Electromyographic Connectivity of Masseter Muscle with Different Retentive Attachments for Implant Overdentures in Patients with Atrophied Mandibular Ridges: A Crossover Study

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Purpose: *The aim of this crossover study was to evaluate electromyographic (EMG) connectivity of masseter muscle with different attachments used to retain implant overdentures in patients with atrophied mandibular ridges.* ***Materials and Methods:*** *Twenty-four edentulous participants with atrophic mandibular ridges received conventional dentures (control). Three months after the adaptation period, two implants were placed in the canine areas of the mandible. After osseointegration, each participant was successively given the following prostheses in a crossover manner: (1) ball-retained overdentures, (2) bar-retained overdentures, and (3) Locator-retained overdentures. The EMG parameters (amplitude, chewing area, chewing rate, duration of chewing cycle, duration of chewing burst, and chewing time) were measured 3 months after wearing the following prostheses: conventional dentures, ball overdentures, bar overdentures, and Locator overdentures. Measurements were made during chewing of hard (carrot) and soft (cake) foods.* ***Results:*** *The highest EMG activity/amplitude, chewing area, duration of chewing cycle, and duration of chewing burst were noted with ball overdentures, followed by bar overdentures and Locator overdentures, and the lowest values were observed with conventional dentures. The highest chewing rate and masticatory time were noted with conventional dentures, and the lowest values were observed with ball overdentures. With the exception of chewing area, no significant differences in all tested parameters between bar overdentures and Locator overdentures were observed. Except for duration of chewing cycle, all tested parameters were significantly higher during chewing of hard food than soft food.* ***Conclusion:*** *Within the limitations of this study, two-implant overdentures recorded higher muscle functions compared to conventional dentures regardless of the type of attachment used. For such overdentures, ball attachment may be recommended over bar and Locator attachments, as it was associated with improved muscle activity and function.* INT J ORAL MAXILLOFAC IMPLANTS 2019;34:1213–1222. doi: 10.11607/jomi.7484

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An atrophic mandibular ridge is the main problem for patients seeking a complete denture due to insufficient area for distribution of masticatory force, pain during mastication, mucosal inflammation, poor retention and instability of the denture, difficulty in speech, and poor patient toleration. All these problems can cause dissatisfaction of the patient and poor quality of life.[1] According to the McGill and York consensus statements,[2,3] two-implant overdentures should become the standard of care of the edentulous mandible, taking into account performance, patient satisfaction, cost, and clinical time. However, such prosthesis may have a long-term effect on the opposing maxillary ridges.[4,5] Several attachments can be used to connect overdentures to the implants such as ball, bar, Locator, and resilient telescopic attachments.[6]

One of the most important aspects in attachment choice is the anatomy of the mandible. Advanced atrophy of the alveolar ridge calls for prosthesis stabilization, especially with regard to horizontal forces.[7] Ball and socket attachments are the simplest ones to use.[8] Such attachments offer high wear resistance, provide additional stability and retention,[8] and are cost-effective, especially for edentulous individuals with resorbed mandibular ridges.[9] Spiekermann[10] reported that bar constructions may provide sufficient horizontal stability if the bar is long enough even when alveolar atrophy is pronounced. Bar attachments act as a splint between the abutments, distribute stress between implants, minimize lateral movement,[4,11] and reduce incidence of prosthetic complications[12] compared with individual attachments. The widely used Locator system has been advocated as an alternative single attachment to the established ball anchor.[13] Locators are low-profile resilient studs that can also provide a limited hinge movement and compensate for implant angulation up to 40 degrees.[14] They have a double retention mechanism, which comes from inner and outer frictional flanges, thus providing stability and limiting lateral movements.[15–17] The self-aligning feature of the Locator aids the patient in a similar manner as a guide plane for the removable partial denture.[18]

Electromyography (EMG) is one of the instrumental techniques that is feasible for characterization of the eating process, as it is noninvasive and can record the electrical activities of masticatory muscles during eating.[19] The muscle activity is an indicator for the force that a subject can exert during chewing or clenching the teeth together. Good muscle activity is needed for proper chewing movements in order to cut or comminute the food. This activity has been found to be directly related to the texture of food.[19,20] Treating complete denture wearers with implants improves chewing efficiency, increases maximum occlusal force and muscle activity, and clearly improves patient satisfaction.[21]

