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The influence of the leaf gauge and anterior jig on jaw muscle electromyography and condylar head displacement: a pilot study

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Abstract

Background: A leaf gauge and an anterior jig may be used to assist the recording of a reproducible jaw position for restorative and prosthodontic treatment. This study investigated possible condylar displacement using an opto-electronic jaw-tracking device and a leaf gauge or anterior jig. The effect of a leaf gauge and anterior jig on jaw muscle electromyography was also examined.

Methods: Five healthy adults without symptoms of temporomandibular disorders were selected. Condylar displacement during clenching were recorded simultaneously with electromyographic activity of superior and inferior heads of the lateral pterygoid, anterior and posterior temporalis, masseter, and suprahyoid muscles. Subjects were trained to bite at maximum and half-maximum bite-force using an anterior jig incorporating a force transducer.

Results: No consistent condylar displacement was observed in x, y and z axes between different bite-forces although there was a trend towards superior displacement. Comparison of maximum intercuspal clench and maximum clench on a leaf gauge and an anterior jig produced significant decrease in anterior temporalis activity ($p<0.05$), whilst an anterior jig with maximum clench significantly decreased posterior temporalis muscle activity.

Conclusion: Within the limits of this pilot study, no consistent change in condylar position was identified with these appliances.

Key words: Leaf gauge, recording technique, EMG, lateral pterygoid muscle.

Abbreviations and acronyms: AJ = anterior jig; CT = computer tomography; EMG = electromyographic; IHLP = inferior head of lateral pterygoid; IP = intercuspal position; LG = leaf gauge; MIPT = mid-incisal point; SHLP = superior head of lateral pterygoid; TMD = temporomandibular disorders; TMJ = temporomandibular joint.

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INTRODUCTION

Prosthodontic treatment planning may require articulation of dental casts following registration of jaw transfer records. A reproducible and stable jaw relationship is a desirable reference point for cast analysis, case planning and subsequent treatment. The antero-superior condyle position with an appropriately aligned inter-articular disc approximating the articular eminence has been an acceptable reference position for the jaw at a clinically acceptable vertical dimension.[1] It has been suggested that condylar position may be achieved by the coordinated activity of the lateral pterygoid muscles during jaw closure and that deflective occlusal interferences may influence the recording of a reproducible jaw position.[1]

The use of an anterior jig (AJ),[2] Roth's power 'centric relation' registration[3] or a leaf gauge (LG),[4] are techniques which have been proposed for jaw transfer records to achieve a superior positioning of the condyles. These techniques use an anterior stop to disclude posterior teeth and eliminate possible tooth contact interferences. However, there is no consensus on which technique allows the recording of this particular patient-specific condylar position.

The LG contains leaves of acetate or other plastic material (usually 10), 0.1mm thick, a number of which may be placed between the anterior teeth. Leaves are added with biting to ensure that posterior teeth do not contact.[4] It is believed that this procedure allows the jaw and condyles to adopt a reproducible position for recording of transfer records for prosthodontic and orthodontic treatment.[5,6]

Some studies have recorded condylar displacement during LG biting. Fenlon and Woelfel[7] used an LG and measured condyle displacement with a Veri-Check (Denar Corporation, Anaheim, California, USA) device. They reported that the LG resulted in superior condyle displacement with little antero-posterior displacement. Braun *et al.*[6] compared transfer records using an LG with those obtained by operator jaw guidance. Condyle-fossa relationships were evaluated using enhanced sagittal cephalometry. Both methods showed variation in condyle-fossa relationships and only 10 per cent of subjects showed a superior and anterior condylar position with the LG.

Lundeen[8] had previously reported that heavy biting on an anterior rigid stop produced the most superior condylar position compared with other methods, and that there was little antero-posterior component.

In the above studies, condylar position recordings were based on interocclusal records in conjunction with condylar hinge axis movement and the use of two-dimensional radiographs.

Using interocclusal records to determine changes in condylar position may be influenced by consistency of the recording medium, operator guidance, cast articulation error, and accuracy of the recording equipment. It is also difficult to interpret a single point representation of a three-dimensional condyle on a radiograph, and track its movement.

