6.
2. Neves FD, Mendes FA, Borges TF, Mendonça DB, Prado MM, Zancopé K. Masticatory performance with different types of rehabilitation of the edentulous mandible. Braz J Oral Sci 2015;14:186-9.
3. Lassila V, Holmlund I, Koivumaa KK. Bite force and its correlations in different denture types. Acta Odontol Scand 1985;43:127-32.
4. Miyaura K, Morita M, Matsuka Y, Yamashita A, Watanabe T. Rehabilitation of biting abilities in patients with different types of dental prostheses. J Oral Rehabil 2000;27:1073-6.
5. Malo P, Rangert B, Nbre M. All-on-4 immediate function concept with branemark system implants for completely edentulous maxilla. A 1 year retrospective clinical study. Clin Implant Dent Relat Res 2005;7:88-94.
6. Malo P, Rangert B, Nbre M. All-on-4 immediate function concept with branemark system implants for completely edentulous mandible. A retrospective clinical study. Clin Implant Dent Relat Res 2003;5:2-9.
7. Prithviraj DR, Madan V, Harshamayi P, Kumar CG, Vashisht R. A comparison of masticatory efficiency in conventional dentures, implant retained or supported overdentures and implant supported fixed prosthesis: A literature review. J Ent Implant 2014;4:153-7.
8. Sharma AJ, Nagrath R, Lahori M. A comparative evaluation of chewing efficiency, masticatory bite force, and patient satisfaction between conventional denture and implant-supported mandibular overdenture: An *in vivo* study. J Indian Prosthodont Soc 2017;17:361-72.
9. Mahoorkar S, Bhat S, Kant R. Single implant supported mandibular overdenture: A literature review. J Indian Prosthodont Soc 2016;16:75-82.
10. Bhat S, Chowdhary R, Mahoorkar S. Comparison of masticatory efficiency, patient satisfaction for single, two, and three implants supported overdenture in the same patient: A pilot study. J Indian Prosthodont Soc 2016;16:182-6.
11. Bera AK, Das S, Bhattacharyya J, Majumdar S, Ghosh S, Goel P. A study on the evaluation of bite force, prosthetic and nutritional status in adult cleft patients in Kolkata. J Indian Prosthodont Soc 2018;18:343-55.
12. Ferrario VF, Sforza C, Zanotti G, Tartagilia GM. Maximal bite force in healthy young adults as predicted by surface electromyography. J Dent 2004;32:451-7.
13. Pereira LJ, Gaviao MB, Bonjardim LR, Castelo PM, Van Der Bilt A. Muscle thickness, bite force, and cranio-facial dimensions in adolescents with signs and symptoms of temporomandibular dysfunction. Eur J Orthod 2007;29:72-8.
14. Carlsson GE. Masticatory efficiency: The effect of age, the loss of teeth and prosthetic rehabilitation. Int Dent J 1984;34:93-7.
15. Lyons MF, Cadden SW, Baxendale RH, Yemm R. Twitch interpolation in the assessment of the maximum force-generating capacity of the jaw-closing muscles in man. Arch Oral Biol 1996;41:1161-8.
16. Tortopidis D, Lyons MF, Baxendale RH. Bite force, endurance and masseter muscle fatigue in healthy edentulous subjects and those with TMD. J Oral Rehabil 1999;26:321-8.
17. Paphangkorakit J, Osborn JW. Effect of jaw opening on the direction and magnitude of human incisal bite forces. J Dent Res 1997;76:561-7.
18. Paphangkorakit J, Osborn JW. Effects on human maximum bite force of biting on a softer or harder object. Arch Oral Biol 1998;43:833-9.
19. Slagter AP, Bosman F, van der Glas HW, van der Bilt A. Human jaw-elevator muscle activity and food comminution in the dentate and edentulous state. Arch Oral Biol 1993;38:195-205.
20. Tiwari P, Karambelkar V, Patel JR, Sethuraman R. The comparative evaluation of the masticatory efficiency of root supported attachment retained overdenture and implant supported overdenture by EMG: An *in vivo* study. J Dent Med Sci 2015;14:78-93.
21. Tribst JP, de Morais DC, Alonso AA, Piva AM, Borges AL. Comparative three-dimensional finite element analysis of implant-supported fixed complete arch mandibular prostheses in two materials. J Indian Prosthodont Soc 2017;17:255-60.
22. Carlsson GE, Lindquist LW. Ten-year longitudinal study of masticatory function in edentulous patients treated with fixed complete dentures on osseointegrated implants. Int J Prosthodont 1994;7:448-53.
23. van der Bilt A. Assessment of mastication with implications for oral rehabilitation: A review. J Oral Rehabil 2011;38:754-80.
24. Koc D, Dogan A, Bek B. Bite force and influential factors on bite force measurements: A literature review. Eur J Dent 2010;4:223-32.
25. Feine JS, Maskawi K, de Grandmont P, Donohue WB, Tanguay R, Lund JP. Within-subject comparisons of implant-supported mandibular prostheses: Evaluation of masticatory function. J Dent Res 1994;73:1646-56.
26. de Grandmont P, Feine JS, Taché R, Boudrias P, Donohue WB, Tanguay R, *et al*. Within-subject comparisons of implant-supported mandibular prostheses: Psychometric evaluation. J Dent Res 1994;73:1096-104.
27. Feine JS, de Grandmont P, Boudrias P, Brien N, LaMarche C, Taché R, *et al*. Within-subject comparisons of implant-supported mandibular prostheses: Choice of prosthesis. J Dent Res 1994;73:1105-11.
28. Shastry T, Anupama NM, Shetty S, Nalinakshamma M. An *in vitro* comparative study to evaluate the retention of different attachment systems used in implant-retained overdentures. J Indian Prosthodont Soc 2016;16:159-66.
29. Ferrario VF, Tartaglia GM, Maglione M, Simion M, Sforza C. Neuromuscular coordination of masticatory muscles in subjects with two types of implant-supported prostheses. Clin Oral Implants Res 2004;15:219-25.
30. Apolinário ME, Mestriner W, Dametto FR, Gadê-Neto CR, Sousa SA. Clinical assessment of masticatory efficiency in the rehabilitation of edentulous patients. Braz J Oral Sci 2011;10:217-20.
31. Heydecke G, Boudrias P, Awad MA, De Albuquerque RF, Lund JP, Feine JS. Within-subject comparisons of maxillary fixed and removable implant prostheses: Patient satisfaction and choice of prosthesis. Clin Oral Implants Res 2003;14:125-30.
32. Salleh NM, Fueki K, Garrett NR, Ohyama T. Objective and subjective hardness of a test item used for evaluating food mixing ability. J Oral Rehabil 2007;34:174-83.