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Effect of orthodontic appliances on masticatory muscle activity

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ABSTRACT

There is limited and conflicting evidence regarding the impact of orthodontic appliances on masticatory muscle activity (MMA), jaw function, and oral parafunctional behaviours. Investigations in this field frequently utilise surface electromyography (sEMG) to analyse changes in muscle contractile activity. Fixed orthodontics appliances have been associated with significant reductions in MMA post archwire activation. Conversely, elevations in masseter and digastric muscle activity have been reported in response to removable functional appliances. Research into the effect of clear aligner therapy (CAT) on MMA is still in its infancy with few studies published. There is a lack of agreement on whether MMA increases or diminishes in response to CAT though there is evidence this relationship may change over time due to muscle adaptation. The impact of CAT on temporomandibular disorder (TMD) symptoms is unclear, particularly how pre-existing risk factors for TMD may alter and individual's response.

Introduction

In recent years, there has been an increase in the demand for orthodontic treatment, particularly amongst adults. The traditional method of comprehensive orthodontic treatment is the pre-adjusted fixed appliance (*i.e.,* braces). However, due to rising aesthetic requirements, patients' desire for an alternative to this well-established treatment modality is increasing.[1]

Clear aligner therapy (CAT) has emerged as an aesthetic treatment alternative. The use of aligners has increased significantly over the last decade with their low impact on smile aesthetics suggested as a key driver for their popularity amongst adults.[2] Aligners are claimed to have several benefits compared with traditional fixed appliances (FA), including reduced treatment and chair time and increased patient comfort.[3–5] Their removable nature also allows them to be taken out during eating and simplifies oral hygiene practices compared to FA, potentially enhancing periodontal health and reducing the impact of treatment on patients' quality of life.[6,7]

Limited knowledge exists about the potential effects of CAT on jaw function. Due to their interference with habitual intercuspal occlusion and jaw position, it can be speculated that CAT may affect the frequency, intensity, or duration of masticatory muscle contractions, which in turn may result in muscle pain and/or development of temporomandibular disorders (TMD) by increasing non-functional oral behaviours in susceptible individuals.

The aim of this review is to assess the current knowledge of the effects of orthodontic appliances including clear aligners on masticatory muscle activity (MMA).

Definition and assessment

MMA refers to jaw functional activities, such as chewing, swallowing, and speaking, as well as to non-functional oral behaviours, which may occur during sleep or when awake.[8] MMA is most accurately assessed by recording muscle contractions via surface electromyography (sEMG). sEMG has a long history of use in dentistry as a tool to assess oral functional and non-functional activities.[9–13] It is non-invasive and provides objective, valid, and reproducible data on muscle contractions that can enhance the understanding of MMA. It is indispensable for a definitive diagnosis of both sleep and wake-time bruxism.[14,15]

Recent advances in technology have led to the development of smartphone assisted wireless wearable EMG devices. These devices have been successfully validated and enable the recording of high-quality EMG signals during routine muscular activity, both during wakefulness and sleep.[13,16–18] They enable extended *in vivo* recordings over prolonged time periods allowing the frequency, magnitude, and duration of all masticatory muscle contractions to be assessed in natural settings. One such device has been developed at the University of Otago, New Zealand as a tool for measuring MMA.[13,16,18]

Despite its advantages, sEMG does have limitations. The technique is sensitive to the size, location, and distance between the electrodes.[19,20] sEMG recordings are less accurate than EMG recordings with intramuscular fine-wire electrodes due to contamination from the activity of adjacent muscles - particularly when assessing low-intensity contractions. Low-level EMG recordings may also be contaminated by noise or artifacts due to other body movements.[18] Moreover, the constituent

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materials, physical dimensions, shape of sensing electrodes and centre-to-centre distance between the conductive areas of active electrodes can further influence EMG signals during muscle activity recordings.[21]

Various protocols have been developed to standardise sEMG methods and increase the validity of measurements.[22] Electrodes placement variables can be controlled by fixing the electrodes' position *via* guides or templates[19]; variations in skin impedance can be managed by calibrating a sEMG device to each subject under investigation.[21] One highly reproducible method of calibration is expression of all contractile activity relative to a muscle's maximum voluntary contraction (MVC). This technique involves participants contracting a muscle as strongly as possible at the beginning of each recording session to set the upper limit of muscle activity.[23,24] Subsequent activity can then be compared to this maximum contractile activity and expressed as a percentage (%MVC).

Research has also explored the use of specific sEMG detection thresholds to differentiate between various oral activities.[25−27] For instance, tentative EMG thresholds have been established for sleep bruxism episodes.[8,28] However, a recent review highlighted that further standardization when scoring of MMA is needed.[29]

The assessment and comparison of MMA between individuals is not without its challenges. Apart from the risk of systematic error caused by recording equipment, several biological factors have been shown to influence MMA, such as facial morphology, biological sex, age, and the number of occlusal contacts.[11,30−34] Research in this area is predominantly historical, with few studies published in recent decades.