Different bite-forces were used with an AJ and an LG to assess the effects on condylar displacement. Bite-forces used in previous studies varied from maximum or 'bite hard',[8] 'firmly',[9,10] 'moderate',[11] to 'comfortable'[12] or 'swallowing force'.[13]

Williamson *et al.*,[5] showed that there was no significant difference in superior condyle placement when an LG was used with different bite-forces, from 'biting easy' to 'biting hard'. There was a significant posterior displacement with 'biting hard' compared with 'biting easy'. However, condyle position changes were interpreted with the use of interocclusal wax records. In contrast the study by Wood *et al.*[14] showed increased condylar seating with increased incisal biting force. Significant anterior and superior condylar displacement was found when subjects performed incisal biting tasks at hinge axis position with maximum bite-force. This study measured antero-posterior and superior-inferior displacements. In our study, different bite-forces were used with an LG to examine the relative positions of the condyles, and condylar displacements were monitored in three-dimensions with an opto-electronic jaw tracking system.

Several studies have attempted to identify the effects of an LG on jaw muscle electromyographic (EMG) activity. The study by Hickman *et al.*[15] showed that an LG produced lowest masseter and anterior temporalis EMG activity compared with three other jaw relation methods (maximum intercuspation, manually guided centric relation position and a so-called 'neuro-muscular' guided position with the aid of a TENS machine).

Williamson *et al.*[5] also proposed that when an LG was used for interocclusal registration, the temporalis muscles were more involved than the masseter muscles in 'seating' the condyles.

Previous investigations have not examined the effect of the LG on the lateral pterygoid muscle and this was a feature of our study. Anatomical studies[16-18] have confirmed the insertion of the superior head at the condylar fovea, with muscle fibres running horizontally with a postero-inferior and medial direction from their origin. As a result, the role of the superior head has been proposed as directing horizontal forces to the condyle.

Recent studies from our research unit have described EMG recordings of the lateral pterygoid superior and inferior heads with indwelling fine wire electrodes, the placement of which was verified with computer tomography (CT).[17,18]

Biting on an AJ and an LG effectively removes potential occlusal interferences and separates the posterior teeth. Current understandings of jaw muscle physiology have shown that incisal biting reduces the level of bite-force and alters jaw closing muscle EMG activity.

Jaw recording should allow a consistent position to be obtained as a condylar reference position for each patient. The use of an AJ and an LG should allow a measurable displacement of the condyle, compared with intercuspal clench. Understanding the implications of these clinical procedures and their possible effects on condylar displacement and associated jaw muscle activity should provide objective clinical data to justify the use of a particular recorded position as a reproducible treatment position.

Aim

This study investigated the effect of an AJ and an LG with maximum and half-maximum bite-forces on condylar displacement, and EMG activity of the superior (SHLP) and inferior (IHLP) heads of the lateral pterygoid; masseter, anterior temporalis, posterior temporalis muscles, and the suprahyoid muscle group.

MATERIALS AND METHODS

Participants

Five healthy volunteers were recruited from dental students and staff (all males, with an age range of 23 to 32 years), without signs or symptoms of temporomandibular disorders (TMD) or history of chronic muscle pain (for criteria, see Klineberg).[19] Informed consent was obtained. The Western Sydney Area Health Service Ethics Committee (Westmead Hospital) and the Human Ethics Committee (The University of Sydney) approved the experimental protocol. Three subjects (1, 3, and 5) presented an Angle Class I incisor relationship with minimal horizontal and vertical anterior tooth overlap. Subject 2 presented with an Angle Class II div II incisor relationship with a deep (60 per cent) overbite, and subject 4 presented with a Class III (edge to edge) incisor relationship.

There were two clinical sessions. During session 1 maxillary and mandibular impressions and study casts

Fig 1. Bite force transducer with stainless steel housing and anterior Duralay resin jig.

