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Impact of clear aligner therapy on tooth pain and masticatory muscle soreness

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Abstract

Background: Clinical findings suggest that orthodontic treatment with clear aligners (clear aligner therapy/CAT) may cause masticatory muscle soreness in some patients.

Objective: This multi-site prospective study investigated tooth pain and masticatory muscle soreness and tenderness in patients undergoing CAT and explored whether psychological traits affected these outcomes.

Methods: Twenty-seven adults (22F, 5M; mean age ± SD=35.3 ± 17.6 years) about to start CAT were recruited at three clinics. During CAT, they reported on 100-mm visual analogue scales their tooth pain, masticatory muscle soreness and stress three times per day over 4 weeks (week 1 = *baseline*; week 2 = *dummy aligner*; week 3 = *first active aligner*; week 4 = *second active aligner*). Pressure pain thresholds (PPTs) were measured at the masseter and temporalis at baseline and after week 4. Mixed models were used to evaluate the outcome measures over time.

Results: Clear aligner therapy caused mild tooth pain, which was greater with the passive than the first and second active aligners (both $P < .001$). Mild and clinically not relevant masticatory muscle soreness was produced by all aligners (all $P < .05$), with the first active aligner producing less soreness than the dummy aligner ($P < .001$). PPTs did not change significantly after 4 weeks. Both tooth pain and masticatory muscle soreness were affected by stress and trait anxiety, whilst muscle soreness was affected also by oral behaviours.

Conclusions: In the short term, CAT produces tooth pain and masticatory muscle soreness of limited significance. Frequent oral behaviours are related to increased masticatory muscle soreness during CAT. The medium- and long-term effects of CAT should be further explored.

KEYWORDS

awake bruxism, clear aligner therapy, masticatory muscles, orthodontic treatment, temporomandibular joint disorders, tooth pain, trait anxiety

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1 | INTRODUCTION

Fear of pain is a significant reason why patients decline orthodontic treatment.[1] In one survey, patients rated pain as the greatest dislike in regard to their experience with orthodontic treatment and ranked fourth amongst major fears and apprehensions.[2] Orthodontic pain – nociceptive and inflammatory tooth pain associated with orthodontic tooth movement[3] – can negatively impact patients' compliance,[1,4,5] lead to an increased frequency of missed appointments,[6] as well as compromise the overall treatment results and patient satisfaction.[5] In some cases, the impact of pain on patients' daily lives could be a significant factor for the termination of orthodontic treatment.[6,7] Therefore, practitioners should focus on improving the pain experience during treatment, to potentially improve patient compliance and treatment time and ensure an overall better orthodontic experience.[1,8]

Previous studies have demonstrated that patients' perception of pain varies between fixed and removable appliances. In general, fixed appliances produce higher levels of pressure and pain compared to functional appliances and removable appliances.[9-11] Orthodontic pain associated with clear aligner therapy (CAT) has been investigated in several studies. CAT appears to follow an analogous pattern of pain progression compared to fixed orthodontic appliances in terms of peaking at 24 hours and trending towards baseline levels after 7 days.[12-15] Deformation of aligners has been reported as the primary cause of this pain and discomfort.[13] The results of the available studies are generally in agreement with each other, suggesting that CAT causes slightly less pain and discomfort than fixed appliances during the first few days of treatment, whilst differences seem to be negligible later in treatment.[15]

The response of masticatory muscle to orthodontic treatment has been investigated in several studies. Patients undergoing orthodontic treatment with fixed edgewise appliances may adapt by avoiding tooth contact to reduce tooth pain related to orthodontic treatment Also, occlusal interferences generated during treatment could trigger an avoidance behaviour.[16] In fact, the electromyographic activity of the masticatory muscles can decrease during fixed appliance treatment.[17,18] However, there is some clinical evidence for a different adaptation mechanism for the masticatory muscles of patients undergoing CAT. Indeed, they have been reported to increase the frequency of wake-time tooth clenching episodes,[19] and produce wear facets on their aligner trays.[20,21] It is possible that repetitive clenching on clear aligners would be an acquired behaviour to reduce the perception of the orthodontic nociceptive stimuli during orthodontic tooth movement. In fact, the amount of pain experienced by patients undergoing orthodontic treatment with fixed appliances could be reduced by having them clench on plastic wafers after appliance activation.[22,23] This repetitive behaviour could induce a temporary displacement of the teeth and promote blood flow through the compressed areas of the periodontal ligament, thus preventing accumulation of pro-algesic mediators in the periodontal ligament space and promoting pain relief.[22-24] One potential drawback is that wake-time tooth clenching could lead to contribute to masticatory muscle pain and temporomandibular disorders (TMD).[25] Therefore, it is possible that patients undergoing CAT may have transient masticatory muscle pain as a result of repetitive clenching on their trays. Yet, the effects of CAT on masticatory muscles have been minimally investigated, and whether CAT could contribute to the onset of TMD symptoms is not currently known.

