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L. R. Iwasaki
Y. M. Gonzalez
H. Liu
D. B. Marx
L. M. Gallo
J. C. Nickel

A pilot study of ambulatory masticatory muscle activities in temporomandibular joint disorders diagnostic groups

Authors' affiliations:
L. R. Iwasaki, H. Liu, J. C. Nickel, Departments of Orthodontics & Dentofacial Orthopedics and Oral & Craniofacial Sciences, School of Dentistry, University of Missouri–Kansas City, Kansas City, MO, USA
Y. M. Gonzalez, Department of Oral Diagnostic Sciences, School of Dental Medicine, University at Buffalo, Buffalo, NY, USA
D. B. Marx, Department of Statistics, University of Nebraska-Lincoln, Lincoln, NE, USA
L. M. Gallo, Clinic of Masticatory Disorders, Removable Prosthodontics, Geriatric and Special Care Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland

Correspondence to:
L. Iwasaki
Department of Orthodontics and Dentofacial Orthopedics
School of Dentistry
University of Missouri–Kansas City
650 E. 25th Street
Kansas City
MO 64108
USA
E-mail: iwasakil@umkc.edu

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Structured Abstract

Objective – To determine differences in masticatory muscle usage between temporomandibular joint disorders diagnostic groups.

Setting and sample population – Seventy-one informed and consented subjects (27 men; 44 women) participated at the University at Buffalo.

Material and methods – Research diagnostic criteria and imaging data were used to categorize subjects according to the presence/absence (+/−) of TMJ disc placement (DD) and chronic pain (P) (+DD+P, n = 18; +DD−P, n = 14; −DD−P, n = 39). Electromyographic (EMG)/bite-force calibrations determined subject-specific masseter and temporalis muscle activities per 20 N bite-force (T_{20N}, μV). Over 3 days and nights, subjects collected EMG recordings. Duty factors (DFs, % of recording time) were determined based on threshold intervals (5–9, 10–24, 25–49, 50–79, ≥80% T_{20N}). ANOVA and Tukey–Kramer *post hoc* tests identified 1) diagnostic group differences in T_{20N} and 2) the effects of diagnostic group, gender, time and interval on muscle DFs.

Results – Mean (± SE) temporalis T_{20N} in +DD+P subjects was significantly higher (71.4 ± 8.8 μV) than masseter T_{20N} in these subjects (19.6 ± 8.8 μV; $p = 0.001$) and in −DD−P subjects (25.3 ± 6.0 μV, $p = 0.0007$). Masseter DFs at 5–9% T_{20N} were significantly higher in +DD−P women (3.48%) than +DD−P men (0.85%) and women and men in both other diagnostic groups (all $p < 0.03$), and in +DD+P women (2.00%) compared to −DD−P men (0.83%; $p = 0.029$). Night-time DFs at 5–9% T_{20N} in +DD−P women (1.97%) were significantly higher than in −DD−P men (0.47%) and women (0.24%; all $p < 0.01$).

Conclusions – Between-group differences were found in masticatory muscle activities in both laboratory and natural environmental settings.

Key words: ambulatory; duty factor; electromyographic; masticatory muscle; temporomandibular joint disorder

Introduction

The likelihood of developing degenerative joint disease of the temporomandibular joint (TMJ) is related to the integrity of the TMJ disc (1). Disc dysfunction occurs in approximately 30% of patients with temporomandibular joint disorders (TMJD) (2, 3). The mean age of onset of degenerative changes in the TMJ is between 25 and 35 years (4–7), which is a decade earlier than in post-cranial joints (8, 9).

The aetiology of TMJ disc failure and factors that promote the development of degenerative joint disease have yet to be elucidated. Articular tissue failure in synovial joints is thought to involve mechanical fatigue and, thus, be dependent on magnitudes and frequencies of applied mechanical stress (10, 11). Why destruction of the articular tissues occurs earlier in the TMJ compared to knees and hips likely reflects the influence of these variables (12, 13). However, how much and how often mandibular loading occurs during the day and night in natural settings have so far rarely been documented. To date, the most comprehensive data describing the muscle behaviours which affect magnitudes of TMJ loads have been reported for masseter muscle activities recorded during polysomnographic monitoring of female subjects with and without myofascial pain (14, 15). Contrary to conventional wisdom and self-reports of significantly higher rates of sleep bruxism in subjects with myofascial pain compared to healthy controls, night-time laboratory recordings showed neither group exhibited high-threshold masseter activities characteristic of bruxism (15). However, subjects with myofascial pain showed significantly higher 'background' masseter muscle activities, not attributable to bruxism or other identifiable orofacial functions, compared to demographically matched controls (14). In addition, this background muscle activity was associated with higher reported pain before or after sleep in the myofascial pain group. The authors posit that persistent low-magnitude activity in the masticatory muscles may be a mechanism of induction and/or maintenance of TMJD symptoms.