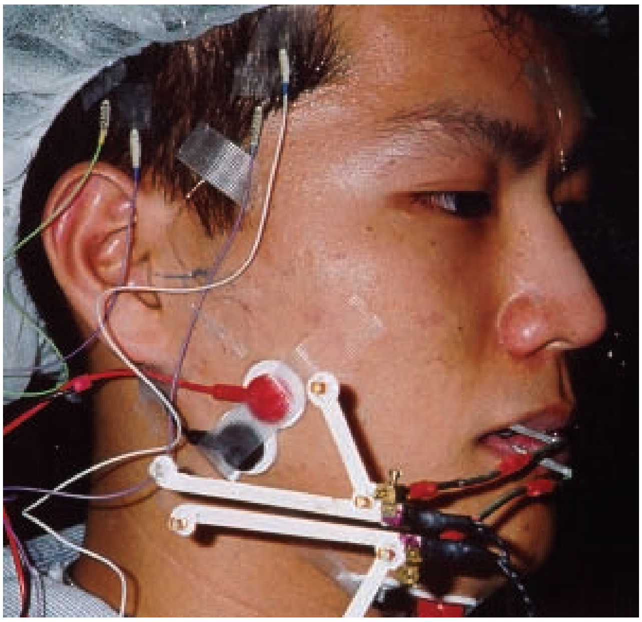

Fig 2. Experimental set up. Hook electrodes for anterior and posterior temporalis muscles, surface electrodes for the masseter and suprahyoid muscles; and target frames attached to the clutches are shown. The fine wire electrodes for the SHLP muscle is secured with adhesive tape above the masseter muscle.

were prepared for each subject to construct an AJ, and upper and lower clutches for condylar recordings.[19] Preliminary computed tomographic scans were required to determine the trajectory for accurate placement of indwelling fine-wire electrodes into the superior head of the lateral pterygoid muscle. In session 2 the recordings of jaw and condyle position and EMG with and without an LG were completed. After each recording, a second series of computed tomograms were made to confirm electrode location.[17]

Anterior jig construction

A 1KN (102.0kgf) (Kyowa Electronic Instruments Co Ltd, Tokyo, Japan) force transducer was used for recording EMG at specific bite-forces. The transducer was supported in a stainless steel housing and secured within the AJ fabricated in acrylic resin (Duralay, Dental Manufacturing, Illinois, USA – Fig 1). The AJ-transducer assemblies were made with minimal height to ensure that the inter-incisor separation was as small as possible to reduce the possibility of condyle translation.

Subjects were asked to bite on a platform attached to the stainless steel housing and positioned parallel to the lower occlusal plane. As a result, the direction of bite-force recorded by the transducer approximated that of the mandibular incisor teeth. The platform extended anteriorly to rest above the incisal edge of the mandibular incisors. This ensured that the bite-force generated by the mandibular incisors in contact with the platform was directed through the centre of the transducer. The AJ was relined intra-orally on the day of the recording to ensure its maximum stability.

An AMLAB data-acquisition system (Associative Measurements, North Ryde, Sydney, Australia) was used to determine bite-force at a sampling rate of 4200 samples/s per channel and a bandwidth of 100Hz.

Leaf gauge recording

The LG was constructed with 10 strips of acetate, 4cm long, 10cm wide and 0.5mm thick.[4] Subjects were asked to bite at the prescribed bite-force on the LG during tasks. In preparation for recordings, should the subject sense posterior tooth contact, additional LG leaves were added to separate the posterior teeth when biting on the anterior teeth.

Jaw movement recording

An opto-electronic jaw tracking system (JAWS-3D, Metropoly AG, Zurich, Switzerland) was used in an attempt to accurately describe movement of the working-side condyle, using the trajectories of at least three radiographically determined condylar points, calculated from mandibular movements recorded in six degrees of freedom. Condylar movement may be monitored and described in three axes of rotation.[20,21]

Target frames were attached to the maxilla and mandible using rigid clutches[20] cast in titanium and designed to provide full buccal coverage of two or three teeth in the canine region. The occlusion was checked to ensure that the clutches did not interfere with tooth contacts or with the AJ or LG.

Lightweight, plastic target frames carrying the light emitting diodes were attached to the clutches with aluminium tubes. The target frames were located inferior and anterior to the region of the temporomandibular joint (TMJ) and were aligned parallel to the sagittal plane, and the long-axis of each target frame was aligned parallel with the Frankfort horizontal plane (Fig 2).

All jaw movements started from postural jaw position. The condylar point was used as the primary reference point and the mid-incisal point (MIPT) for the secondary reference point. (The sampling rate was

67 samples per second). For each movement task, computer data files were created and contained antero-posterior (x), medio-lateral (y) and supero-inferior (z) positions of each condylar point with respect to time.