The magnitude of orthodontic pain varies considerably across individuals. Pain perception is influenced by factors such as somatosensory amplification[26,27] – an estimate of an individuals' somatic awareness – stress, anxiety, depression and pain catastrophising.[27-31] Patients with prolonged pain during orthodontic treatment exhibit higher levels of anxiety than do individuals with pain of short duration.[32] In addition, experimentally induced orthodontic pain is greater in individuals with higher levels of trait anxiety and somatosensory amplification.[27] Of note, anxiety and somatosensory amplification have also been associated with increased frequencies of oral waking-state parafunctional behaviours, including tooth clenching.[33]

In this study, we aimed to investigate the short-term effects of CAT on orthodontic tooth pain and masticatory muscle soreness and tenderness. Further, we explored whether levels of stress, trait anxiety, somatosensory amplification, depression and pain catastrophising influence perceived orthodontic pain and masticatory muscle soreness during CAT. We hypothesise that (a) CAT produces mild to moderate tooth pain and transient masticatory muscle soreness and tenderness and (b) the individual pain response to CAT correlates with indices of stress and anxiety, somatosensory amplification, depression and catastrophising.

2 | MATERIALS AND METHODS

2.1 | Participants

Subjects, 17 years or older, treatment planned to undergo CAT, were recruited from the graduate orthodontic clinics at the University of Western Ontario (London, ON, Canada), University of Toronto (Toronto, ON, Canada) and University of Turin (Italy). Ethics approval was obtained from the corresponding Research Ethics Boards at each institution, and informed consent was acquired from each subject prior to entering the study. Each potential participant completed an initial screening questionnaire using the TMD-Pain screener.[34,35] Also, each participant underwent a TMD examination by a single examiner at each research unit according to the DC/TMD protocol.[35] The operators were extensively trained in the DC/TMD protocol by the senior investigator (IC). All operators attended clinical and laboratory sessions about the TMD clinical exam provided by the senior investigator (IC). During these sessions, the clinical TMD assessment was carefully reviewed, and disagreements were discussed and resolved. Exclusion criteria consisted of current symptoms of TMD[35] or orofacial pain, current use of muscle relaxants or other medications affecting masticatory muscle activity, presence of any systemic disorders affecting motor behaviours and pain perception, migraine, daily use of any analgesics and orthodontic treatment requiring extractions.

From an initial sample of 34 eligible individuals, a total of 27 subjects (5M, 22 F; mean age ± SD =35.3 ± 17.6 years) participated in the study (Figure 1). Seven individuals decided not to participate in the study because of the time commitment needed to fill in the diaries (see below). All patients were treated with Invisalign© clear aligners (Align Technology), made of the latest generation of multilayer thermoplastic polyurethane-based material, SmartTrack. Using the ClinCheck Pro software (Align Technology), the first stage of aligners for all patients consisted of upper and lower aligners programmed with no active tooth movements (passive aligners). Active tooth movements were programmed for the subsequent stages at the standard rate recommended by the ClinCheck Pro algorithms. All participants had class I or mild class II malocclusion with mild to moderate crowding or spacing in the upper and lower dental arches. Participants were asked not to use Chewies to improve aligner seating.

2.2 | Questionnaires

At the beginning of the study, subjects were asked to complete sets of questionnaires including the State Trait Anxiety Inventory[36] (STAI, trait anxiety: score range 20-80), the Oral Behaviour Checklist[37] (OBC, score range: 0-84), the Somatosensory Amplification Scale[26] (SSAS, range: 10-50), the Pain Catastrophising Scale[29] (PCS, range 0-52) and the Beck Depression Inventory[38] (BDI, range: 0-63). The use of these questionnaires allowed for determining the effect of these psychological traits, as well as pre-existing parafunctional oral behaviours, on differences in individual pain perception.