Controversies exist in the literature regarding the effect of different attachments of implant-retained mandibular overdentures on muscle activity. Uçankale et al[22] found a difference in muscle activity between ball and bar attachments of implant-retained overdentures, and they claimed that the type of attachment affects the stability and retention, which affects the chewing process and muscle activity. In contrast, other authors found no influence of attachment type of implant overdentures on muscle activity.[23,24] Several authors[19,20,22,25–28] found that mandibular overdentures supported by two implants were associated with higher electrical activity of the masseter muscles compared with conventional dentures.

Unfortunately, these studies did not compare muscle activity of different attachment systems within the same patient. Moreover, the effect of attachment type on muscle activity in patients with an atrophied mandible was not investigated. A question to be answered is whether the type of attachments used to stabilize mandibular overdentures in patients with atrophied ridges can affect masseter muscle activity. The null hypothesis was that there would be no significant difference in muscle activity between tested attachments.

MATERIALS AND METHODS

Patient Selection

Twenty-four edentulous participants with atrophied mandibular ridges were selected from a previous study.[29] Inclusion criteria were as follows: *(1)* insufficient retention and stability of mandibular dentures; *(2)* sufficient bone quantity and quality in the canine areas of the mandible to receive implants of at least 11-mm length and 3.7-mm width; *(3)* a minimum 15 mm restorative space (class I according to Ahuja and Cagna[30] [2010]) to accommodate all types of tested attachments. Exclusion criteria were as follows: bone metabolic diseases that affect osseointegration; radiotherapy to the head and neck region; and harmful habits such as smoking, bruxism, and clenching. The sample size was selected to yield 80% power based on the results of a previous crossover study[25] in which the authors detected a significant difference in EMG activity of masseter muscle with three different designs for implant-supported mandibular overdentures during clenching of hard and soft foods (effect size = 3.63, $\alpha = .05$). The calculated sample size (18 patients) was increased 30% to yield 24 patients due to the nonparametric tests used and the anticipated dropouts. The patients were informed about the treatment objectives before obtaining written consent. The study was approved by the ethical committee of the Faculty of Dentistry, Mansoura University, Egypt, which utilizes the ethical guidelines of the Helsinki declaration.

Surgical and Prosthetic Procedures

All participants received new conventional maxillary and mandibular dentures (control group) and were encouraged to wear them for 3 months to enhance neuromuscular adaptation. Two implants (TioLogic, Dentaurum) were inserted in canine areas of the mandible by the same oral and maxillofacial surgeon. A tissue-borne stereolithographic surgical template constructed using cone beam computed tomography (CBCT) was used for implant placement utilizing the flapless surgical approach. The healing abutments were screwed to the implants, and the mandibular dentures were relined using a soft liner during the healing period. Three months later, each participant was successively given

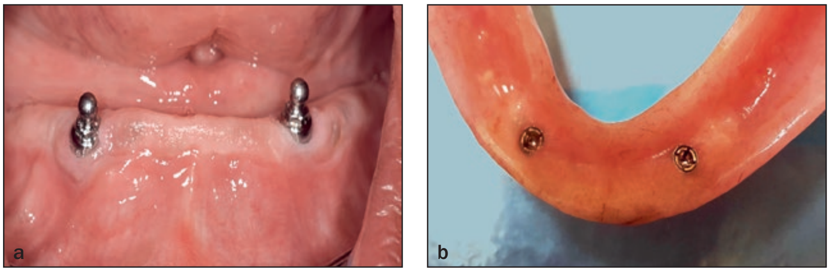

Fig 1 Ball-retained mandibular overdentures. *(a)* Intraoral view. *(b)* Fitting surface of the overdenture.