To understand better why the TMJ is susceptible to early degenerative changes compared to post-cranial joints, gaps in knowledge about the magnitude and frequency of jaw loading behaviours should be addressed. For example, to date, there are no known comparisons of frequencies of mandibular loading via the masseter and temporalis muscles during the day and night in diagnostic groups with and without TMJD. This study aimed to address the knowledge gap by testing the hypothesis that there were differences amongst two groups with TMJD and a healthy group without TMJD in jaw loading behaviours, specifically: muscle activations to produce the same bite-force and percentages of time of muscle use in the subjects' natural environments.

Materials and methods

Subjects

Seventy-one subjects (male n = 27; female n = 44) gave informed consent to participate in this pilot study. Subjects were recruited at the University at Buffalo School of Dental Medicine. Study protocols were approved by Institutional Review Boards at both University at Buffalo and University of Missouri–Kansas City. Inclusion and classification of subjects were based on research diagnostic criteria for the TMJ (RDC/TMJ) (16) and magnetic resonance (MR) and cone-beam computed tomography (CBCT) images of the TMJs (2). Individuals were excluded from participating if they were pregnant, had a diagnosed systemic musculoskeletal or rheumatological disease such as fibromyalgia or muscular atrophy or had TMJ-degenerative disease based on CBCT imaging. As well, subjects were not allowed to participate if they had multiple missing teeth, large dental restorations, or fixed orthodontic appliances. Participants included 14 subjects with bilateral disc displacement, but without TMD pain (+DD−P, 3 men, 11 women, average age 36 ± 10 years); 18 subjects with bilateral disc displacement and chronic myofascial and/or TMJ pain (+DD+P, 2 men, 16 women, average age 36 ± 14 years); and 39 healthy control subjects (−DD−P, 22 men, 17 women, average age 31 ± 10 years).

Laboratory calibrations

Characterization of ambulatory muscle behaviour was accomplished by determining masseter and temporalis duty factors (DFs) (17, 18). DF represented the amount of time each muscle was activated at specific magnitudes during a given time period (%). To standardize the analysis amongst subjects, right masseter and temporalis electromyographic activities (root mean square EMG, μV) were calibrated relative to bite-force (N). Calibration data consisted of a set of static and dynamic molar bites of light to moderate magnitudes on a previously described custom bite-force transducer (19) performed on one side at a time. Five static bites on the right and then the left sides each lasted about 5 s, with approximately 5 s of rest between bites (Fig. 1A). Dynamic bites on the right and then the left sides were performed at each of four frequencies: 0.5, 1, 1.5 and 2 Hz, with approximately 10 s rest between frequencies (Fig. 1B), by following an auditory signal from a digital metronome (TempoPerfect; NCH Software Inc., Greenwood Village, CO, USA). The centroids of the right and left masseter and anterior temporalis muscles were determined by palpation, the skin overlying cleaned with isopropyl alcohol, and then self-adhering bipolar surface electrodes (Ambu Neuroline 720; Ambu A/S, Olstykke, Denmark) were affixed. Similarly, a single electrode was affixed to the right mastoid process as a ground. Electrical signals from each muscle were amplified and filtered (10 P511 AC Grass Preamplifiers; Astro-Med, West Warwick, RI, USA). These muscle activities and bite-forces were tape-recorded (Sony PC-216A 16 Channel Recorder; Spectris Technologies Inc., Norcross, GA, USA), digitized at 1000 Hz/channel using commercial software