EMG recording

Superior and inferior heads of the lateral pterygoid

The technique for placement and verification of fine wire electrodes in the superior and inferior lateral pterygoid was followed as per the protocol from our research unit.[17,18] EMG activity of the superior head was recorded with bipolar Teflon-coated indwelling stainless-steel wire electrodes using an extra-oral approach. An intra-oral approach (modified from Wood *et al.*[22]) was used for the inferior head. Surgical adhesive tape was used to secure both sets of electrodes to the skin and the terminal ends were connected to the amplifiers.

Superficial jaw muscles

Bipolar recordings were made with surface patch electrodes (Duo-Trode, Myo Tronics, Seattle, USA) placed over the lower one-third of the masseter muscle, approximately 10mm posterior to the anterior border; and over the mid-body of the suprahyoid muscle (Fig 2). Also, intradermal hook electrodes (A-M Systems Inc, Washington, USA; 75μm diameter, with teflon coating: 110μm) were placed through the skin overlying the anterior and posterior temporalis muscles (Fig 2) identified by palpation. Muscles signals were digitized using the micro1401 from Cambridge Electronic Design (Cambridge, UK). Intra-muscular EMG sampling rate was 15 000 samples/seconds; bandwidth 100-10 kHz. Surface EMG sampling rate was 5000 samples/seconds. Data management software was custom-written for the data recorded with AMLAB or Spike 2 from Cambridge Electronic Design.[18]

Tasks

At the beginning of each trial, the subject held their postural jaw position for five seconds. An LED located at the subjects' eye level was the signal for the subject to clench for five seconds. A second light signal instructed the subject to relax. There was no jaw guidance. The recording time was approximately 20 seconds and subjects performed clenching tasks as follows: (1) Clenching from postural jaw position to intercuspal position (IP clench) at maximum bite-force was the reference or 'control' for each subject; (2) Clenching with the AJ at maximum bite-force; (3) Clenching with the AJ at half-maximum bite-force; (4) Clenching with the LG at half-maximum bite-force; and (5) Clenching with the LG at maximum bite-force. Five recordings were made for each task with a two-minute rest period between tasks. The AJ incorporating the transducer was used to train each subject to bite at maximum and half-maximum. Visual feedback was used to assist in subject training. The LG was used following the two bite-force levels practised with the AJ. Bite-force was not measured when the LG was used. All recordings were made from the right for each participant and each session was 3–4 hours from beginning the set-up to recording the second set of CT images.

Data analysis

Condylar displacements were recorded in antero-posterior (x), medio-lateral (y) and supero-inferior (z) axes. A positive value for the x-, y- and z-axes indicated posterior, lateral, and superior displacement respectively. For each task, a mean and standard deviation was calculated and used for comparison.

EMG activity from each muscle was rectified and smoothed with a digital filter (Butterworth filter;[23] cut-off: 2Hz). A computer script was written to calculate the area beneath the curve, allowing a numerical value for the task. For each muscle and task, a mean and standard deviation was derived from the data.

The mean for the control recordings were used to normalize the data and set at 100 per cent. Values from other tasks were then expressed as a percentage of the 'control' values. A value over 100 per cent indicated a higher EMG level and less than 100 per cent a lesser EMG level than that of IP clench. To determine the significance ($p<0.05$) of each trial, a non-parametric Wilcoxon Signed Ranks Test was performed on values of maximum bite-force with the AJ and LG against the control group (IP clench), and between maximum and half-maximum bite-force with the AJ.

Table 1. Means and standard errors (SE) of the condylar displacement in millimetres (mm) from postural position and clench at IP (Control); Half-maximum bite force with anterior jig (Half AJ); Maximum bite force with anterior jig (Max AJ); Half-maximum bite force with leaf gauge (Half LG); and Maximum bite force with leaf gauge (Max LG). For explanation on the direction of displacement please see text. No significant values were observed ($p>0.05$)

Displacement	Tasks				
	Control	Half AJ	Max AJ	Half LG	Max LG
X axis	-0.16±0.47	0.06±0.42	-0.29±0.56	0.04±0.16	-0.05±0.44
Y Axis	-0.07±0.21	-0.22±0.21	-0.18±0.15	0.18±0.30	0.06±0.16
Z Axis	0.79±0.35	1.15±0.84	1.06±0.50	0.60±0.31	0.91±0.12