2.3 | Study design

The study design is depicted in Figure 2. All subjects commencing treatment with CAT were monitored over 4 weeks for tooth pain, masticatory muscle soreness and daily stress using custom-made diaries. Specifically, data were collected prior to the start of CAT for 1 week without aligners (week 1 = *baseline stage*), for 1 week wearing a passive aligner (week 2 = *dummy stage*), for 1 week wearing their first active aligner (week 3 = *active1 stage*) and finally for 1 week wearing their second active aligner (week 4 = *active2 stage*). A full TMD clinical assessment[35] was performed before the baseline stage and after the active2 stage.

2.4 | Pressure pain thresholds

Pressure pain thresholds (PPTs) – the minimum pressure that is perceived as painful – were measured at baseline and at the end of week 4 with an electronic algometer (Wagner Inc.) equipped with a rubber tip of 1 cm^2 surface area. The PPT data served as an objective measurement of participants' masticatory muscle tenderness and to determine whether CAT resulted in trigeminal and extra-trigeminal sensory changes.

Pressure pain thresholds were taken at three locations on both right and left sides, the superficial masseter, anterior temporalis and

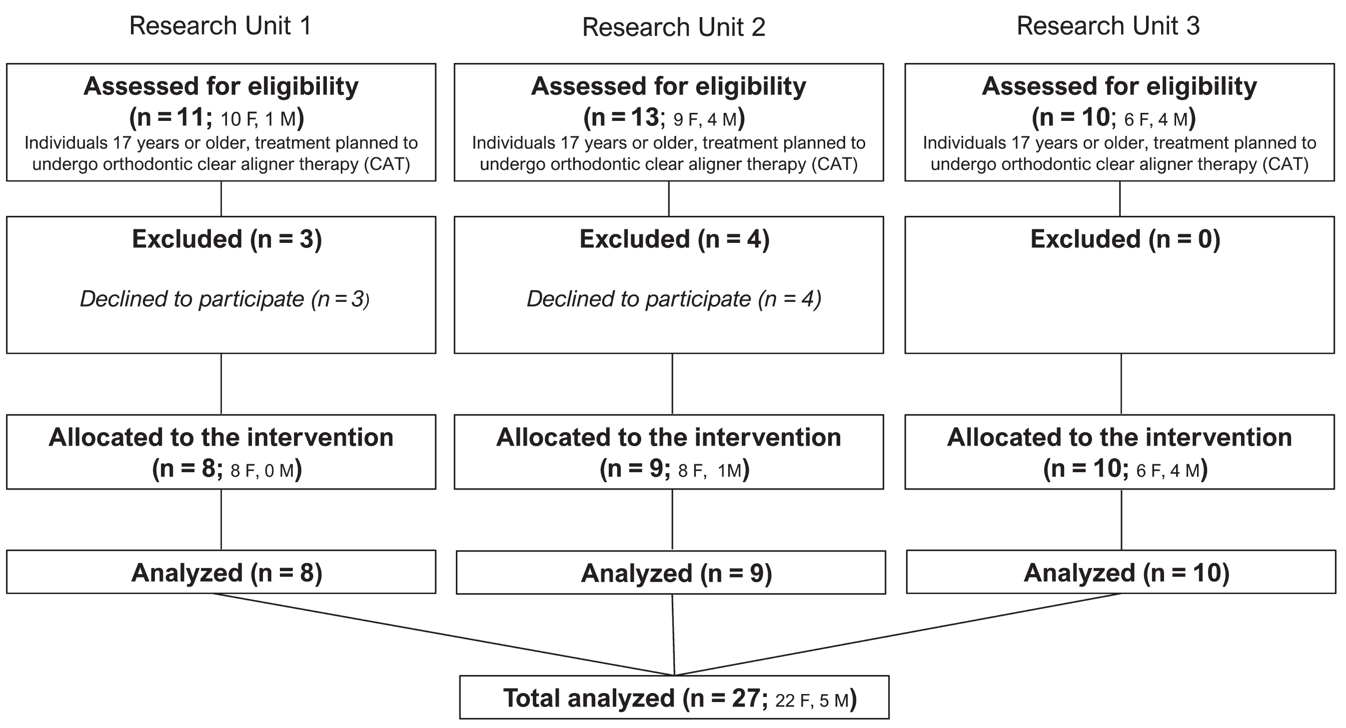

FIGURE 1 Recruitment of participants from the three university-based clinics.

