Jaw Motor Plasticity in Health and Disease

Christopher C. Peck **Alexander Wirianski** **Greg M. Murray**

Faculty of Dentistry, University of Sydney
Westmead Hospital Centre for Oral Health
Westmead, NSW 2145, Australia

cpeck@usyd.edu.au, awir7858@mail.usyd.edu.au, gregm@usyd.edu.au

Abstract

One of the important general findings from the research into human jaw motor control over the past 20 years is the evidence for enormous complexity in structure-function relationships. An example of this complexity has recently been demonstrated for the lateral pterygoid muscle which is best considered as a single unit made up of independent functional regions where the distribution of activity within each region depends on the biomechanical demands of the task. We have also recently characterised the effects on the jaw motor system of pain or exercise, as examples of how the jaw motor system adapts. Using synchronised jaw tracking and electromyographic (EMG) acquisition systems, the effects on jaw muscle EMG activity of experimentally induced masseter muscle pain was studied during goal-directed tasks. The principal finding was that jaw motor activity changed in the presence of pain. The effects on jaw muscle EMG activity of resistance exercises have also been studied during goal-directed tasks. Here, subjects were able to perform the same movement with different muscle co-activation strategies. The biomechanical effects on the orofacial structures of motor changes with pain or exercise may be investigated with mathematical jaw modelling. Such models could propose clinical interventions that could alter jaw motor function to reduce adverse joint and muscle loads.

Keywords: functional heterogeneity, electromyography, jaw muscles, pain, modelling.

1. Introduction

The jaw motor system is structurally and functionally complex and consequently is able to generate large compressive forces during mastication and achieve fine motor control with the precise positioning of the mandibular teeth against the maxillary teeth. The system consists of at least 18 functional muscle groups which drive the mandible in three dimensions. As this is a mechanically redundant system, it is possible that a jaw task could be achieved by a number of different muscle co-activation strategies. This is important clinically where structural changes (e.g. to the jaws or muscles through surgical reconstruction or trauma) necessitate a change in motor programming if the same task is to be achieved. We present data demonstrating the functional complexity of the jaw musculature and the ability of the jaw system to adapt and achieve a task in the presence of painful stimuli or a physiotherapy exercise intervention.

2. Functional Properties of the Human Lateral Pterygoid Muscle

Some disturbance to the activity of the lateral pterygoid muscle is thought by many clinicians to play a role in the aetiology of orofacial musculoskeletal problems: Temporomandibular Disorders (TMD). There is, however no good evidence to support this notion. Further, the role of the lateral pterygoid muscle, anatomically defined as consisting of two heads, in normal function is still controversial. Thus, the classically defined function of each head of the muscle is that the superior head (SHLP) is active on closing, retrusion, and ipsilateral jaw movements, while the inferior head (IHLP) is active in the reciprocal jaw movements of opening, protrusion and contralateral movement. We have recently demonstrated however that these concepts are too simplistic. For example, most of the SHLP can be active on those movements where the IHLP is active, viz., opening, protrusion and contralateral jaw movements, and not in a reciprocal manner to the IHLP as previously supported [1;2]. Further, the similarities in many of the functional properties between SHLP and IHLP supported the hypothesis of Hannam and McMillan [3] that both SHLP and IHLP should be regarded as parts of one muscle with the distribution of activity shaded according to the biomechanical demands of the task.

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In addition, the superior head appears to consist of three mediolaterally arranged functional zones with the medial zone exhibiting evidence of becoming active first during a protrusive and contralateral jaw movement in comparison with the other zones of the SHLP. This and other lines of evidence suggest that the SHLP is functionally heterogeneous, namely that the brain is capable of selective activation of subcompartments of the muscle to achieve the requirements of a task [4] and this may relate to the mechanical advantage of the jaw motor system [5].