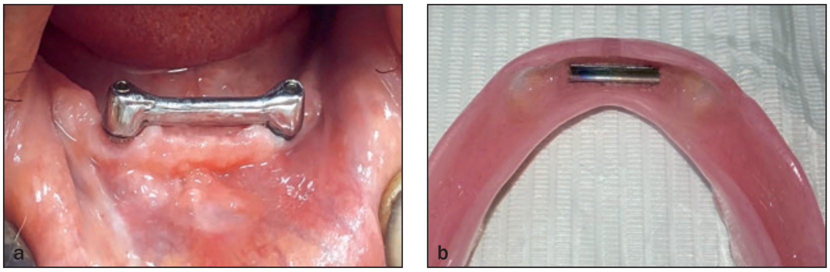

Fig 2 Bar-retained mandibular overdentures. *(a)* Intraoral view. *(b)* Fitting surface of the overdenture.

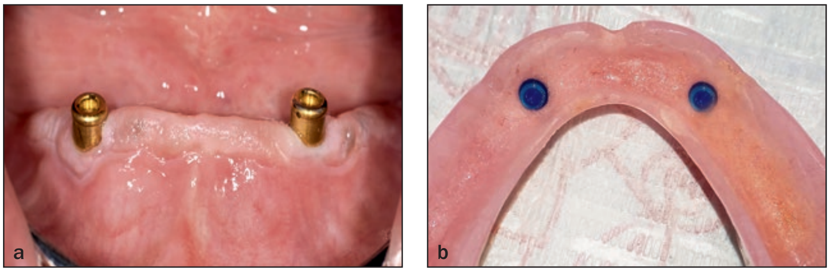

Fig 3 Locator-retained mandibular overdentures. *(a)* Intraoral view. *(b)* Fitting surface of the overdenture.

the following prostheses in a crossover study design: *(1)* ball-retained mandibular overdentures (ball overdentures, Fig 1), *(2)* bar-retained mandibular overdentures (bar overdentures, Fig 2), and *(3)* Locator-retained mandibular overdentures (Locator overdentures, Fig 3). The sequence in which the overdentures were received was randomized to avoid the effect of the order of the prosthesis on masticatory function measurements. In that way, six blocks of four subjects were formed using a quasi-random method, each having a different sequence of successive overdenture attachments. The six possible sequences were: *(1)* ball overdentures, then bar overdentures, then Locator overdentures; *(2)* ball overdentures, then Locator overdentures, then bar overdentures; *(3)* bar overdentures, then ball overdentures, then Locator overdentures; *(4)* bar overdentures, then Locator overdentures, then ball overdentures; *(5)* Locator overdentures, then ball overdentures, then bar overdentures; and *(6)* Locator overdentures, then bar overdentures, then ball overdentures.

For each patient, the healing abutments were removed after 3 months of implant insertion, and an open-tray impression procedure was performed using the long transfer copings.[29] Implant analogs were threaded to the copings, and the impression was poured to obtain a master cast. The cast was duplicated to produce three casts (one cast for each prosthesis) with the aid of impression copings and analogs. For each patient, ball, bar, and Locator abutments with the appropriate gingival height (TioLogic, Dentaurum) were screwed to the implant analogs on the master casts. For the ball overdenture and Locator overdenture groups, the ball (Unor Ecco Au/Pt standard, retention = 800 g) and Locator (Extra-light retention nylon insert, blue, retention = 680 g) matrices were placed over the abutments, and the undercuts around the abutments were blocked out before packing of the acrylic resin. For bar overdentures, bar abutments were screwed to the analogs on the master cast. The plastic caps were screwed to the bar abutments, and the plastic bar (Dolder bar joint, Resilient bar plastic, macro) was luted to the plastic caps using luting wax leaving 1.5 mm space between the bar and the ridge for oral hygiene purposes. The plastic bar and cap assembly was invested and cast into cobalt chromium alloy, finished, and tried in intraorally for passivity. Titanium Dolder bar clips (retention = 700 gm[31]) were used over the bar before backing of the acrylic resin. For standardization of prosthetic factors, the occlusal and polished surfaces of all overdentures were duplicated from the conventional mandibular denture with the aid of silicone key.[25,32]

