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Longitudinal changes in electromyographic activity of masseter and anterior temporalis muscles before and after alloplastic total joint replacement in patients with temporomandibular ankylosis: a prospective study

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Abstract

The purpose of the study was to evaluate the longitudinal changes in electromyographic (EMG) activity of the masseter and temporalis muscles before and after temporomandibular joint (TMJ) total joint replacement (TJR) in ankylosis patients. A prospective longitudinal study was designed on patients undergoing unilateral or bilateral TMJ-TJR. EMG activity at rest and maximal voluntary contraction (MVC) was recorded for the muscles preoperatively (T0), and at one-week (T1) and six-month (T2) follow up. The study sample was composed of 10 (male: female 2.3:1) patients undergoing TMJ-TJR. The number of unilateral and bilateral cases was three and seven, respectively. In both unilateral and bilateral cases a statistically significant reduction in EMG activity of the masseter and anterior temporalis muscles was observed at T1. At T2, EMG activity of the muscles was found to be approaching the preoperative value. In unilateral cases, when the affected side at T0, T1, and T2 was compared with T0 for the unaffected side, statistically significant differences were seen for the masseter. In the case of the temporalis, similar results were seen except at T2 for the postural rest position. The results indicate that re-attachment of the masseter and temporalis muscles occurs progressively post TMJ-TJR.

Keywords: Temporomandibular joint ankylosis; Total joint replacement; Electromyographic activity

Introduction

Alloplastic joint replacement is the standard of care in adult patients with temporomandibular joint ankylosis (TMJA).[1,2] In a natural TMJ, muscles and ligaments play an important role in mandibular motion and masticatory forces. Disease involving the TMJ affects the stomatognathic system, including the surrounding musculature. Prolonged isometric contraction of the masseter and temporalis muscles leads to enlargement of the coronoid and a deepened antegonial notch.[3] In patients with TMJA, the affected muscles show hyperaemia, raised temperature, increased tonicity, and atrophy.[4] Ultrastructurally, the temporalis and masseter have been found to undergo degenerative changes in cases of mandibular hypomobility.[5]

Placement of a TMJ-TJR requires extensive stripping of the masseter muscle and pterygomasseteric sling, especially in the case of a stock prosthesis. Temporal myotomy with coronoidectomy is often required to improve the range of motion. Activity of the masseter and temporalis muscles has been analysed using electromyography (EMG) after gap arthroplasty.[6] Animal studies have shown that the reattachment interface of the masseter following surgical detachment was similar to that of the control.[7] EMG is a conventional means of analysing masticatory muscle

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activity. In orthopaedic literature, EMG of limb muscles has shown favourable changes that have helped after placement of total knee and hip prostheses.[8] The curiosity to know about the prognosis of these detached muscles prompted us to evaluate their activity electromyographically.

Material and methods

Study design

The investigators implemented a prospective longitudinal study after approval by the institute's ethics committee (IECPG-341/29.05.2019). The study sample was composed of all TMJA patients aged over 15 years who were undergoing TMJ-TJR between June 2019 and December 2020. Patients with a known allergy to metals, and those with neuromuscular disorders were excluded.

Study variables

The primary objective was to compare EMG activity of the masseter and temporalis muscles preoperatively (T0), and one week (T1), and six months postoperatively (T2), both at rest and maximum voluntary contraction (MVC). In unilateral cases EMG activity at T0, T1, and T2 on the ankylosed side was also compared with T0 on the non-ankylosed side. Secondary objectives were to evaluate maximal incisal opening (MIO), time to fatigue, and demographics.