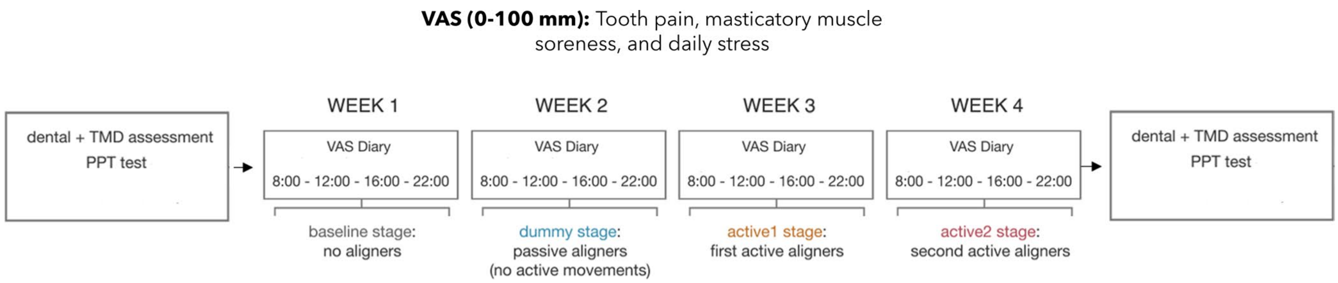

FIGURE 2 Study design. [Colour figure can be viewed at wileyonlinelibrary.com]

thenar eminence of the right hand. For the superficial masseter, the site was located midway between the origin and insertion, 1 cm posterior to its anterior boundary. For the anterior temporalis muscle, the site was located on the line from the top edge of the eyebrow to the highest point of the pinna of the ear, 2 cm posterior to the anterior margin of the muscle as determined by palpating the muscle during voluntary contraction. For the thenar muscle, measurements were taken on the skin of the palmar side of the hand, on the thenar prominence. PPTs at the thenar muscles were measured with hands supinated flat on a tabletop. The latter measurement was collected to assess whether participants had significant changes at extra-trigeminal locations, which could have been determined by other conditions, unrelated to CAT.

For all sites, the algometer was positioned perpendicular to the skin surface at the selected sites and pressure applied at a constant rate of 20 kPa/sec. The PPT was determined as the point at which the pressure stimulus changed from a sensation of pressure into a sensation of pain. The participant indicated this by raising one hand to signal the examiner to release the pressure, which froze the current pressure value on the digital display, and this peak pressure value was subsequently recorded. Measurements were repeated for a total of 4 trials at each muscle, with 1-minute intervals between trials. The order of muscle site measurements was randomised across patients.

The operators were trained in pressure algometry by an expert researcher (IC) with more than 15 years of experience in PPTs. Using a visual feedback (Medoc), they were trained to apply pressure at a constant rate of 20 KPa/sec. The operators repeated the training for a few days. The intra-operator reliability in applying pressure at the specified rate of 20 KPa/sec with the algometer was measured during a session prior to the start of data collection. During this session, the operators were asked to use their algometers (the ones assigned by each research unit, and previously calibrated by the vendor) and apply pressure at 20 KPa/sec against a vertical flat surface without using the visual feedback, and to stop after pre-determined time intervals. Inter-rater reliability was computed thereafter (see statistical analysis paragraph).

2.5 | Longitudinal behavioural assessment

A diary was provided to each participant to evaluate and record their tooth pain and masticatory muscle soreness at four time points (8:00, 12:00, 16:00 and 20:00) during each day of the four conditions (baseline, dummy stage, active1 and active2). The diary included the following questions, with corresponding 100 mm visual analogue scales (VAS) and anchors:

- Tooth Pain (VAS = 0-100 mm). '*How severe is your tooth pain?*' Anchors: 'no pain', 'pain as bad as could be';
- Masticatory Muscle Soreness (VAS = 0-100 mm). *'Are your jaw muscles sore?'*

Anchors: 'no soreness', 'sore as bad as could be'.

Participants' stress was rated at the end of each day using a separate single VAS:

- Perceived Stress (VAS = 0-100 mm). '*How bad is your stress today?*'

Anchors: 'no stress', 'stress as bad as could be'.

In specific, participants were asked to report their daily stress unrelated to the use of clear aligners. All participants were instructed to take note of any intake of analgesics and to return their diary after the end of the fourth experimental week.

2.6 | Statistical analysis

Normality of data was tested using the Kolmogorov-Smirnov test. Correlations between tooth pain, masticatory muscle soreness and stress, STAI, SSAS, PCS and BDI scores were tested using the Spearman's test. Because daily stress was correlated with both tooth pain and masticatory muscle soreness and included data from all days of the experiment (state measure), it was incorporated in the mixed models (see below) as a covariate. Missing data from the diaries were included as missing value in the statistical dataset.