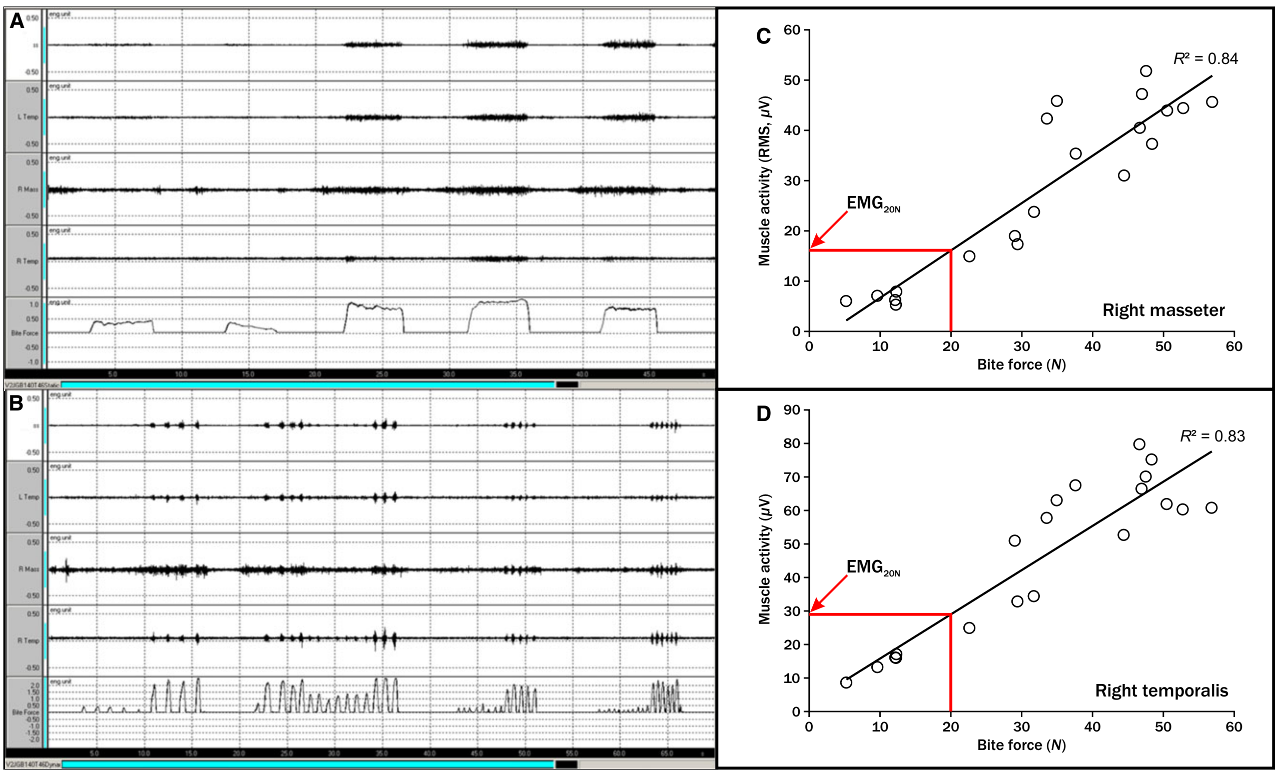

Fig. 1. Left masseter and temporalis and right masseter and temporalis muscle electromyographic (EMG) (Rows 1–4, respectively, of each graph) during (A) static and (B) dynamic biting (row 5 of each graph shows bite-forces) on the left first molar of one subject during one laboratory visit. For each subject, side of biting and visit, root mean square muscle activities (μV) vs. bite-force (N) were plotted; for example: (C) right masseter and (D) right temporalis muscles, where EMG$_{20N}$ indicates activity associated with a 20 N bite-force for the particular muscle.

(PCScan II; Sony Precision Technology American Inc., Lake Forest, CA, USA), and then analysed using custom-written computer programs (MatLab; MathWorks, Natick, MA, USA). Muscle activities (RMS EMG, mV) during the static and dynamic biting tasks were plotted vs. bite-force, and four separate linear regressions were fit to the masseter and temporalis data for biting on the right and left molars (Excel; MicroSoft, Inc., Redmond, WA, USA). During a second laboratory visit, the calibration protocol was repeated.

The resultant eight muscle activity vs. bite-force regressions from the two sides of biting and two visits for the same subject and muscle were averaged and used to estimate overall mean masseter and temporalis muscle activities required to produce a threshold bite-force of 20 N (T_{20N}, mV). The purposes of establishing muscle- and subject-specific T_{20N} were twofold. Firstly, this facilitated investigating whether there were muscle and diagnostic group differences in activities to produce a standardized bite-force. Secondly, the T_{20N} threshold data enabled comparing DFs due to different magnitudes of ambulatory muscle activities amongst diagnostic groups.

Ambulatory recording

During the first laboratory visit, subjects were trained in how to use the portable recording equipment. Custom portable EMG recorders were used for field recording of muscle activities (Fig. 2A) via surface electrodes. Signals were band-pass-filtered (20–1000 Hz) and amplified (5000×) digitally (DISA 15C 01; Disa Elektronik, Skovlunde, Denmark) using an input impedance of 250 MΩ, noise level of 0.7 μV, and common mode rejection ratio of 100 dB. Following training, each subject was able to use the portable EMG recorder to log muscle behaviour over three daytime and three night-time periods, each of at least 5 h duration. To accomplish this, subjects prepared the skin on one side of the face and behind one ear, then applied adherent pregelled disposable surface EMG electrodes (Alpine Biomed, Tonsbakken, Denmark) in pairs over the masseter and temporalis muscles and singly (as a ground) over the mastoid process (Fig. 2A).