Sample size calculation

G Power software (version 3.0.10) was used for sample size calculation. Based on a calculated effect size of 0.893, 5% level of precision, 95% confidence level, and 80% power of the study, the minimum sample size calculated was 10 patients**.**

EMG technique

EMG was performed by a physiologist (RB) who was not blinded. Bilateral EMG signals were recorded from the masseter and anterior temporalis muscles. A 4-channel EMG, BSL pro V 3.6.7 MP 30 model (Biopac Student Lab, BIOPAC Systems Inc) was used. Two Ag/AgCl disc electrodes were placed along the major direction of muscle fibres. Subjects were instructed to maintain a natural head position in a shielded room to eliminate outside electrical interferences. To place the electrodes, the function test, which consisted of muscular palpation during simultaneous bilateral isotonic contraction, was performed. For the masseter, electrodes were placed between the gonion and body of the zygomatic bone. For the anterior temporalis, electrodes were placed just above the upper edge of the zygomatic arch and posterior to a line passing through the posterior limit of the prominence formed by the zygomatic process of the frontal and frontal process of the zygomatic bone, and anterior to the scalp.[9] Ground electrodes were placed on the respective mastoid process. Time to fatigue was recorded as time (in seconds) during which the muscles on both sides were able to perform maximum contraction until pain due to fatigue was first perceived by the patient.

Data analysis

Data analysis was done with the use of IBM SPSS Statistics for Windows version 21 (IBM Corp). Normality of data was checked by the Shapiro-Wilk W test. Analysis was therefore performed using parametric tests. The independent *t* test was used to compare two groups, and the paired *t* test for pairwise comparison. Repeated measures of ANOVA were used for comparisons at different time periods. Probabilities of less than 0.05 were considered statistically significant.

Results

The study sample consisted of 10 (male: female = 2.3:1) patients (7 bilateral and 3 unilateral cases). The mean (SD) duration of ankylosis (DOA) was 11.9 (8.0) years. A statistically significant increase in MIO was seen from T0 to T2 ($p = 0.001$). Six stock and four custom prostheses were used. Bilateral coronoidectomies were performed in all bilateral cases and one unilateral case. Unilateral coronoidectomy was performed in two unilateral cases. Five patients with stock prostheses underwent bilateral coronoidectomy and one underwent unilateral coronoidectomy. Of four patients with custom prostheses, three had bilateral coronoidectomy and one unilateral coronoidectomy (Table 1).

Table 1
Summary of the study sample (n = 10).

Study variables	Descriptive statistics
Sample size	10 patients (17 joints)
Affected side:	
Unilateral:	
Right	3
Left	0
Bilateral	7
Mean (SD) age (years)	26.6 (10.6)
Gender:	
Male	7
Female	3
Aetiology: ankylosis	
Post-traumatic	9
AS	1
Recurrent cases	6
Mean (SD) duration of ankylosis (years)	11.9 (8.0)
Follow up (months)	6
Type of prosthesis:	
Stock	6
Custom	4
Coronoidectomy:	
Bilateral	8
Ipsilateral	2
Mean (SD) MIO (mm):	
Preoperative (T0)	7.2 (8.0)
Follow up (T2)	29.5 (8.7)

TMD: temporomandibular joint disease; AS: ankylosing spondylitis; MIO: maximal incisal opening

Table 2
Trends of electromyographic activity on affected side in unilateral cases.

	No.	Mean (SD)	Mean SE	Pairwise comparison	p[a] value	p[b] value
Affected masseter:						
Postural rest position						0.0001
T0	3	33.37 (24.54)	14.17	T1	0.297	
				T2	0.366	
T1	3	13.13 (12.94)	7.47	T0	0.297	
				T2	0.801	
T2	3	12.00 (14.93)	8.62	T0	0.366	
				T1	0.801	
Maximum voluntary contraction						0.0001
T0	3	114.1 (10.36)	5.98	T1	0.183	
				T2	0.403	
T1	3	31 (38.97)	22.5	T0	0.183	
				T2	0.027*	
T2	3	69.33 (45.88)	26.49	T0	0.403	
				T1	0.027*	
Affected temporalis:						0.0001
Postural rest position						
T0	3	13.60 (9.71)	5.61	T1	0.011*	
				T2	0.901	
T1	3	9.33 (7.57)	4.37	T0	0.011*	
				T2	0.07	
T2	3	7.00 (4.58)	2.65	T0	0.336	
				T1	0.065	
Maximum voluntary contraction						0.0001*
T0	3	181.97 (18.27)	10.55	T1	0.212	
				T2	0.224	
T1	3	121.67 (35.53)	20.51	T0	0.212	
				T2	0.004*	
T2	3	266.00 (51.16)	29.54	T0	0.224	
				T1	0.004*	