Past studies have consistently demonstrated that the number of occlusal contacts between an individual's teeth can impact the EMG activity of jaw muscles through periodontal mechanoreceptor feedback.[35] Occlusal contacts can occur during functional (*e.g.,* chewing and swallowing) and non-functional oral activities both during awake-time and sleep-time. Individuals with fewer than ten occlusal contacts exhibited a statistically significant reduction in MVC amplitude compared to those with more than ten contacts.[11]

The relationship between vertical facial morphology and MMA is less clear. Historical research has indicated that short-faced individuals have greater bite-force than long-faced people.[31,34,36−38] However, investigations comparing habitual MMA in long- and short-faced individuals in natural settings have not shown any significant differences between the two facial morphologies.[39]

MMA and non-functional oral behaviours

Non-functional oral behaviours by definition refer to activities which lie outside the typical function of the jaws. These behaviours themselves are not necessarily abnormal and are observed in healthy subjects without harmful consequences.[25,40] Such activities can be divided into two distinct categories: awake-time and sleep - each of which are associated with unique MMA profiles.[15,41,42]

MMA related to awake-time non-functional behaviours is typically associated with activities such as tooth clenching, oral habits, lip or object biting, jaw play, and tooth tapping, amongst others.[15,26,43−46] Tooth clenching is reported to be more common in females and is closely linked to stress, anxiety, and temporomandibular disorders.[41,47] Some researchers have hypothesised that tooth clenching may serve as a natural form of stress relieving mechanism in healthy individuals.[48]

Sleep-time MMA is more commonly characterised by both phasic and tonic contractions which may include tooth grinding and clenching.[44,49] Several studies have suggested that it is associated with factors including stress, sleep apnoea, anxiety, the consumption of caffeine or alcohol, gastroesophageal reflux, and potentially having a genetic component.[40,42−44,50,51] Dysregulation of the autonomic nervous system and micro-arousal during sleep have also been proposed as possible risk factors.[40] It is worth noting that tooth clenching and grinding during sleep may serve other purposes as well, such as stimulating saliva production for oral lubrication and help maintain a patent airway.[40,52] These potential functions support the assertion that sleep-time MMA may have an important protective role and not necessary be detrimental.

When non-functional activities occur in excess, this normal physiological behaviour transitions to one that is pathological. Heightened somatisation, stress and anxiety have all been associated with increased levels of parafunctional behaviour.[41,47,53] Long-lasting tooth clenching and high levels of non-functional activities have been consistently linked to muscle pain and fatigue, tooth sensitivity, and headaches.[41,43]

It is hypothesised that excessive muscle use leads to repetitive strain injury, resulting in pain and impaired muscular function.[18,44,45,54−58] For example, prolonged low-level tooth-clenching in healthy young women has been shown to induce delayed soreness in the jaw elevator muscles.[59] Furthermore, individuals suffering from masticatory muscle pain have been shown to present with differences in contraction time compared to healthy controls. A study which aimed to compare the wake-time masseter activity of women with masticatory muscle pain and age-matched pain-free controls showed the relative contraction time in those with pre-existing muscle pain was longer than in the pain-free group.[18]

Non-functional MMA is not necessarily related to tooth contacts, and it has been proposed that activities such as bracing and thrusting of the mandible may be potential causes of masticatory muscle pain, at least under experimental settings.[60] Interestingly, such activities have been included in a formal definition of bruxism, despite the current lack of evidence regarding co-contraction of jaw elevator and depressor muscles during ambulatory assessments.

MMA and traditional orthodontic appliances

A number of investigations have explored the impact of traditional orthodontic appliances on MMA. Much of this research is historical and there is a paucity of contemporary literature on the subject. The initial tooth movement following orthodontic archwire activation of fixed appliances has been associated with a short-term decrease in muscle activity.[61,62] The most plausible cause of this decrease is a nociceptive reflex in response to the dental pain produced by the resulting inflammatory reaction.[61,63] Previous studies have documented a reduction in MMA as an immediate response to occlusal discomfort.[64,65] The discomfort caused by the adjustment of fixed appliances may also mimic the signs of muscle pain and dysfunction[61,62] and influence the pressure tenderness of the masticatory muscles.[66]

Occlusal interferences caused by fixed appliances may also play a role in modulating MMA. Experimentally introduced of occlusal interferences have been shown to cause a significant decrease in the number of masseteric contraction episodes per hour and in their mean amplitude.[64] However, this effect appears to be short lived with MMA returning to baseline levels after seven days - suggesting an adaptive response. The impact of fixed appliances on MMA over time is less certain with a lack of longitudinal studies present in the literature.