The effect of the conditions (baseline, dummy, active1 and active2) on tooth pain and muscle soreness was assessed over time using generalised linear mixed-effect models. Data from the four timepoints (8:00, 12:00, 16:00 and 20:00) were aggregated for each day. Two models were used, one for tooth pain and one for masticatory muscle soreness. In each model, day, sex and condition (baseline, dummy, active1 and active2) were used as fixed factors and daily stress as covariate. Interactions between the model's variables were tested and retained in the model when statistically significant.

Pressure pain thresholds data were aggregated by computing the mean of the trials obtained at each location, after having discarded the first trial, as performed previously.[39] Differences between right and left sides of PPTs at the masseter, temporalis and thenar eminence were tested using *T*-test. Because there were no differences between sides (all $P > .05$), the data were pooled for each location. Inter-rater reliability in PPT assessments was measured by computing intra-class correlation to estimate the inter-rater reliability between the researches using the data collected during the calibration sessions. ANOVA was used to test whether PPTs at different muscle locations changed after 4 weeks. Sex was included in the model as a fixed factor.

A power analysis was conducted using G*Power (Heinrich-Heine-Universität Düsseldorf).[40] The analysis showed that a total sample of 27 participants would have been sufficient to achieve a power of 0.80 with a moderate effect size (d = 0.5) and an alpha of .05. Statistical significance was set at $P < .05$. SPSS software ver. 24.0 (IBM, Armonk, NY, USA) was used for statistical analysis. The analysis was performed by a single operator (IC) who was blinded to the CAT stage.

3 | RESULTS

There were no dropouts during the 4-week period. None of the patients at each research unit developed TMD[35] after 4 weeks.

3.1 | Tooth pain

The average tooth pain (VAS data) experienced by participants during the 4 weeks and tooth pain trajectories during each day are reported in Figure 3. Overall, CAT determined mild tooth pain. Results from the mixed-effect model are reported in Table 1A. Tooth pain was significantly affected by sex and by the interactions day by stress ($P < .001$) and day by condition ($P < .001$). During the dummy condition, participants had greater tooth pain compared to the baseline ($P < .001$). Overall, the dummy aligner produced significantly more tooth pain than the active aligners (active1 and active2, all $P < .001$). There was also a significant decrease in tooth pain transitioning from the dummy aligner to active1 ($P < .001$) and from active1 to active2 ($P < .001$). Significant difference in mean tooth pain was detected between males (mean ± SEM = 3.2 ± 0.8 mm) and females (11.2 ± 1.6 mm; $P < .001$). For the majority of days (days 1 to 4), the dummy and active aligners produced more tooth pain than at baseline (all $P < .05$), and during the first four days, the dummy aligner produced more pain than the active aligners (all $P < .05$). The highest tooth pain (VAS = 16 mm) occurred on day 2 of the dummy aligner stage and decreased significantly from day 2 to day 7 (all $P < .05$). No significant differences were evident across days within the active1 condition (all $P > .05$). Tooth pain was significantly less at day 7 than at day 1 during active2 ($P < .05$).

3.2 | Masticatory muscle soreness

The average masticatory muscle soreness (VAS data) experienced by the participants during the 4 weeks and muscle soreness trajectories during each day are reported in Figure 4. Results from the mixed-effect model are reported in Table 1B. Overall participants had mild masticatory muscle soreness, which was significantly affected by the interactions day by stress ($P < .001$) and day by condition ($P < .001$). Sex did not affect masticatory muscle soreness ($P = .361$). Compared to baseline, both the dummy aligner ($P < .001$) and active2 ($P < .001$) caused an increase in muscle soreness. Active1 resulted in significantly less muscle soreness than the dummy aligner ($P < .001$). Active2 resulted in a significant increase in muscle soreness compared to active1 ($P < .001$). At baseline and during active1 and active2, there were no significant differences across the days ($P > .05$). During the dummy condition, masticatory muscle soreness decreased significantly from day 1 to day 6 (all $P < .05$).

3.3 | Pressure pain thresholds

The inter-rater reliability for PPT measurements between the operators was high (ICC 0.966 [95%CI: 0.938-0.981]; $P < .001$). PPTs at all muscle locations did not change significantly from baseline to week 4 ($P = .639$) after having corrected for sex (data not shown). Females had lower PPTs at all locations than males (all $P < .001$).