T0: preoperative time; T1: 1-week follow up; T2: 6-month follow up.
*significant p value

In unilateral cases, the mean (SD) resting EMG value of the masseter on the affected side at T0, T1, and T2 was 33.33 (24.54) μV, 13.13 (12.94) μV, and 12.0 (14.93) μV, respectively. The difference between T0, T1, and T2 was statistically insignificant (Table 2). The mean (SD) EMG value at MVC for the masseter on the affected side was 114.1 (10.36) μV, 31 (38.97) μV, and 69.33 (45.88) μV at T0, T1, and T2, respectively. The difference was statistically significant between T1 and T2 (p = 0.027) (Table 2). Repeated measures ANOVA for resting and MVC at all time periods revealed a statistically significant difference (p = 0.0001) (Table 2).

The difference in EMG activity of the temporalis at rest was statistically significant between T0 and T1 only (p = 0.011) (Table 2). Repeated measures ANOVA for all time periods revealed a statistically significant difference (p = 0.0001). At MVC, the difference was statistically significant between T1 and T2 (p = 0.004) (Table 2). Comparison of EMG activity at different intervals on the affected side and with the preoperative (T0) value on the unaffected side is given in Table 3. For the masseter there was a statistically significant difference between all intervals on the affected side and T0 on the unaffected side (Table 3). For the temporalis, the difference was statistically significant at all intervals except between the T0 value on the unaffected side and the T2 value on the affected side at the resting position (Table 3).

Bilateral cases

On the right-side masseter at rest, the paired *t* test revealed a statistically significant reduction in EMG value between T0 and T1 (p = 0.001) and a statistically significant increase between T1 and T2 (p = 0.001) (Table 4). Likewise, on the left side at rest there was a statistically significant reduction in EMG value between T0 and T1 (p = 0.001), and a statistically significant increase from T1 and T2 (p = 0.001) (approaching the preoperative value). At MVC the right masseter muscle showed a statistically significant reduction in EMG activity between T0 and T1 (p = 0.03), and between T0 and T2 (p = 0.001), but a statistically significant increase between T1 and T2 (p = 0.001). Similar results were observed in left masseter EMG activity at MVC (Table 4).

On the right temporalis at rest there was a statistically significant increase from T1 to T2 (p = 0.001). Similarly, the left temporalis at rest showed a statistically significant increase from T1 to T2 (p = 0.001). At MVC, the right temporalis

Table 3
Trends in electromyographic (EMG) activity in unilateral cases when compared with preoperative value of unaffected side.

		No.	Mean (SD)	Mean SE	p value
Masseter:					
Postural rest position					
T0	Affected	3	33.37 (24.54)	14.17	0.049*
	T0 unaffected	3	27.20 (23.33)	13.47	
T1	Affected	3	13.13 (12.94)	7.47	0.001*
	T0 unaffected	3	27.20 (23.33)	13.47	
T2	Affected	3	12.00 (14.93)	8.62	0.001*
	T0 unaffected	3	27.20 (23.33)	13.47	
Maximum voluntary contraction					
T0	Affected	3	114.10 (10.36)	5.98	0.001*
	T0 unaffected	3	95.33 (25.96)	14.99	
T1	Affected	3	31.00 (38.97)	22.50	0.001*
	T0 unaffected	3	95.33 (25.96)	14.99	
T2	Affected	3	69.33 (45.88)	26.49	0.001*
	T0 unaffected	3	95.33 (25.96)	14.99	
Temporalis:					
Postural rest position					
T0	Affected	3	13.60 (9.71)	5.61	0.001*
	T0 unaffected	3	6.67 (6.35)	3.67	
T1	Affected	3	12.80 (5.52)	3.19	0.001*
	T0 unaffected	3	6.67 (6.35)	3.67	
T2	Affected	3	7.00 (4.58)	2.65	0.300
	T0 unaffected	3	6.67 (6.35)	3.67	
Maximum voluntary contraction					
T0	Affected	3	181.97 (18.27)	10.55	0.046*
	T0 unaffected	3	162.67 (39.17)	22.62	
T1	Affected	3	121.67 (35.53)	20.51	0.001*
	T0 unaffected	3	162.67 (39.17)	22.62	
T2	Affected	3	266.00 (51.16)	29.54	0.001*
	T0 unaffected	3	162.67 (39.17)	22.62	