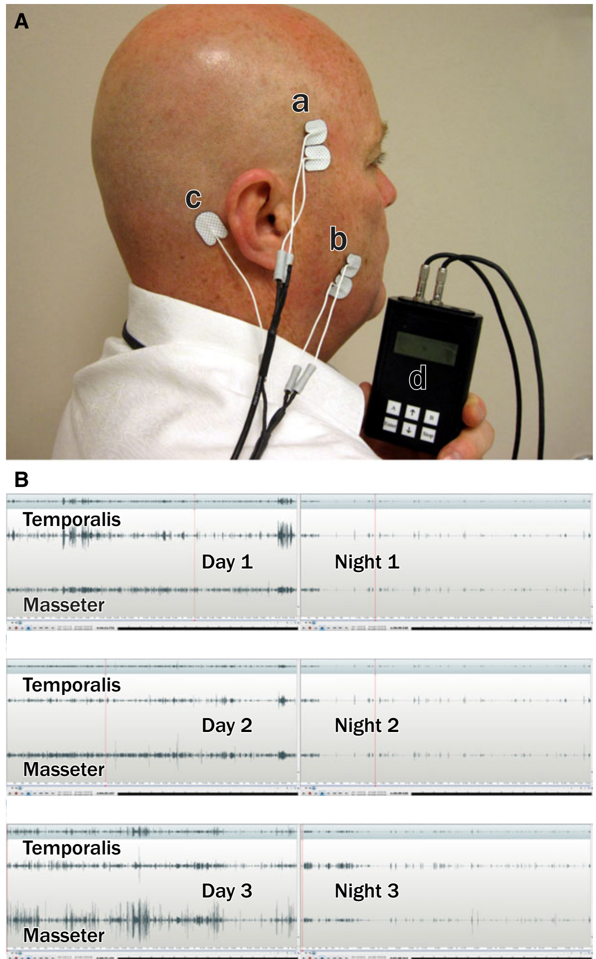

Fig. 2. (A) Custom portable electromyographic (EMG) recorders like the one shown were used by subjects in their natural environments during the day and night. Subjects were trained to apply surface electrodes in pairs over (a) temporalis and (b) masseter muscles, and singly (as a ground) over the (c) mastoid process and to use (d) recorder. (B) Example set of three day- and three night-time recordings from one subject.

Subjects followed training to start and stop the recorder, to remove the data storage chip at the end of a recording period and replace with a new one to begin the next recording period. Subjects kept a diary to note any usual or unusual events during the six recording periods (Fig. 2B) and returned equipment and data at the second laboratory visit.

Data analysis and statistics

The objective of recording and analysing masseter and temporalis muscle behaviours in subjects was to quantify the effect of intensity of loading of the mandible (%T_{20N}, μV) on muscle DFs (%).

Ambulatory EMG signals were recorded at 2000 samples/s/channel. Commercial software (WavePad Sound Editor Master Edition, Greenwood Village, CO, USA) was used to filter low-level noise. Custom computer programs (MatLab 7.9 R2009b; MathWorks) were used to process masseter and temporalis muscle activities over contiguous 128 ms time-windows and express results as RMS values (μV). Software automatically processed data in each 128 ms time-window using subject- and muscle-specific threshold intervals: 5–9, 10–24, 25–49, 50–79 and ≥80% T_{20N}. The number of windows meeting each inclusion criteria was added, and DF for each of the threshold intervals was calculated according to the equation:

$$\mathrm{DF} = \frac{(\#\mathrm{Windows})128\,\mathrm{ms}}{\mathrm{Total\ Recording\ Time}}.$$

ANOVA and Tukey–Kramer *post hoc* tests were used to compare the effects of muscle and diagnostic group on T_{20N} activities measured in the laboratory plus the combined effects of diagnostic group, gender, time (day or night), and threshold interval (%T_{20N}) on masseter and temporalis muscle DFs measured in the field.

Results

Differences in T_{20N} muscle activities

Subjects with +DD+P used significantly higher (mean ± SE) temporalis (71.4 ± 8.8 μV) compared to masseter (19.6 ± 8.8 μV) muscle activities to produce 20 N bite-forces (T_{20N}; $p = 0.001$, Fig. 3). There were no significant differences between masseter and temporalis T_{20N} within other diagnostic groups. The mean temporalis T_{20N} in +DD+P subjects was also significantly higher than mean masseter T_{20N} in −DD−P subjects (25.3 ± 6.0 μV, $p = 0.0007$, Fig. 3). Based on the current results, a power analysis showed that by approximately doubling the number of subjects, significant temporalis T_{20N} differences could be expected between +DD+P and +DD−P groups (Table 1).

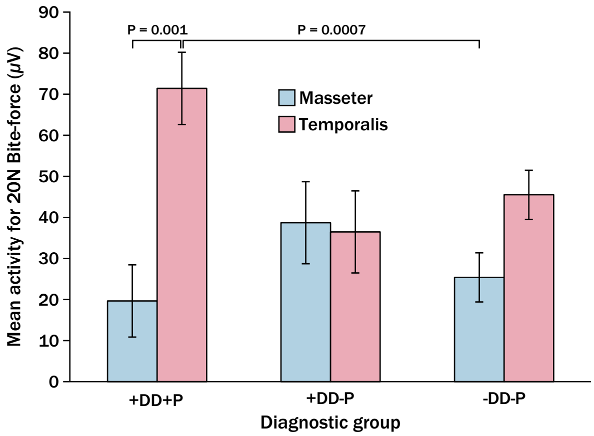

Fig. 3. Least-square means (LSM ± SE, μV) of muscle activities for 20N bite-force (T_{20N}) for diagnostic groups (+DD = bilateral disc displacement, +P = chronic jaw muscle and/or joint pain) and muscle (Masseter, Temporalis), where all p = Tukey–Kramer adjusted values.