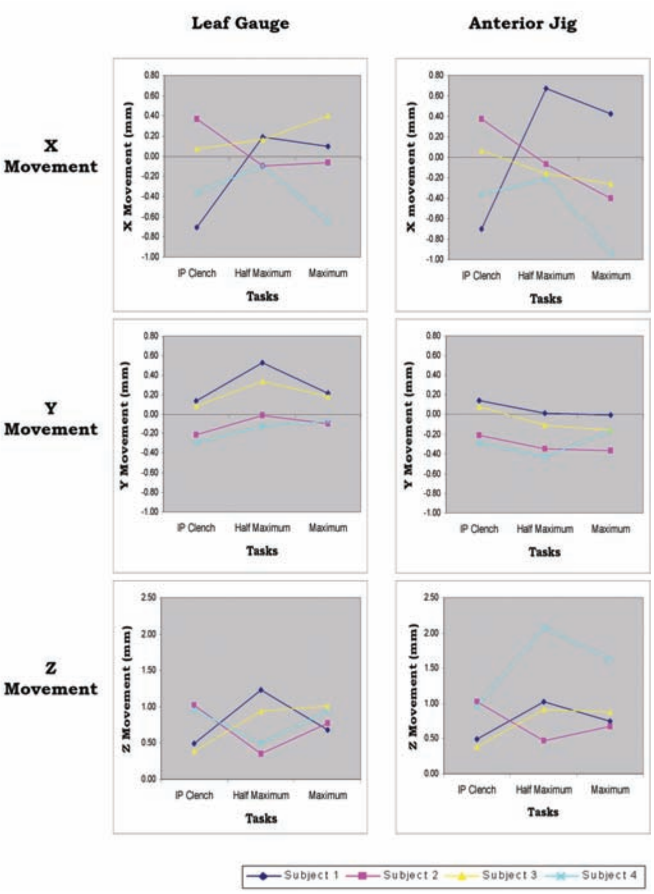

Fig 3. Comparison of averaged raw values of condylar displacement (in mm) along the antero-posterior (x), medio-lateral (y) and supero-inferior (z) axes in 4 subjects between clenches of leaf gauge and anterior jig, using intercuspal position clench (IP clench), half maximum and maximum bite forces. A positive value for the x-, y- and z-axes indicates posterior, lateral, and superior, respectively.

RESULTS

Condylar head displacement

The JAWS 3D data are in Table 1. Subject 5 was not included due to instability of the clutches during the recording. No significant differences ($p<0.05$) were found at different bite-force levels or with different appliances. Individual data for four subjects is shown in Fig 3. Maximum bite-force with the LG produced greater superior and lateral displacement than IP clench in three subjects. Half-maximum bite-force with the LG produced more lateral displacement compared with IP clench and maximum bite-force in three subjects. However, antero-posterior displacement was not consistently observed.

Maximum muscle contraction did not always correlate with greatest superior condylar displacement, and three subjects showed greater superior displacement at half-maximum (average: 1.15±0.84mm) than maximum clench (average: 0.79±0.35mm), and maximum AJ (average: 1.06±0.50mm). However, in three subjects there was a trend for the condyle to be displaced antero-superiorly and medially with the AJ and maximum bite-force. Maximum bite-force and the AJ produced greater anterior displacement (average: 0.29±0.56mm) than half-maximum in all subjects (posterior displacement: 0.06±0.42mm). The AJ generally appeared to result in greater condylar displacement than IP clench and the LG in all axes.

EMG activity

Data for each subject are presented in Fig 4. Statistical data is presented in Table 2. Data from the suprahyoid muscles were not included due to their low activity. A second CT scan was performed after the trial to verify placement of the fine wire electrodes. Electrodes were accurately placed and verified within the mid-body of the SHLP muscle in four subjects. In subject 1, the electrode tips were located in the muscle but close to the attachment to the AT muscle.

In most subjects with maximum IP clench, EMG activity of masseter and anterior and posterior temporalis was greater than biting on either the AJ and LG with half-maximum and maximum bite-forces.

During clenching with the AJ and the LG, the anterior temporalis EMG was significantly lower than at maximum clench ($p<0.05$). Clenching with the AJ also produced significantly lower posterior temporalis EMG than at maximum clench ($p<0.05$). As expected, EMG at half-maximum bite-force was less than that at maximum bite-force in most subjects. The masseter EMG at maximum and half-maximum bite-forces using an AJ, was significantly different ($p<0.05$).