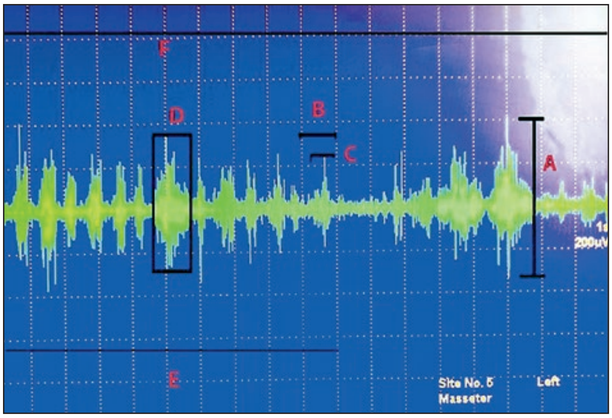

Fig 4 EMG parameters. *(a)* The amplitude. *(b)* Duration of chewing cycle. *(c)* Duration of chewing burst. *(d)* Chewing area. *(e)* Chewing rate. *(f)* Masticatory time.

Evaluation of EMG Activity of Masseter Muscle

The EMG activity was measured using a similar methodology described in a previous crossover study.[25] The patients were seated in an upright position with their head unsupported. The skin on which the electrodes were placed was shaved and cleaned with alcohol. Bipolar Ag/Ag Cl-surface electrodes were placed on the bellies of the masseter muscle of the preferred chewing side of the patient.[33] The active electrodes were positioned on mid-longitudinal fibers of the muscle parallel to the direction of muscle fibers (15 mm apart), and the reference electrode was placed on the patient's forehead. The electrodes were connected to the measuring system (MEB-9400K, NIHON KOHDEN). Electro conductive gel (Elefix, NIHON KOHDEN) was used on the electrode before fixing it to the skin using adhesive bandage tape. Each patient was instructed to chew a sample (dimensions 3 × 1 × 1 cm) of hard (carrot) and soft (cake) foods[34] until the foods became ready for swallowing. The order of chewing food types was randomized. Sensitivity (vertical measuring) was set at 200 μV, and sweep speed (horizontal measuring) was set at 1 s/division. Analysis of EMG signals was performed with programs of EMG equipment. The signals were acquired by a single operator (T.M.B.). EMG signals were amplified and filtered (20 Hz to 10 KHz), full wave rectified, and smoothed electronically. The following parameters of EMG activity were recorded (Fig 4):

1. Peak amplitude (μV): the difference between the –ve and +ve peak
2. Chewing area: the area of the wave (vertical and horizontal)
3. Chewing rate: the number of chewing bursts per 10 seconds
4. Duration of chewing cycle: from the end of one burst to the end of the next burst
5. Duration of chewing burst
6. Masticatory time: the time needed for chewing the food until ready for swallowing

If the patient made any excessive movements or coughing occurred, the recording was repeated. The recordings were done in three sessions; then averages of the parameters were taken as the reading. In each session, four peaks of EMG muscle activity were evaluated and averaged. The operator repeated the test five times (separated by a rest period of at least 2 minutes) for each type of food, and the mean was subjected to statistical analysis. The same experienced examiner (T.M.B.) carried out all the measurements. EMG activity was measured 3 months after wearing each of the following prostheses: conventional dentures, ball overdentures, bar overdentures, and Locator overdentures.

Statistical Analysis

Kruskal-Wallis tests were used to compare tested parameters between groups followed by Dunn post hoc tests for pairwise comparisons. To compare food textures, Wilcoxon's signed-rank test was used. *P* value was significant if it was less than .05. The data were analyzed using the statistical package for social science (SPSS, version 22).

RESULTS

Twelve men and 12 women (ages ranged between 45 and 70 years) completed the analysis. The average restorative space was 17.5 ± 2.1 mm.

Peak Amplitude (EMG Activity in μV)

There was a significant difference in EMG activity (in μV) between groups during chewing of soft ($P = .0002$) and hard ($P = .00561$) foods. The highest EMG activity was noted with ball overdentures, followed by bar overdentures and Locator overdentures (without difference), and the lowest EMG activity was observed with conventional dentures. Except for ball overdentures, EMG activity during chewing of hard food was significantly higher than chewing of soft food (Table 1).