Diagnostic group differences in muscle duty factors

Subjects produced 401 ambulatory EMG recordings, with average durations of 6.7 and 7.6 h for awake and night recordings, respectively. For the range of threshold intervals (%T_{20N}) investigated, DFs tended to be highest for 5–9% T_{20N} and decrease as threshold intervals increased to ≥80% T_{20N} for both muscles (Fig. 4 shows example data for masseter muscle). In general, DFs were larger for the masseter compared to the temporalis muscle and for women compared to men (Table 2). In particular, at the lowest threshold interval (5–9% T_{20N}), female subjects in the +DD−P, +DD+P and −DD−P groups used their masseter muscles 3.48, 2.00 and 1.19%, respectively, of ambulatory recording time, whereas male subjects in these groups used their masseter muscles 0.85, 0.35 and 0.83%, respectively, of ambulatory recording time (Table 2, Fig. 4). These masseter DFs at 5–9% T_{20N} where significantly higher for +DD−P women compared to +DD−P men and compared to women and men in both other diagnostic groups (Fig. 5, all $p < 0.03$), and for +DD+P women compared to healthy men ($p = 0.029$). No other gender-diagnostic group combinations had significantly different DFs for either masseter or temporalis muscles at the higher threshold intervals.

Table 1. **Least square mean differences (ΔLSM) and variance (± SE) for combined effects of muscle and diagnostic group (n = 68) showing results of ANOVA (T, *p* values), Tukey–Kramer *post hoc* tests (T-K $p_{Adjusted}$) and power analyses (using $\alpha = 0.05$, $\beta = 0.80$; N = total sample size)**

Combined effects (Muscle*diagnostic groups)	ΔLSM ± SE	*T*	*p*	T-K $p_{Adjusted}$	Power analysis (N)
Masseter*+DD+P*+DD−P	−19.1 ± 13.4	−1.43	0.158	0.710	510
Masseter*+DD+P*−DD−P	−5.7 ± 10.7	−0.54	0.593	0.994	5540
Masseter*+DD−P*−DD−P	13.3 ± 11.7	1.14	0.258	0.862	1030
Temporalis*+DD+P*+DD−P	34.9 ± 13.4	2.62	0.011	0.106	156
Temporalis*+DD+P*−DD−P	25.9 ± 10.7	2.43	0.018	0.161	276
Temporalis*+DD−P*−DD−P	−9.1 ± 11.7	−0.78	0.441	0.971	2230

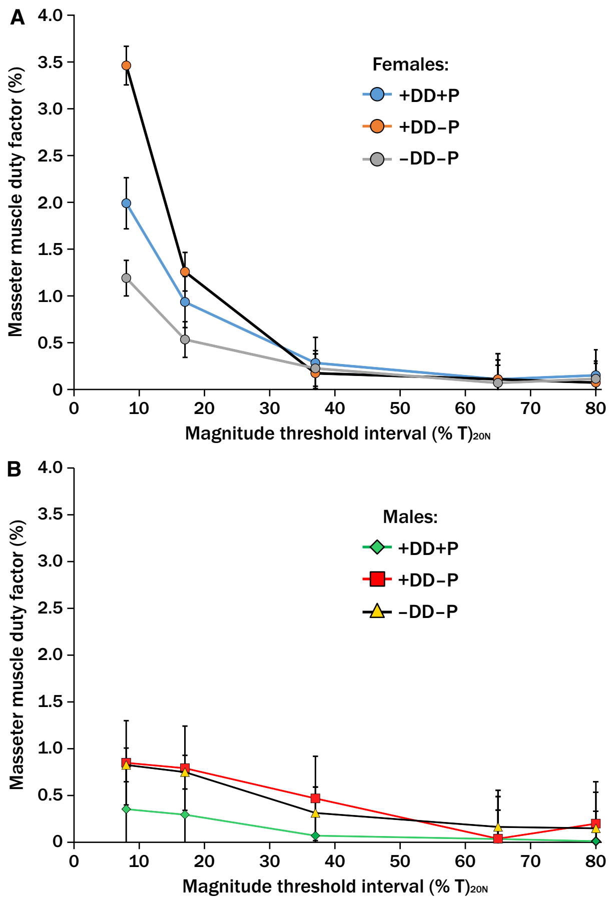

Fig. 4. Masseter muscle duty factors (DFs) in (A) women and (B) men where data from daytime and night-time recordings were pooled by diagnostic group (+DD = bilateral disc displacement, +P = chronic myofascial and/or temporomandibular joint pain) and least-square means calculated. Vertical bars show standard errors about the means.

When DFs (combined for masseter and temporalis muscles) at 5–9% T_{20N} were compared for day- and night-time recording periods, only +DD−P women showed similar results (2.02 and 1.97%, respectively) for both periods (Fig. 6). All other gender-diagnostic group combinations showed night-time DFs were 50–84% less than daytime DFs (Fig. 6). Furthermore, night-time DFs were significantly higher in +DD−P women compared to healthy women (0.24%) and men (0.47%) (Fig. 6, all $p < 0.01$).

Discussion

Individual-specific EMG vs. bite-force data from repeated standardized laboratory tasks were used to normalize and calibrate each subject's ambulatory EMG data collected in the field during the day and night. The pilot results showed that during the standardized tasks, subjects from three different diagnostic groups used their temporalis and masseter muscles differently. More specifically, +DD+P subjects used their temporalis muscles significantly more than their masseter muscles and significantly more than healthy subjects used their masseter muscles. In addition, the analysis of DFs showed that female +DD−P subjects used their masseter muscles at low levels of activation (5–9% T_{20N}) significantly more than men in the same group and women and men in the other two diagnostic groups. The female +DD−P subjects were also distinguished from healthy women and men by their significantly higher night-time use of masseter muscles at low levels of activation.