The response of MMA to functional appliances has been studied in greater detail. However, many of these studies only assess masticatory muscle activity only for a limited period (before and after treatment) and under laboratory settings. The interest in this area likely stems from the mechanism of action of these appliances. Functional appliances aim to modify dento-facial growth and facilitate orthodontic correction by altering the soft-tissue environment and influencing the forces generated by the orofacial musculature.[67]

Increased muscle activity in response to functional appliances has been reported. An investigation on twin-blocks found statistically significant increases in the activity of the masseter with the appliance *in situ* during six months of treatment. This increase was observed both during MVC and at rest.[68] A separate longitudinal study on the Teuscher activator in children reported sustained increases in the activity of the masseter and anterior temporalis for up to two years post-debond.[69] However, with no control or evidence that maturation was considered as a confounder, the results of this study are difficult to interpret in the context of growth.

Long-term EMG recordings have been obtained from patients wearing an activator appliance during both daytime and sleep.[70] Analysis revealed an increase in the activity of the digastric muscle, while a decrease in activity of the temporalis was observed at all time points; similar findings have been reported by others.[71] It appears that MMA is considerably influenced by the use of an activator both during daytime and sleep. This is unsurprising given the sustained muscle activation required to wear the appliance in place.

Muscle adaptation towards baseline values during functional therapy has been observed. One study which assessed MMA in 15 children over six months of treatment with an activator appliance reported increases in posterior temporalis activity at rest at the beginning of treatment. However, this had declined towards control values by the end of the study period[72]; a similar response has been described in the lateral pterygoid muscle in response to the Herbst appliance.[73] Two different studies which assessed muscle activity in response to functional treatment using animal models have also reported evidence of adaptation.[74,75]

Not all studies have found changes to muscle activity during treatment with functional appliances. An investigation on lip-bumpers reported an increase in MMA at rest after insertion of the appliance. However, this activity remained unchanged during the investigation and no adaptation was identified after 12 months.[76]

MMA and clear aligners

At the present time, there is limited and conflicting evidence regarding the effect of CAT on MMA. Broadly, the investigations available on the subject can be divided into those which examine the relationship in conscious participants, and those which examine it during sleep. As stated previously, the characteristics of muscle activity and non-functional oral behaviours when awake or asleep vary markedly.[41] The relationship between CAT and MMA during sleep is therefore likely to be different to that observed in conscious subjects, in part from changes in jaw positioning when supine, limiting the comparison of investigations utilising sleeping and conscious participants.[77]

Of the studies using conscious participants, one found that MMA increases and remains high during CAT.[78] After three months, statistically significant increases in MMA *at rest* were only recorded in the anterior temporalis. When MVC was considered at the same time point, increases were noted for both the anterior temporalis and sternocleidomastoid muscles. No differences in MMA at rest and during MVC were identified for the masseter muscle during the investigation. Oral parafunction was also assessed using the OBC (oral behaviour checklist). A significant decrease in self-reported oral parafunction was identified after three months of treatment and remained low compared to baseline scores after six months.[78]

The second study which investigated the effect of CAT on multiple masticatory muscles in conscious subjects published contradictory findings to those outlined above.[79] In this investigation, MMA in the masseter and anterior temporalis at rest and MVC was assessed in patients receiving CAT at three intervals. During MVC assessment, no differences in MMA were noted for either muscle throughout the study period. In contrast to previous findings,[78] MMA during rest remained constant for the anterior temporalis, while masseter activity decreased after one month of treatment before returning to baseline levels at three months.[79]

It must be noted the external validity of the aforementioned papers is questionable. All EMG recordings were carried out in laboratory settings at isolated time points, without the aligners *in situ*. Furthermore, the MMA measured consisted only of activity at rest and during MVC. Data was also displayed in microvolts - rather than calibrating results to the MVC of each participant limiting the accuracy of inter-participant comparisons. It is hard to generalise the findings of these papers to the effect of CAT on MMA in natural settings.

Increases in masseter activity has been reported in response to CAT when assessed in real-life settings over several hours.[17] Three masseter sEMG recordings of four-hour duration were collected over four weeks from 17 participants undergoing CAT. Significant increases in MMA were observed during the first and second weeks of aligner wear. During the third week, a significant decrease in activity was noted, although it still remained higher than baseline levels.[17] It remains unclear whether this downward trend would have continued had the study extended beyond four weeks, or if it would have remained as high as found in other studies.[78] The suggested explanation for the decrease in MMA observed in the final week of CAT was muscle adaptation.[17] A limitation of this investigation was the use of z-scores to assess and compare participants' MMA instead of calibration to MVC. By averaging all muscle activity which occurred during the recording period in a z-score, confounding muscle activity unrelated to the presence of the aligners could have been included in the analysis.