Chewing Area

There was a significant difference in chewing area between groups during chewing of soft and hard foods ($P < .001$). The highest chewing area was noted with ball overdentures, followed by bar overdentures and Locator overdentures, and the lowest area was observed with conventional dentures. During chewing of hard food, no difference in chewing area between conventional

Table 1 Comparison of EMG Activity (in μv) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	200.3A	94.2	158.7	137.5	361.0	485.9A	141.0	547.1	271.3	618.0	.0002*
Ball overdentures	570.5B	84.5	551.4	454.0	678.2	668.9B	63.1	654.8	583.0	754.8	.1151
Bar overdentures	329.9C	129.8	274.0	211.0	507.0	541.1C	85.4	563.0	424.0	637.5	.0025*
Locator overdentures	307.2A,C	67.9	281.0	227.2	404.0	507.8C	109.5	547.2	390.0	634.0	.0036*
P	.0002*					.00561					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

Table 2 Comparison of Chewing Area (μv ms) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	.86A	0.17	.92	.58	1.03	1.86A	0.24	1.91	1.46	2.07	< .001*
Ball overdentures	2.64B	0.22	2.66	2.28	2.84	2.92B	0.11	2.97	2.75	3.02	.0196*
Bar overdentures	2.02C	0.15	1.98	1.85	2.22	2.51C	0.12	2.52	2.35	2.68	.0003*
Locator overdentures	1.33D	0.10	1.35	1.16	1.42	1.79A	0.05	1.77	1.74	1.85	.0005*
P	< .001*					< .001*					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

Table 3 Comparison of Chewing Rate (N of burst in 10 seconds) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	15.60A	1.140	16.00	14	17	21.00A	1.581	21.00	19	23	< .001*
Ball overdentures	10.80B	1.304	11.00	9	12	16.20B	1.304	16.00	15	18	< .001*
Bar overdentures	13.40C	1.140	13.00	12	15	17.80B	1.643	17.00	16	20	< .001*
Locator overdentures	13.60C	1.342	13.00	12	15	17.40B	2.074	18.00	14	19	< .001*
P	.0002*					.0024*					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

dentures and Locator overdentures was observed. Chewing area of hard food was significantly higher than chewing area of soft food for all groups (Table 2).

Chewing Rate

There was a significant difference in chewing rate between groups during chewing of soft food ($P = .0002$) and hard food ($P = .0024$). During chewing of soft food, the highest chewing rate was noted with conventional dentures, followed by bar overdentures and Locator overdentures (without difference), and the lowest chewing rate was observed with ball overdentures. During chewing of hard food, the highest chewing rate was noted with conventional dentures, and the lowest chewing rate was observed with ball overdentures, Locator overdentures, and bar overdentures without significant difference. For all groups, the chewing rate for hard food was significantly higher than the chewing rate for soft food (Table 3).

Duration of Chewing Cycle

There was a significant difference in duration of chewing cycle between groups during chewing of soft food ($P = .0059$) and hard food ($P = .0185$). The shortest duration of chewing cycle was noted with conventional dentures, and the longest duration of chewing cycle was observed with ball overdentures. No difference in duration of chewing cycle between conventional dentures, bar overdentures, and Locator overdentures was observed for hard and soft foods. For all groups, soft food recorded a significantly longer duration of chewing cycle than hard food (Table 4).

Table 4 Comparison of Duration of Chewing Cycle (in seconds) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	0.636A	0.080	0.642	0.544	0.750	0.476A	0.011	0.479	0.458	0.485	.0158*
Ball overdentures	0.926B	0.187	0.885	0.687	1.200	0.599B	0.078	0.633	0.514	0.666	< .001*
Bar overdentures	0.721A	0.050	0.698	0.668	0.785	0.536A	0.063	0.571	0.444	0.587	.0067*
Locator overdentures	0.770A	0.070	0.769	0.670	0.862	0.569A	0.049	0.545	0.529	0.642	.0038*
P	.0059*					.0185*					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

Table 5 Comparison of Duration of Chewing Burst (in seconds) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	0.294A	0.013	0.298	0.280	0.310	0.400A	0.043	0.385	0.355	0.459	.0162*
Ball overdentures	0.427B	0.054	0.412	0.355	0.499	0.702B	0.113	0.654	0.600	0.890	< .001*
Bar overdentures	0.357C	0.027	0.359	0.320	0.396	0.484A	0.060	0.505	0.421	0.550	.0052*
Locator overdentures	0.344C	0.020	0.330	0.329	0.365	0.565A	0.109	0.508	0.463	0.685	< .001*
P	.0004*					.0001*					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