The intra- and intergroup differences in how temporalis and masseter muscles were used during standardized laboratory tasks may

Table 2. **Maximum duty factors (mean ± SE) for women and men in each diagnostic group (+DD = bilateral disc displacement, +P = chronic jaw muscle and/or joint pain) for muscle electromyographic threshold intervals relative to production of a 20 N bite-force (% T_{20N})**

Diagnostic group	Gender	Muscle	Maximum duty factor (%, mean ± SE)	% T_{20N}
+DD+P	Female	Masseter	2.00 ± 0.21	5–9
+DD+P	Male	Masseter	0.35 ± 0.52	5–9
+DD+P	Female	Temporalis	0.70 ± 0.21	10–24
+DD+P	Male	Temporalis	0.21 ± 0.52	5–9
+DD−P	Female	Masseter	3.48 ± 0.27	5–9
+DD−P	Male	Masseter	0.85 ± 0.45	5–9
+DD−P	Female	Temporalis	0.52 ± 0.27	5–9
+DD−P	Male	Temporalis	0.84 ± 0.45	5–9
−DD−P	Female	Masseter	1.19 ± 0.19	5–9
−DD−P	Male	Masseter	0.83 ± 0.18	5–9
−DD−P	Female	Temporalis	0.52 ± 0.19	5–9
−DD−P	Male	Temporalis	0.74 ± 0.18	5–9

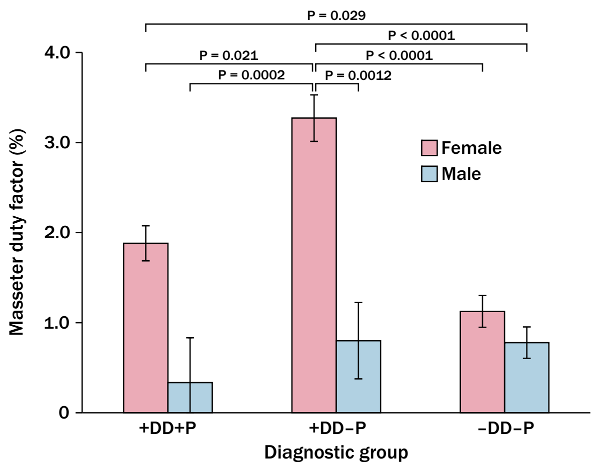

Fig. 5. Gender and diagnostic group (+DD = bilateral disc displacement, +P = chronic myofascial and/or temporomandibular joint pain) differences in masseter duty factors (DFs) (day- and night-time results combined) at 5–9% T_{20N}. +DD−P women showed masseter DFs that were significantly higher than those in +DD−P men and in women and men in all other diagnostic groups (all p = Tukey–Kramer adjusted values).

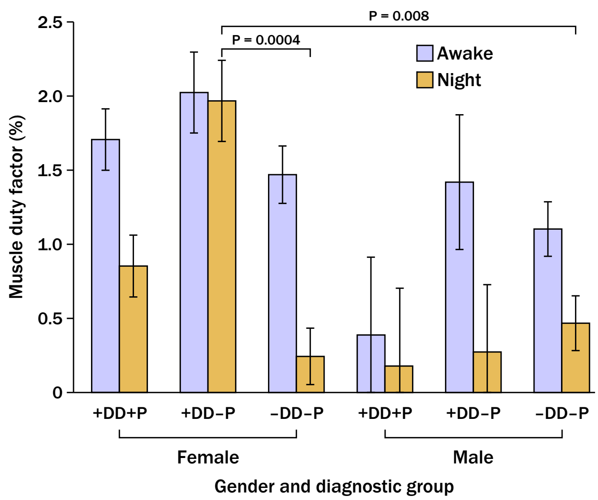

Fig. 6. Gender and diagnostic group (+DD = bilateral disc displacement, +P = chronic myofascial and/or temporomandibular joint pain) differences in duty factors (masseter and temporalis muscles combined) during day- and night-time recordings at 5–9% T_{20N}. Night-time DFs were significantly higher in +DD−P women compared to −DD−P women and men (all p = Tukey–Kramer adjusted values).

reflect central nervous system reorganization of muscle recruitment patterns to produce a bite-force, as hypothesized by the integrated pain adaptation model (20), where individuals are expected to alter neuromuscular organization of the jaw muscles because of pain. Additional indirect support for this hypothesis can be found; for example, right–left differences in muscle organization during incisor biting were more frequent in subjects with pain (40%) compared to control (11%) subjects (21). It may be possible to test further the integrated pain adaptation model by increasing the number of subjects. As indicated by the power analysis on the current data (Table 1), doubling the number of subjects is expected to show significant differences in temporalis T_{20N} between +DD+P and +DD−P subjects, thus, potentially demonstrating differences in temporalis muscle use during biting in subjects with pain.