EMG for SHLP muscles were inconsistent in all trials. Although not significant as a group, SHLP EMG showed the greatest increase. For example, in subject 2, with biting on the AJ, the SHLP EMG increased eight times with maximum bite-force, and more than four times with half-maximum bite-force, compared with IP clench.

DISCUSSION

The purpose of this pilot study was to examine the relationship between condylar displacement and jaw muscle EMG when biting on an AJ or an LG with half-maximum and maximum bite-forces, relative to maximum IP clench.

EMG recording

The AJ with force transducer was used to train subjects to bite at maximum and half-maximum. Muscle fatigue would occur with time. However, the two-minute rest between tasks and five-second clenching tasks was used to minimize this possibility. Biting comfort of the softer LG or harder AJ, may affect subjects' ability to exert maximum and half-maximum bite-forces. However, this did not appear to be a concern to subjects. Fine wire and hook electrodes were used for EMG recordings of the SHLP, IHLP and anterior and posterior temporalis muscles respectively.

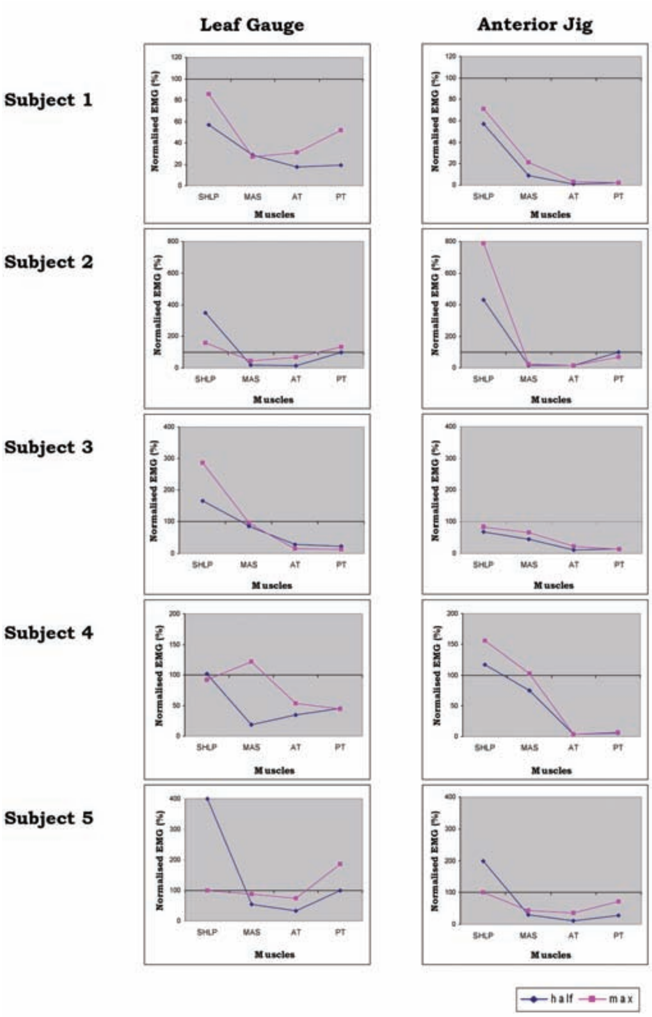

Fig 4. Comparison of normalized EMG values of IP clench (represented by the horizontal line at 100%) between clenches of leaf gauge and anterior jig, using half-maximum and maximum bite force. Muscles recorded were SHLP (superior head of lateral pterygoid), Mas (masseter), AT (anterior temporalis), and PT (posterior temporalis). A value over 100% indicates an EMG value higher to that of IP clench; and a value less than 100% indicates a less EMG value to that of IP clench. Please see text for statistical interpretations of data.

The use of the AJ required an increased occlusal vertical dimension compared with the LG. The bite-force transducer in the AJ was used to train the subjects' perception of a 'half-maximum' bite-force. Greater posterior tooth disclusion with the AJ compared with the LG may contribute to the different task results.