Table 6 Comparison of Masticatory Time (in seconds) Between Different Groups and Food Textures

	Chewing soft food					Chewing hard food					
	Mean	SD	M	Min	Max	Mean	SD	M	Min	Max	*P*
Conventional dentures	22.60A	1.14	20.00	18.00	21.00	24.80A	0.84	24.00	22.00	24.00	< .001*
Ball overdentures	18.40B	1.14	18.00	17.00	20.00	22.20B	0.84	21.00	21.00	23.00	< .001*
Bar overdentures	17.80B	0.84	19.00	18.00	20.00	22.20B	0.84	22.00	21.00	23.00	< .001*
Locator overdentures	18.20B	0.84	19.00	18.00	20.00	21.80B	0.84	22.00	21.00	23.00	.0003*
P	.025*					.047*					

SD = standard deviation; M = median; Min = minimum; Max = maximum. Different letters indicate a significant difference between groups.
*Statistically significant difference.

Duration of Chewing Burst

There was a significant difference in duration of chewing burst between groups during chewing of soft ($P = .0004$) and hard ($P = .0001$) foods. The shortest duration of chewing burst was noted with conventional dentures, and the longest duration of chewing burst was observed with ball overdentures. For soft food, no difference in duration of chewing burst between Locator overdentures and bar overdentures was observed. For hard food, no difference in duration of chewing burst between conventional dentures, Locator overdentures, and bar overdentures was noted. For all groups, hard food recorded a significantly longer duration of chewing burst than soft food (Table 5).

Masticatory Time

There was a significant difference in masticatory time between groups during chewing of soft ($P = .025$) and hard ($P = .047$) foods. Conventional dentures showed significantly higher masticatory time than other groups. No significant difference in masticatory time was noted between ball overdentures, bar overdentures, and Locator overdentures. Hard food recorded a significantly longer masticatory time than soft food for all groups (Table 6).

DISCUSSION

The crossover study design standardized patient-based factors that may affect EMG activity such as age, sex, muscle activity, muscle power, neuromuscular control, and ridge morphology. The comparison between different types of the prosthesis was performed within the same subject. Moreover, a small sample size can be used with crossover studies compared with parallel group studies.[26] The degree of the retentive force of the attachment may have a significant effect on patient perception and muscle activity.[22] In the present study, the authors decided to use a single retentive force of each attachment, as it was difficult to test the whole retentive forces of each attachment type. The selection of the tested attachment was made on the basis that these attachments have similar retention forces (Au/Pt ball attachment retention = 800 gm, Extra-light nylon insert retention = 680 gm, and titanium Dolder bar retention = 700 gm). However, future studies may be needed to test the EMG activity of masseter muscle with different retentive forces of each attachment type.

In this study, implant-retained overdentures recorded higher EMG activity than the conventional denture regardless of the type of attachments used. This finding is not surprising and is in agreement with several previous studies.[19,20,26,27] Similarly, Chen et al[35] found that mandibular implant-supported overdentures recorded higher EMG activity and control of chewing cycles compared with complete dentures. The decreased muscle activity with conventional dentures may be attributed to the instability of the dentures associated with the atrophied mandibular ridges, the weaker jaw muscles, mucosal discomfort, and decreased occlusal forces during mastication as a result of long insufficient use of the jaw muscles.[36] Moreover, during chewing of food by conventional dentures in patients with atrophied ridges, part of the muscle activity is used to control the denture to keep it in place and the other part for comminution of food.[24] The increased muscle activity with implant overdentures could be attributed to the improved retention and stability of the conventional dentures by the use of implants and attachments, which creates a stable occlusal plane, increases patient comfort during chewing, and improves oral perception.[19,20] Moreover, the denture stabilization reduces soft tissue irritation, protects mental nerve, and diminishes problems of high muscle attachment.[37] Furthermore, the rapid elastic bone deformation occurring during the loading of implants might trigger periosteal receptors, which might be useful in preservation of masticatory muscle function[35] and improving chewing efficiency.[38] In addition, the absence of periodontal receptors causes an increase in muscle activity during mandibular posture and chewing of different food types for implant-supported prostheses.[39] However, it should be noted that the increased muscle activity may be associated with increased occlusal force, which may have a negative effect on peri-implant marginal bone and opposing ridge bone. Controversy exists in the literature regarding the effect of increased occlusal force on marginal bone loss around implants supporting overdentures. Geckili et al reported that increased maximum occlusal force was associated with increased marginal bone loss around the implants.[40] In contrast, Jofré et al found no relationship between maximum occlusal force and marginal bone loss around implants supporting overdentures.[41] The increased occlusal force in patients wearing a two-implant–retained mandibular overdenture encourages the patients to incise anteriorly, which increases occlusal pressure and causes degenerative changes similar to combination syndrome with anterior maxillary bone loss.[5] Therefore, if the patient is able to adequately chew both the hard and soft foods with lower EMG activity levels, this may be advantageous in terms of bone preservation around implants and in the opposing ridge. However, this question cannot be answered in the present study and needs a separate investigation.