An important role has also been demonstrated electromyographically for progressive changes in activity in the inferior head as the direction of horizontal jaw force shifts from one side to the other. This suggests an important role for the lateral pterygoid muscle in the generation of side-to-side and protrusive jaw forces. In the clinical context, the lateral pterygoid muscle is likely therefore to play an important role in jaw movements associated with sleep bruxism (e.g. tooth grinding) and also possibly a role in influencing jaw position in patients who do not have a stable dental bite. Furthermore, in light of our findings, the proposal that clicking and/or locking conditions arise in the temporomandibular joint through some form of lack of coordination between the two heads of the muscle, needs to be re-evaluated.

Our findings are consistent with the notion that not only the IHLP but also the SHLP is concerned with the control of the movement of the temporomandibular joint condyle forwards along the articular eminence during protrusion and contralateral jaw movements [1;3]. While SHLP and IHLP, like the other jaw muscles, may be functionally complex, we have demonstrated both heads have many similar functional properties [4;6-10]. The broad range of fibre directions established by both SHLP and IHLP provides a wide range of force vectors for guiding the condyle during normal masticatory movements.

The above data provide new insights into the normal function of the lateral pterygoid muscle. The proposal that the lateral pterygoid muscle plays some role in the aetiology of TMD needs now to be rigorously tested.

3. Effects of Experimental and Clinical Orofacial Pain on Jaw Muscle Activity

A common symptom of TMD is limitation of jaw movement, however the precise relationship between orofacial pain and jaw motor behaviour is unclear. The Pain Adaptation Model is generally considered the most appropriate explanation of this relationship, and as applied to the jaw motor system proposes that pain leads to alterations in jaw muscle activity that lead to a reduction in the amplitude and velocity of jaw movement. The outcome of these changes is an adaptive response which will reduce compressive and tensile loads to the jaw system thus protecting it from further injury and thereby promoting healing [11;12].

In general, the findings from many human experimental and clinical muscle pain studies lend support to the Pain Adaptation Model [11;13]. However, the effects reported in some of these previous studies of the relationship between pain and jaw motor behaviour do not always appear to be consistent with some aspects of motor behaviour that are suggested by the Model [14;15]. As there are limited data of the effects of orofacial pain on jaw movements in humans, we have recently reinvestigated the effects of clinical and experimental orofacial pain on the jaw motor system.

The jaw was tracked with a six degrees of freedom optoelectronic system in 22 asymptomatic subjects during standardised (at 2.2 mm/s) protrusion, lateral excursion, and open jaw movements, as well as free, right-sided chewing and chewing standardised for timing (900 ms/cycle). Electromyographic activity was recorded from a number of jaw muscles including IHLP, bilateral masseter, anterior temporalis and right digastric muscles. Tonic infusion of 4.5% hypertonic saline into the right masseter muscle maintained pain intensity between 30-60 mm on a 100-mm visual analogue scale. Subjects performed tasks in 3 sessions on the same experimental day: control condition (baseline trials), test 1 condition (during hypertonic or 0.9% isotonic saline infusion), and test 2 condition (during isotonic or hypertonic saline infusion).

In comparison with control, there were no significant effects of hypertonic saline infusion (i.e. pain condition) on amplitude or velocity for protrusion or contralateral jaw movements or on velocity for jaw opening. Jaw opening amplitude was significantly smaller in comparison with control during hypertonic, but not isotonic (i.e. control condition), saline infusion. During free but not standardised chewing, subjects chewed faster and exhibited larger amplitude gapes during hypertonic and isotonic infusion in comparison with control. The principal EMG findings were that the significant effects of hypertonic saline-induced pain on EMG activity varied with the task in which the muscle participated irrespective of whether the muscle was an agonist or an antagonist in the tasks. The direction of the hypertonic saline-induced pain effect on EMG activity (i.e. whether the hypertonic saline EMG activity was less than or greater than control EMG activity) could change with the magnitude of jaw displacement. Hypertonic saline infusion had no significant effect on postural EMG activity in any of the recorded jaw muscles. The data suggest that under constrained goal-directed tasks, the pattern of pain-induced changes in jaw muscle EMG activity and/or jaw movement is not clear cut but can vary with the task performed, jaw displacement magnitude, and the subject being studied. Recent studies of the effects of clinical TMD pain on jaw movement has provided preliminary data indicating significant associations between some jaw movement parameters and some psychosocial variables, e.g. depression, anxiety. The biomechanical changes associated with pain in the jaw system need to be explored as this may also help explain an individual's unique motor response.