In contrast, a recent study which examined the effect of CAT on awake-time MMA in a natural setting over time reported a significant decrease in the amplitude of masseter muscle contractions after insertion of the aligners.[13] The sample included two sub-groups – individuals with high or low self-reported oral parafunction; the observed decrease in MMA was found to be independent of oral parafunction. However, those with high parafunction experienced significantly more occlusal discomfort than their low parafunction counterparts suggesting they were more perturbed by the presence of the aligners; the higher somatisation levels reported in these individuals was reported as the likely reason for this finding.[13]

The studies assessing the effect of CAT on MMA during sleep do not add any further clarity or consensus to the relationship. One study investigated the influence of CAT on sleep bruxism events and total muscle contractions.[80] The authors observed a slight increase in bruxism events after the insertion of aligners, but this increase was not statistically significant. Furthermore, the presence of the aligners did not affect the overall muscle activity.[80] These findings closely mirror those of a French-Canadian study that also reported no changes in the number or duration of muscle contractions per hour during sleep following the introduction of clear aligners.[81]

A different study involved participants diagnosed with sleep bruxism.[27] MMA was monitored for six months during a course of CAT. While increases in phasic contractions were noted during the first and third months, the overall effect of aligners on MMA and sleep bruxism events was considered negligible.[27] These findings suggest that although MMA may increase as a result of aligner wear, its variation is not clinically significant.[27,80]

In the short-term, the above finding contrasts with another investigation which analysed sleep bruxism events during CAT in a 'case group' with a confirmed diagnosis of sleep bruxism.[24] After one month of CAT, episodes of nocturnal bruxism were found to markedly decreased compared to baseline levels. However, activity returned to baseline levels after three months of wear again suggesting CAT has minimal effect on sleep bruxism events when assessed over a longer time period.

Few of these studies monitor TMD symptoms during data collection. Interestingly, several used the presence of TMDs as an exclusion criterion for participant selection - despite the significant association between excessive MMA and the development of TMDs.[17,24] A more contemporary study reported that TMD symptoms remained unchanged from pre-treatment after eight days of aligner wear, irrespective of non-functional activity levels.[13] Short-term increases in muscle tenderness in response to CAT have also been reported, without progression to TMD development.[79]

Clinical implications

The reduction in MMA observed in the presence of fixed appliances[61,62] suggests that clinicians can prescribe fixed appliances to individuals with high levels of MMA without fear of intensifying their muscle activity. In contrast, functional appliances have been shown to increase MMA.[68,69] Care should therefore be taken when proposing functional growth modification in people with pre-existing high MMA levels. There is some limited evidence that the effect of functional appliances on the orofacial tissues may be predicted by pre-treatment muscle thickness and bite-force, both of which are associated with MMA; greater dentoalveolar changes in response to functional appliances have been observed in individuals with thinner master musculature and lower bite-force.[82,83]

The effect of CAT on MMA is conflicting. However, individuals with high levels of non-functional oral behaviour and increased somatisation have been shown to experience more discomfort in response to CAT.[13] In the future, these characteristics could be used as 'red flags' to help better screen for patient suitability for CAT.

Conclusions

Given the widespread use of orthodontic appliances, it is important to understand their effects on MMA. The findings of this review indicate that there is limited and conflicting knowledge regarding the effects of orthodontic fixed appliances, functional appliances, and clear aligners on MMA. Moreover, previously published studies are difficult to compare due to their different methodologies and outcome measures. Research in this field would benefit from standardisation in the way MMA is reported. Calibration of all MMA relative to %MVC and assessment of contraction episodes is one possible way forward in this regard.

From the current evidence, it appears that orthodontic appliances have different effects depending on the type of appliance, its mechanism of action, and whether they induce pain or dental discomfort. It is well-established that orthodontic archwire activations in patients wearing fixed appliances significantly reduces MMA. On the other hand, removable functional appliances have been associated with increases in digastric muscle activity. However, not all studies have found changes in muscle activity during treatment with functional appliances.

The impact of CAT on MMA is still unclear, though there is evidence this relationship may change over time due to muscle adaptation. There is also inconclusive evidence that the wearing of clear aligners could be related to an exacerbation of temporomandibular disorder (TMD) symptoms such as muscle tenderness. This may be especially true for subjects already prone to muscle hyperactivity and high oral parafunction, as these individuals often have interrelated characteristics such as heightened somatization and stress, which may modify their response to the orthodontic appliance.

Patient consent

Patient consent is not required.

Author contributions

All authors attest that they meet the current ICMJE criteria for authorship.

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