During chewing of soft and hard foods, the highest EMG activity was noted with ball overdentures, followed by bar overdentures and Locator overdentures, and the lowest EMG activity was observed with conventional dentures. The increased EMG activity with ball attachments was in line with the findings of several studies[19,22,42] in which the authors reported increased muscle activity and maximum occlusal force during chewing of hard and soft foods after rehabilitation with ball-retained mandibular implant overdentures compared with conventional dentures. The increased EMG activity with ball attachments may be attributed to the design of the ball attachments used in this study. Ball attachments were supplied in the form of ball and socket, which consists of a titanium ball and platinized gold socket without space in between. Therefore, they allow denture rotation and limit vertical movement. The lateral flanges of the socket contact the ball firmly, thus providing excellent retention and stability without lateral (side to side) movement. The increased denture stability and retention stabilize the occlusion, provide adequate chewing, transmit masticatory load axially to the implants,[43] and increase the ability to grind the food during chewing independently of the degree of denture support.[44] Furthermore, the increased height of ball attachments compared with bar and Locator attachments makes patients more aware of the attachment, prompting patients to place their mandibles forward to acquire the advantage of better occlusal forces. On the other hand, the Dolder bar joint used in this study allows vertical, rotational, and side-to-side movements. Also, Locator attachments have a vertical resiliency and allow movements of the prosthesis in both the vertical plane and the hinge axis.[45] Therefore, the amount of retention and stability provided by Locator and bar attachments in this study may be lower than the ball and socket attachment. This may explain why ball overdentures recorded higher EMG activity than bar overdentures and Locator overdentures. In contrast to this finding, van der Bilt et al[24] found no significant difference in the EMG activity of the masticatory muscles between magnet, ball, and bar attachments despite the different degree of retention and stability provided by each attachment type. The difference in the results may be because all patients included in this study had atrophy of mandibular ridges with increased liability of lateral movement of the denture during mastication. Therefore, the increased stability and retention provided by the ball attachment compared with the other attachments, as stated previously, eliminates patient discomfort, reduces lateral movement of the denture, and encourages the patients to exert their maximum occlusal pressure. In contrast, when the patients have adequate ridge height, lateral movement of the denture saddles is minimized regardless of the type of attachment used. This could be responsible for the lack of difference in muscle activity between attachments in these patients.

The increased EMG activity with hard food compared to soft food was in line with other studies[19,26,46] and may reflect the modulation of the contraction mechanisms through information from intraoral receptors.[47] The increased activity with hard food may be attributed to the diminished tactile sensation (absence of periodontal receptors caused by teeth extraction) and loss of inhibitory reflexes that increase maximum occlusal force and muscle activity.