T0: preoperative time; T1: 1-week follow up; T2: 6-month follow up
* significant p value

showed a statistically significant reduction in EMG activity between T0 and T1 (p = 0.003), but a statistically significant increase between T0 and T2 (p = 0.001) (follow-up value was more than the preoperative value) (Table 5). The left temporalis at MVC showed a statistically significant reduction in EMG activity from T0 to T1 (p = 0.001) but a statistically significant increase between T1 and T2 (p = 0.003) and between T0 and T2 (p = 0.001) (follow-up value was more than the preoperative value) (Table 5). Repeated measures ANOVA for all the time periods revealed a statistically significant difference (p = 0.0001) (Table 5).

Time to fatigue

Time to fatigue for the masseter revealed a statistically significant reduction between T0 and T1 (p = 0.001). The difference was statistically insignificant between T0 and T2 (p = 0.07) and between T1 and T2 (p = 0.32) (Table 6).

For the temporalis, there was a statistically insignificant reduction between T0 and T1 (p = 0.059) and unexpectedly, a statistically significant increase in time to fatigue from T0 to T2 (p = 0.001) and from T1 to T2 (p = 0.001) (Table 6).

Discussion

In an ideal theoretical scenario, reattachment of the masseter muscle over the rest of the prosthesis-free surface of the mandible, as well as over the mandibular component of the TMJ-TJR, is expected. Animal studies have shown measurable attachment of titanium implants with muscle tissue.[10] For a given muscle, the firing of motor units and their subsequent recruitment increases with the intensity of contraction.[11] The measure of EMG activity at MVC indicates frequency and number of working motor units.[12]

In unilateral cases, the mean EMG activity of the masseter and temporalis muscles was significantly greater on the affected side when compared with the unaffected side. In cases of TMJA, the masticatory muscles usually remain in a state of ‘myostatic contracture’. To maintain optimum function, increased effort is exerted by these groups of muscles during forced opening, and when clenching or chewing.[13] This finding is in agreement with previous reports.[7]

At T1, as the muscles have been detached, it is not surprising that muscle activity is reduced (due to the detachment of the muscle). In primates, masticatory muscle detachment and

Table 4
Comparison of electromyographic (EMG) activity of right and left masseter muscle in bilateral temporomandibular joint replacement (TMJR) cases (intra-group).

	No.	Mean (SD)	Mean SE	Pairwise comparison	p^a value	p^b value
Right masseter:						
Postural rest position						0.0001*
T0	7	14.00 (11.34)	4.287	T1	0.001	
				T2	0.767	
T1	7	4.67 (4.83)	1.824	T0	0.001*	
				T2	0.001*	
T2	7	12.43 (7.76)	2.935	T0	0.767	
				T1	0.001*	
Maximum voluntary contraction						0.0001*
T0	7	108.53 (54.45)	20.582	T1	0.03*	
				T2	0.001*	
T1	7	29.10 (32.17)	12.160	T0	0.03*	
				T2	0.001*	
T2	7	65.29 (32.06)	12.118	T0	0.001*	
				T1	0.001*	
Left masseter:						
Postural rest position						0.0001*
T0	7	13.49 (6.77)	2.559	T1	0.001*	
				T2	0.784	
T1	7	6.14 (7.91)	2.990	T0	0.001*	
				T2	0.001*	
T2	7	11.77 (12.73)	4.813	T0	0.784	
				T1	0.001*	
Maximum voluntary contraction						0.0001*
T0	7	106.44 (73.41)	27.75	T1	0.001*	
				T2	0.001*	
T1	7	21.83 (9.74)	3.68	T0	0.001*	
				T2	0.001*	
T2	7	84.14 (53.88)	20.36	T0	0.001*	
				T1	0.001*	