The laboratory data used to analyse ambulatory EMG recordings were individual-specific and based on a threshold of EMG activities used to produce a 20 N bite-force (T_{20N}). This is a relatively low magnitude of jaw loading force, expected to be commonly used during ordinary jaw functions. Ambulatory EMG data were, thus, analysed using T_{20N} to estimate muscle DFs for a range of threshold intervals, representing applied jaw loads ranging from ≥1 to ≥16 N. For the range investigated, maximum DFs generally occurred at 5–9% T_{20N} (Table 2), where jaw loads were approximately 2 N.

Overall, masseter DFs were higher than temporalis DFs. Female +DD−P subjects showed the highest masseter DFs, which were 3.48% at the lowest threshold interval (5–9% T_{20N}; Fig. 4A). This equates to approximately 15 min of cumulative masseter muscle activity over a 7-h recording period. Note that at the highest threshold interval (≥80% T_{20N}), maximum cumulative masseter muscle activity over a 7-h period was 0.02%, or <1 min (Fig. 4A). At 5–9% T_{20N}, +DD−P women had masseter DFs that were 1.7 times higher than +DD+P women, and on average 3.6 times that seen in women and men in the −DD−P group. Another distinguishing feature of the female +DD−P subjects is that jaw loading via masseter and temporalis muscle activities at low levels (5–9% T_{20N}) occurred at the similar levels during the night and during the day, approximately 8 min per 7-h period, and this night-time muscle activity was significantly higher than in +DD+P women, and both women and men in the −DD−P group. Due to the low number of men in the +DD+P (n = 2) and +DD−P (n = 3) groups in this pilot study, it remains to be determined whether there are similar patterns of masseter and temporalis muscle activities amongst men and within diagnostic group gender differences in DFs.

The interesting current finding of significantly different night-time DFs amongst women in the three diagnostic groups and −DD−P men, where there was significantly higher low-level jaw loading at night in +DD−P women, could be consistent with a fatigue model of TMJ disc failure. That is, the overuse of the jaw muscles, without inhibiting stimuli caused by pain, could at least partly explain relatively early failure of the TMJ disc leading to +DD in these subjects. It is important to note that contrary to prevailing expectations but in keeping with recently reported polysomnography data (14, 15), the magnitudes of night-time jaw loads were inconsistent with bruxism and clenching. Instead, the ambulatory EMG data collected in subjects' natural environments suggest the predominant jaw loading activities were in the range of 2 N, similar to low-magnitude tooth contact (22). What then explains fatigue of the TMJ disc in +DD+P women? Masseter DFs in this group were lower than +DD−P women but were 1.7 times and 2.4 times higher compared to healthy women and men, respectively. Consideration of other variables contributing to fatigue failure may be in order; for example, TMJ energy densities (ED) may be an even more important factor, as supported by recent findings (23). That is, mean ED for a 20 N load on the mandibular canine in +DD+P subjects was 12.7 mJ/mm^3 and significantly higher compared to 7.4 and 5.8 mJ/mm^3 in +DD−P and −DD−P groups, respectively. As an estimation, chronic loading of the mandible in +DD subjects is likely <10% of a 20 N load (reflecting 5–9% T_{20N}). If DF and EDs are approximately equivalent in determining rate of cartilage fatigue, a simple product of the ED and DF variables results in total energy inputs per volume of cartilage of 1.5, 1.6 and 0.6 mJ/mm^3 in the +DD−P, +DD+P and −DD−P groups, respectively. Thus, the estimated cumulative work per cartilage volume is roughly the same between the two +DD groups, but 2.6 times higher compared to control subjects.

Limitations of this pilot study should be addressed in future studies and include: relatively small and unequal numbers of subjects in diagnostic and gender groups; 3 day- and night-time recordings may not be sufficient to minimize effects of accommodation to the portable equipment; cross-talk from nearby muscles were not investigated; and biting tasks were used to interpret ambulatory EMG where other jaw loading activities were possible and likely. Furthermore, bilateral DD was an inclusion criteria for +DD subjects, whereas asymmetric conditions may be important to investigate in future.

Conclusions

This pilot study showed differences amongst two groups with TMD and a healthy group without TMD in jaw loading behaviours. Specifically, for the same 20 N bite-force, temporalis muscle activities in +DD+P subjects were significantly higher than their masseter muscle activities and masseter activities in −DD−P subjects. In subjects' natural environment, +DD−P women used their temporalis and masseter muscles at low levels for a significantly greater percentage of time compared to +DD+P women and women and men in −DD−P group. Significantly more night-time masseter muscle activities at low levels of jaw loading in the +DD−P women compared to other groups at least partly accounted for this difference and could be an important variable contributing to fatigue failure of the TMJ disc.

Clinical relevance

The precocious development of degenerative joint disease in the TMJ compared to knees is thought to involve earlier mechanical fatigue of the articulating surfaces. The variables determining the rate of cartilage fatigue are 1) frequency of loading and 2) magnitude of applied mechanical stress. Activity levels and durations of the masticatory muscles during day- and night-time affect these variables. The findings of higher muscle night-time DFs in women with +DD−P suggest that low magnitude, higher frequency loading may be a unique contributing factor to TMJ disc failure within this diagnostic group.