The increased chewing area with ball overdentures compared with other attachments and conventional dentures may be attributed to the improved muscular coordination as a result of better stability and retention of ball overdentures. Similarly, Chen et al (2002)[48] noted increased integrated chewing area of EMG when EMG reading displays a greater amplitude. They attributed the increased chewing area to the increased muscle contractions and occlusal force caused by improved retention of the prosthesis. Chewing area of hard food was significantly higher than soft food. This may be because chewing hard food usually requires more muscle activity compared with soft food.[46]

The decreased chewing rate with different types of attachments compared to conventional dentures was in agreement with the finding of van der Bilt et al,[24] who reported that patients with conventional dentures needed almost twice the number of chewing strokes compared to patients with implant-supported dentures (retained by bar-clip or ball attachments). The decreased chewing rate with conventional dentures may be due to subjects with mucosa-supported dentures compensating for their low exerted occlusal forces during mastication by increasing the number of chews.[49] The chewing rate for hard food was significantly higher than soft food. Similarly, Karkazis[19] studied the influence of food texture on chewing rate and found a significantly higher chewing rate for harder food (carrot) than soft food (apple) for patients wearing ball-retained mandibular overdentures. They added that the rhythm of chewing is directly related to food consistency and harder food requires higher rates of chewing.

The rate of chewing inversely related to the duration of the chewing cycle.[50] Therefore, the lowest duration of chewing cycle was noted with conventional dentures, and the highest duration of chewing cycle was observed with ball overdentures. The increased duration of chewing cycle with ball overdentures is probably due to the increased stability and retention of the denture that enables more extreme chewing movements.[51] Similarly, Karkazis[19] found that chewing cycle duration was longer with a ball-retained implant-retained overdenture than complete dentures. No difference in duration of chewing cycle between ball overdentures, bar overdentures, and Locator overdentures was observed for hard and soft foods. Similarly, van der Bilt et al[24] reported that the different retentive capacities of the attachments (magnet, ball, and bar-clip) had no noticeable effect on the cycle duration. The increased duration of chewing cycle of soft food compared to hard food was in line with the finding of Karkazis,[19] who found that chewing apple had higher duration of chewing cycles than chewing carrot. Similarly, Tang et al (1999)[23] reported a significant increase in cycle duration during chewing of bread, but for carrot, it decreased rapidly.

The improved stability and retention of the prosthesis enables the patient to exert high muscular effort for a longer time (when clenching teeth in centric position) and give a longer time of chewing burst. Therefore, the lowest duration of chewing burst was noted with conventional dentures, and the highest duration of chewing burst was observed with ball overdentures. Hard food recorded a significantly higher duration of chewing burst than soft food. Similarly, Karkazis[19] found higher chewing burst duration for carrot than apple. He attributed this finding to the increased relative contraction period and high levels of energy required for hard food.

Conventional dentures showed significantly higher masticatory time than implant overdentures regardless of the attachment type used. A similar finding was also observed in previous studies.[52,53] No significant difference in masticatory time was noted between ball overdentures, bar overdentures, and Locator overdentures. This finding agrees with Uçankale and colleagues,[22] who reported no significant differences in chewing time between the ball and bar attachment groups. The increased masticatory time with hard food compared with soft food was in line with Tang et al,[34] who found that carrot and sausage took a longer time to chew than apple, cheese, and bread.

Finally, ball attachments may be recommended to retain overdentures in patients with atrophied mandibles more than bar and Locator attachments, as they were associated with increased muscle activity, which may increase chewing efficiency for these patients. However, another study is needed to test if the difference in muscle activity between the attachments has a significant clinical effect on subjective patient rating of chewing ability with these attachments. Also, it should be noted that the selection of implant attachments is more likely to be based on other factors than muscle activity such as cost, ease of use, room needed for attachment within the denture, need for maintenance, and the longevity of satisfactory retention as rated by the patient. Therefore, long-term clinical trials are still needed to evaluate the patient-based outcome, prosthetic aspects, chewing efficiency, and maximum occlusal force of the tested attachments in patients with atrophied mandibular ridges.

CONCLUSIONS

Within the limitations of this short-term crossover study, the following conclusions could be drawn: *(1)* implant-retained mandibular overdentures recorded higher masticatory functions compared with conventional dentures regardless of the type of attachment used; and *(2)* ball and socket attachment is recommended to retain two-implant mandibular overdentures more than bar and Locator attachments, as it was associated with increased EMG activity, increased chewing area, reduced chewing rate, and increased durations of chewing cycle and chewing bursts.

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