[B]Repeated measures of ANOVA, [a] paired t test, Level of significance set at $p < 0.05$
* significant p value
T0: preoperative; T1: 1 week postoperatively; T2: 6 months postoperatively

temporalis muscle transposition result in a transient reduction in muscle activity.[14] Detached jaw muscle without subsequent reattachment has been found to shorten spontaneously, and frequently reattaches at a shorter length.[15] Other reasons can be postoperative pain and swelling and postoperative occlusal changes. Subjects with skeletal or dentoalveolar open bite have been reported to have lower EMG activity.[16] After the release of ankylosis, altered occlusal contacts affect masticatory muscle activity by the stimulation of periodontal mechanoreceptors.[15]

At T2, mean EMG activity at rest and MVC of the masseter were found to be approaching pre-treatment EMG activity. A similar longitudinal increase in muscle activity after TMJ arthroplasty has been observed.[7] However, during revision surgery, the masseter would reattach to the bone, not to the prosthesis. The periosteum can more easily be pushed off the prosthesis than the normal ramus. Muscle reattachment takes around six weeks to occur, and at that stage patients tend to get myofascial pain, as mouth opening has started to recover and the muscles are being stretched more than they were previously. Functional activity does not start to recover until six months despite opening and pain being significantly improved at that stage. The ability to eat a normal diet starts to improve from five to six months but is not fully restored until one year. At that stage opening should be stable, and myofascial pain should start to reduce. Studies on biomaterials for orthopaedic use have shown higher proliferation and adhesion of osteoblasts and fibroblasts over titanium, and cobalt-chromium and molybdenum alloys when compared with ultra-high molecular-weight polyethylene (UHMWPE) and polyether sulphone.[17] It can therefore be assumed that the masseter is being reattached to the surface of the mandibular component of the TMJR. Activity of the temporalis at T2 was found to exceed the pre-treatment levels at rest and MVC. In a cadaveric study, it was demonstrated that the distal insertion of anterior temporalis extends to the retromolar triangle along its medial and lateral margin.[18] It can therefore be expected that even after coronoidectomy, this portion of distal attachment remains preserved. In unilateral cases at T2, anterior temporalis muscle demonstrated higher activity on the TMJ-TJR side, whereas masseter muscle activity was higher on the contralateral side. In marginal mandibulectomy cases, Haraguchi et al found increased temporalis activity on the resected side to counterbalance muscular activity with the non-resected side.[19]

Table 5
Comparison of EMG activity of right and left temporalis muscle in bilateral temporomandibular joint replacement (TMJR) cases.

	No.	Mean (SD)	Mean SE	Pairwise comparison	p^a value	p^b value
Right temporalis:						
Postural rest position						0.0001*
T0	7	21.34 (21.46)	8.11	T1	0.067	
				T2	0.542	
T1	7	12.14 (12.94)	4.89	T0	0.067	
				T2	0.001*	
T2	7	24.79 (28.91)	10.93	T0	0.542	
				T1	0.001*	
Maximum voluntary contraction						0.0001*
T0	7	168.36 (105.31)	39.80	T1	0.003*	
				T2	0.001*	
T1	7	77.00 (60.68)	22.93	T0	0.003*	
				T2	0.042*	
T2	7	204.71 (46.90)	17.73	T0	0.001*	
				T1	0.042*	
Left temporalis:						
Postural rest position						0.0001*
T0	7	20.63 (21.07)	7.96	T1	0.387	
				T2	0.254	
T1	7	12.26 (12.87)	4.86	T0	0.387	
				T2	0.001*	
T2	7	22.43 (18.34)	6.93	T0	0.254	
				T1	0.001*	
Maximum voluntary contraction						0.0001*
T0	7	155.21 (99.11)	37.46	T1	0.001*	
				T2	0.001*	
T1	7	94.67 (57.43)	21.70	T0	0.001*	
				T2	0.003*	
T2	7	195.57 (56.26)	21.26	T0	0.001*	
				T1	0.003*	