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References

1. Roh HS, Kim W, Kim YK, Lee JY. Relationships between disk displacement, joint effusion, and degenerative changes of the TMJ in TMD patients based on MRI findings. *J Craniomaxillofac Surg* 2012;40:283–6.
2. Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;107:844–60.
3. Schiffman EL, Truelove EL, Ohrbach R, Anderson GC, John MT, List T et al. The research diagnostic criteria for temporomandibular disorders. I: overview and methodology for assessment of validity. *J Orofac Pain* 2010;24:7–24.
4. Heloe B, Heloe LA. Characteristics of a group of patients with temporomandibular joint disorders. *Community Dent Oral Epidemiol* 1975;3:72–9.
5. Nilner M. Prevalence of functional disturbances and diseases of the stomatognathic system in 15–18 year olds. *Swed Dent J* 1981;5:189–97.
6. Pullinger AG, Seligman DA, Solberg WK. Temporomandibular disorders. Part I: functional status, dentomorphologic features, and sex differences in a nonpatient population. *J Prosthet Dent* 1988;59:228–35.
7. Solberg WK, Woo MW, Houston JB. Prevalence of mandibular dysfunction in young adults. *J Am Dent Assoc* 1979;98:25–34.
8. Felson DT, Zhang Y, Hannan MT, Naimark A, Weissman B, Aliabadi P et al. Risk factors for incident radiographic knee osteoarthritis in the elderly: the Framingham Study. *Arthritis Rheum* 1997;40:728–33.
9. Lawrence RC, Hochberg MC, Kelsey JL, McDuffie FC, Medsger TA Jr, Felts WR et al. Estimates of the prevalence of selected arthritic and musculoskeletal diseases in the United States. *J Rheumatol* 1989;16:427–41.
10. Brandt KD, Dieppe P, Radin EL. Etiopathogenesis of osteoarthritis. *Rheum Dis Clin North Am* 2008;34:531–59.
11. Buckwalter JA, Anderson DD, Brown TD, Tochigi Y, Martin JA. The roles of mechanical stresses in the pathogenesis of osteoarthritis: implications for treatment of joint injuries. *Cartilage* 2013;4:286–94.
12. Iwasaki LR, Crosby MJ, Gonzalez Y, McCall WD, Marx DB, Ohrbach R et al. Temporomandibular joint loads in subjects with and without

disc displacement. *Orthop Rev (Pavia)* 2009;1:90–3.
13. Nickel JC, Iwasaki LR, Gallo LM, Palla S, Marx DB. Tractional forces, work, and energy densities in the human TMJ. In: Kapila SD, McNamara JA, editors. *Temporomandibular Disorders and Orofacial Pain – Separating Controversy from Consensus*. Ann Arbor, MI: Needham Press; 2009. pp. 427–50.
14. Raphael KG, Janal MN, Sirois DA, Dubrovsky B, Wigren PE, Klausner JJ et al. Masticatory muscle sleep background electromyographic activity is elevated in myofascial temporomandibular disorder patients. *J Oral Rehabil* 2013;40:883–91.
15. Raphael KG, Sirois DA, Janal MN, Wigren PE, Dubrovsky B, Nemelivsky LV et al. Sleep bruxism and myofascial temporomandibular disorders: a laboratory-based polysomnographic investigation. *J Am Dent Assoc* 2012;143:1223–31.
16. Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomandib Disord* 1992;6:301–55.
17. van Wessel T, Langenbach GE, Brugman P, van Eijden TM. Long-term registration of daily jaw muscle activity in juvenile rabbits. *Exp Brain Res* 2005;162:315–23.
18. Kawai N, Tanaka E, Langenbach GE, van Wessel T, Brugman P, Sano R et al. Daily jaw muscle activity in freely moving rats measured with radio-telemetry. *Eur J Oral Sci* 2007;115:15–20.
19. Gonzalez Y, Iwasaki LR, McCall WD Jr, Ohrbach R, Lozier E, Nickel JC. Reliability of electromyographic activity vs. bite-force from human masticatory muscles. *Eur J Oral Sci* 2011;119:219–24.
20. Peck CC, Murray GM, Gerzina TM. How does pain affect jaw muscle activity? The integrated pain adaptation model. *Aust Dent J* 2008;53:201–7.
21. Nickel JC, Gonzalez YM, McCall WD, Ohrbach R, Marx DB, Liu H et al. Muscle organization in individuals with and without pain and joint dysfunction. *J Dent Res* 2012;91:568–73.
22. Glaros AG, Owais Z, Lausten L. Reduction in parafunctional activity: a potential mechanism for the effectiveness of splint therapy. *J Oral Rehabil* 2007;34:97–104.
23. Gallo LM, Iwasaki LR, Gonzalez YM, Liu H, Marx DB, Nickel JC. Diagnostic group differences in temporomandibular joint energy densities. *Orthod Craniofac Res*; 2015;18(Suppl. 1):164–9.