4. The Effects of Resistance Exercises on Jaw Muscle EMG Activity

The above findings demonstrate that the jaw motor system's mechanical redundancy allows similar tasks to be achieved with different motor patterns. Here we wanted to explore if other (not unpleasant) procedures could alter jaw motor activity and it was hypothesised that exercise training on the jaw could alter motor activation strategies to achieve the same jaw task. If this were the case, such procedures could be used to help improve jaw motor function.

Exercise training is a common physical therapy in rehabilitation and has produced specific changes in timing and patterning of EMG activity [16]. Furthermore, it has resulted in improvements in disability and function scores as well as an improvement in pain-free active range of motion [17]. Specifically in the orofacial region, neural plasticity has been observed in the primary motor cortex of the tongue following fifteen-minutes training of a novel tongue protrusion task [18]. Resistance exercises have been used to improve jaw function and coordination of movements [19-21].

Electromyographic activity was acquired from the masseter, temporalis and digastric muscles with bipolar surface electrodes in 12 healthy adults during a standardised lateral jaw movement task. These subjects were randomly allocated into an exercise or control group for 4 weeks and the standardised movements were repeated after this and again 4 weeks later. The exercise group were trained in performing isotonic resistance exercises, where subjects applied finger pressure at 60% of maximum voluntary contraction to the mandible against right lateral movement of the jaw, and performed these 3 times a day for 4 weeks. Raw EMG signals were rectified, filtered (Butterworth 1Hz, order 3) and normalised to maximum voluntary contraction. An analysis of total EMG activity, maximum EMG activity, rate of EMG activity increase and timing of EMG activity onset and offset of this processed EMG signal was undertaken. These EMG activity variables between the control and exercise groups and before and after exercise sessions were analysed statistically (ANOVA, Mann-Whitney test). At the completion of the study all subjects were able to perform the same standardised right lateral movements during each testing session and between each testing session.

The muscles showing changes most consistently throughout all the tested variables were the left (contralateral) anterior temporalis, the left (contralateral) masseter and the right (ipsilateral) anterior digastric. These three muscles showed significant ($p < 0.05$) changes in 3 out of the 4 variables over the testing period.

Furthermore, following the application of isotonic resistance exercise there was a reduction in the duration of EMG activity in the ipsilateral anterior temporalis, with a concomitant increase in the duration of EMG activity in the ipsilateral anterior digastric. Such changes in the duration of EMG activity may imply that, as a consequence, other muscles of mastication would have altered their activity in order to complete the standardised jaw movement task. After 4 weeks of the resistance exercise programme, the exercise group showed less EMG changes than the control group, which suggests the possible maintenance of a more stable motor control pattern with exercise therapy.

5. The Predictable Modification of Plasticity in Health and Disease

Pain and exercise therapy have been shown to modify the jaw motor system to allow the successful completion of a defined jaw motor task. The ability to modify the jaw motor system in a predictable fashion would offer strategies to improve its effective and efficient use and offer management which could reduce adverse articular and muscle loads. With the enormous variability in craniofacial form within humans, it is to be expected that individuals would have unique individual motor responses to such interventions.

Mathematical modelling of the jaw motor system offers an attractive approach to change systematically structural (e.g. imitate trauma, surgical changes) and functional (e.g. change muscle activity) variables to assess their effects on the individual. Here modelling can be used to generate hypotheses which can then be tested with human experimentation. Impaired function is not uncommon in the jaw motor system and management that predictably alters the biomechanical environment is an attractive goal. As an example, if an aim was to minimise joint loads in a patient with arthralgia, modelling could suggest muscle activity strategies which could achieve this whilst still enabling jaw function.

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