[B]Repeated measures of ANOVA, [a] paired t test, level of significance set at $p < 0.05$
*signifies significant p value

Table 6
Comparison of time to fatigue of masseter and temporalis muscles on both sides.

Muscles	No.	Mean (SD)	Mean SE	Pairwise comparison	p^a value	p^b value
Masseter:						0.001*
T0	10	69.18 (22.56)	7.134	T1	0.001*	
				T2	0.070	
T1	10	48.03 (23.35)	7.383	T0	0.001*	
				T2	0.320	
T2	10	66.31 (22.36)	7.070	T0	0.070	
				T1	0.320	
Temporalis:						0.0001*
T0	10	48.81 (20.50)	6.48	T1	0.059	
				T2	0.001*	
T1	10	43.66 (26.30)	8.32	T0	0.059	
				T2	0.001*	
T2	10	77.93 (32.34)	10.23	T0	0.001*	
				T1	0.001*	

[B]Repeated measures of ANOVA, [a] paired *t* test, level of significance set at $p < 0.05$
*signifies significant p-value
T0: preoperative; T1: 1 week postoperatively; T2: 6 months postoperatively

The smallest of the stock prostheses is often not suitable for use in ankylosis patients due to ramal shortening. Ramal lengthening, which happens if the correction of the maxillary plane is done simultaneously with TJR, has an adverse effect on muscle function, as the pterygomasseteric sling is divided and bone and the prosthesis are pushed between it. This does not lengthen the muscle, and it has to reattach much higher up causing a prolonged period of restricted mouth opening. In the present study, no ramal lengthening was done.

The anterior temporalis showed higher EMG activity than the masseter muscle during the whole observation period of six months; similar observation has been reported previously.[13,20] The difference between these two muscles can be attributed to their diverse structural composition[21–23] and allocated function. The temporalis primarily controls mandibular posture and is sensitive to positional changes around the maximum intercuspal position.[24,25] To preserve TMJ function, restoration of optimal occlusion should allow a masseter: temporalis ratio of about 1:5 during clenching.[26]

The time to fatigue was longer than in healthy adults. In TMJA patients the masticatory muscles are in a state of hyperactivity with a larger cross-sectional area than in controls,[27,28] which leads to the increase in endurance time. This can be related to the fact that patients who have undergone TMJ-TJR have improvements in chewing efficiency, function, and dietary limitations.[29] Linsen et al reported higher average EMG activity of both muscles during postoperative years one to three when a custom prosthesis was used, though this was not statistically significant.[30] However, mean EMG activity at four years postoperatively was similar for both prostheses.

Our results support the fact that muscles are reattached to the same pre-treatment levels. However, for evaluation of exact metal-muscle integrations, histological studies in human subjects are required. The present study will contribute to the evidence of the changes in masticatory muscle activity after TMJ-TJR placement. The limitations of the present study are the absence of EMG examination of internal muscles such as the lateral pterygoid, which is often detached during condylectomy for TMJ-TJR, and the low number of analysed subjects. Another potential limitation is the short follow up, as activity of the masticatory muscles following alloplastic replacement will not return to near normal until one year, as full function does not recover until this stage. Further studies with larger sample sizes and longer follow up are recommended.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

Ethics approval taken (Ref No. IECPG-341/29.05.2019). Consent taken.

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