This study is the first to record EMG activity of SHLP and IHLP muscles with an AJ and an LG. These muscles have been shown to have reciprocal activity in different jaw positions,[24] however, no significant changes in EMG in these muscles occurred in this study. Minimal EMG activity of IHLP and suprahyoid muscles was expected, as these muscles are mainly involved in jaw opening.[16,25]

Although not significant as a group, in three subjects SHLP EMG increased more than twice the EMG at IP clench. In subject 1, indwelling fine wire electrodes although in the SHLP, were found to be located close to the attachment of the anterior temporalis muscle, which may explain the low EMG activity.

Table 2. The significance of results of Wilcoxon Signed Ranked Test ($p<0.05$) of SHLP (Superior head of lateral pterygoid muscle); Mas (Masseter); AT (Anterior Temporalis); PT (Posterior Temporalis), comparing half-maximum bite force with anterior jig (Half AJ); maximum bite force with anterior jig (Max AJ); Half-maximum bite force with leaf gauge (Half LG); and maximum bite force with leaf gauge (Max LG) to IP clench

Tasks	Jaw Muscles			
	SHLP	Mas	AT	PT
Hmax AJ	No	No	No	No
Max AJ	No	No	Yes	Yes
Hmax LG	No	No	No	No
Max LG	No	No	Yes	No

Indwelling fine wire electrode placement within the SHLP muscle may influence EMG. While the position of the electrode was verified to be in the SHLP muscle, it has been shown[26] that some parts of the muscle may exhibit similar activity to the IHLP or anterior temporalis muscles.

Phanachet *et al.*[26] identified functional heterogeneity of the SHLP with single motor unit recordings. If the SHLP muscle is functionally heterogeneous, recordings at different sites within the muscle may yield different functional properties. This may explain the variation between studies as to the task relations of the SHLP.

The use of an AJ or an LG with maximum bite-force significantly reduced anterior temporalis EMG ($p<0.05$). Maximum clench with an AJ also produced a significant decrease of EMG activity of posterior temporalis muscle ($p<0.05$).

A similar result was found by Hickman *et al.*,[15] where a significant decrease in masseter and anterior temporalis EMG was found with an LG compared with other jaw position recording techniques.

The data using the AJ showed similarities to studies using a flat plane AJ[27] and acrylic incisor stops.[28] Becker *et al.*[27] used a pre-fabricated anterior bite stop and measured the activity of anterior and posterior temporalis, masseter and anterior digastric muscles during clenching. The anterior bite stop had a significant effect in reducing EMG in clenching for all muscles examined, except the anterior digastric.

MacDonald and Hannam[28,29] described the relationships between EMG of the jaw closing muscles (bilateral medial pterygoid, anterior and posterior temporalis, masseter) and the location, area and direction of effort (vertical and laterally) applied to specific tooth contact points. They found that an incisal stop with vertical clench evoked the least jaw muscle activity. These data confirmed that posterior tooth disclusion reduced jaw elevator muscle activity.

This effect may also involve anterior tooth periodontal mechanoreceptors. In their neurographic studies, Trulsson and colleagues[30] have shown that population effects of these mechanoreceptors occur at all bite-force levels, but it is greater at low force levels. As the higher population of these mechanoreceptors is associated with anterior teeth, anterior contact with an AJ or an LG may have a greater effect on influencing bite-force.

Posterior tooth disclusion also alters jaw muscle recruitment patterns, reducing EMG activity compared with maximum clench at IP.[31] In our study, the masseter muscle remained active and at similar EMG levels to IP clench. In some subjects, the SHLP muscle increased, but was not statistically significant.

Our study indicated that use of an AJ and an LG produced minimal change to the EMG of SHLP, IHLP, suprahyoid, and masseter muscles, compared with maximum IP clench.

Condylar movement recording

Condylar displacement was expected to be small, and limited by joint space, initial condyle-disc relationships, and the ability for the disc to undergo viscoelastic deformation with compression. The inherent error of the recording system (JAWS-3D) of 0.2mm, limited the extent of condylar displacement values.[32]

Airoldi and colleagues[32] concluded that the small error of JAWS-3D together with its low invasiveness supported its use in clinical research. However, subject movement may influence the accuracy of recordings. Data interpretation needs to recognize such factors where displacement is small.

Assessment of condyle position needs to recognize the variation in condyle-fossa position that is functionally acceptable in asymptomatic subjects. In addition, there is no research data to indicate whether there is an optimal condylar position as a reference point for function. In studies of condyle position the choice of a reference point that represents condylar movement is important. Data indicate that three-dimensional movement cannot be accurately represented by a single reference point,[21] although there is some controversy about this.[33]

Condylar displacement in the x (horizontal) and z (vertical) axes

The introduction of an AJ and an LG did not significantly alter condylar displacement. Inconsistent displacement in the antero-posterior direction in this study was similar to other studies.[8,34] Superior condyle displacement was observed as the jaw closed from postural position, but maximum muscle contraction did not correlate with greater superior condylar displacement.

Wood *et al.*[14] measured condylar position using an anterior stop with no force, then bite-forces of 4.5kg, 7.5kg and a comfortable maximum. The study reported that the condyle continued to move antero-superiorly with an average of 0.49mm anteriorly, and 0.27mm superiorly with increasing incisal bite-force. Subjects were guided into a retruded jaw position at the start of the recording.

Data from the above study was similar to the trends in our study and indicated that the condyle was more anteriorly displaced with increased bite-force on an anterior stop. However, our study found that the condyle was less superiorly displaced with increased bite-force on an anterior stop (as in the AJ).

Teo and Wise[35] also found that biting on an anterior jig with chin point guidance produced the most superior and posterior condyle position (0.22mm). Our study found no significant displacement when an LG was used. Carr *et al.*[36] also found that an LG caused no effect on condylar displacement. They used EMG and incisor point movement to determine the effect on jaw displacement of biting on an LG for 15 minutes. Without jaw guidance, subjects held the LG comfortably between the anterior teeth during recordings. The authors reported that the LG did not change jaw displacement during normalized postural muscle activity, nor with increasing the duration of maximum voluntary isometric contraction, after using an LG for 15 minutes.

Maximum incisal clench with an AJ and an LG for five seconds may not allow sufficient condylar displacement to significantly influence muscle contraction. Submaximal incisal clenching (such as with nail biting) may induce a greater jaw and condyle displacement.

During recordings, there was no jaw guidance by a clinician, which eliminated operator-induced variability. Manual jaw guidance may result in significant change in condylar displacement. In the article by Long,[4] patients were asked to retrude the jaw and close firmly. In our study, the mandibular position would be determined by the subjects' own muscular force, anterior tooth relationship and level of comfort when performing the clenching tasks.

Condylar displacement in the y (transverse) axis

Condylar displacement in the latero-medial direction was also measured. Maximum bite-force produced a medial condylar displacement in most subjects. Subject 4 had an edge-to-edge anterior tooth relationship, which may contribute to lateral condylar displacement with maximum bite-force. Omar and Wise[37] reported that lateral mandibular flexion in the horizontal plane occurred when an anterior jig was used to record retruded jaw position. However, a larger sample size is needed before reliable information could be determined.

The data suggested that an AJ and an LG may not provide a consistent condylar displacement compared with IP clench. It is important in clinical practice for jaw position to be patient-specific and consistent at the time of treatment. Clinicians should consider that jaw recoding is operator, patient and technique-sensitive during jaw registration procedures. It may be possible for distinct condylar positions to be identified between maximum intercuspation and a leaf-gauge generated jaw position.[38] There may be value in determining the significance of anterior tooth relationships, different bite-force levels, the extent of mandibular guidance and how these variables influence jaw muscle EMG activity to achieve a reproducible jaw position.

CONCLUSION

Within the limitations of this study the following can be concluded: (1) The use of an AJ or an LG with maximum bite-force resulted in no significant difference in condylar displacement in the three axes compared with maximum IP clench; a superior condylar displacement in all subjects, however, maximum bite-force did not necessarily correlate with greater superior displacement – this was especially the case when an AJ was used; significantly reduced EMG activity of the anterior temporalis muscle; no significant change in EMG activity for SHLP and IHLP muscles relative to IP clench and different bite-forces. (2) An AJ significantly decreased the activity of the posterior temporalis muscle. (3) Anterior tooth relationships, levels of bite-force and degree of mandibular guidance may influence jaw muscle EMG and condylar displacement when an AJ or an LG is used for jaw records. (4) Further studies with more subjects, incorporating a bite-force transducer into an LG are required to provide precise information of bite-force while performing prescribed LG tasks.

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