3.4 | Correlations between tooth pain, masticatory muscle soreness, and psychological data and self-reported oral behaviours

Masticatory muscle soreness was moderately correlated with self-reported wake-time oral parafunctions (OBC; $r = .409$; $P = .042$;

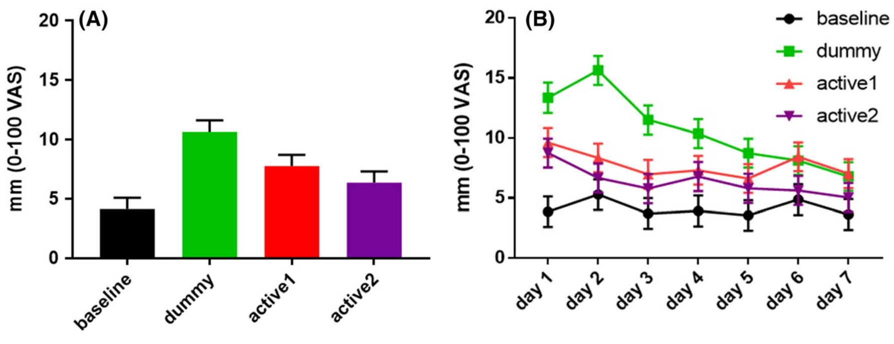

FIGURE 3 Visual analogue scales (VAS) scores for tooth pain. A, Mean estimated marginal means of tooth pain (±SEM) for each condition. All pairwise comparisons were statistically significant at $P < .001$. B, Mean estimated marginal means of tooth pain trajectories (±SEM) over 7 d for each condition. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Results from the mixed-effect models for (A) orthodontic pain and (B) masticatory muscle soreness. **Bold type:** statistically significant at *P* <.05

Independent variable	*F*	*P*-value
A		
Sex	19.176	**<.001**
Day	4.872	**<.001**
Condition	68.293	**<.001**
Stress	210.945	**<.001**
Day × stress	10.576	**<.001**
Day × condition	2.982	**<.001**
B		
Sex	0.833	.361
Day	2.403	**.026**
Condition	16.772	**<.001**
Stress	380.471	**<.001**
Day × stress	23.877	**<.001**
Day × condition	2.914	**<.001**

Note: Bold type: statistically significant at *P* < .05.

TABLE 2 Correlations between longitudinal Visual analogue scales (VAS) data and depression (BDI), pain catastrophising (PCS), oral behaviour checklist (OBC) scores, somatosensory amplification (SSA) and trait anxiety. **Bold type:** statistically significant at *P* < .05.

		Correlation coefficients	
	Median [IQR]	Tooth pain (VAS)	Masticatory muscle soreness (VAS)
BDI	2 [7]	−0.370 (*P* = .075)	−0.305 (*P* = .148)
PCS	7 [16]	−0.042 (*P* = .840)	−0.237 (*P* = .254)
OBC	25 [16]	0.150 (*P* = .476)	**0.409 (P = .042)***
SSAS	15 [9]	−0.367 (*P* = .071)	−0.155 (*P* = .460)
Trait anxiety	37 [22]	**0.473 (P = .008)***	**0.343 (P = .047)***

*Statistically significant at *P* < .05.

Table 2). A significant correlation was found between trait anxiety and tooth pain (*r* = .473; *P* = .008) and muscle soreness (*r* = .343; *P* = .047). Tooth pain and masticatory muscle soreness did not correlate with PCS, BDI and SSAS (all *P* > .05; Table 2).

4 | DISCUSSION

This study sought to determine the short-term effects of CAT on tooth pain and masticatory muscle soreness. Furthermore, we explored whether levels of daily stress, trait anxiety, somatosensory amplification, depression and pain catastrophising influence perceived pain and masticatory muscle soreness during CAT. It was found that CAT is associated with mild tooth pain and muscle soreness of limited clinical significance over 4 weeks. A mild increase in tooth pain was evident from baseline to the dummy (i.e., passive aligner) condition. The passive aligner stage produced the greatest tooth pain. Thereafter, when active tooth movements were programmed into the aligners (active1 and active2 stages), tooth pain decreased, being lower in the second than the first active aligner. Therefore, it was likely that the fitting of the aligner rather than the active tooth movement was perceived painful by the subjects. Subjects also reported mild masticatory muscle soreness during the first few weeks of treatment, which was greater with the passive aligner and the second active aligner.

The temporal profile of tooth pain measured in this study follows the same pattern of conventional fixed appliances, being the greatest during the first 24-48 hours and the lowest after 5 days. However, in contrast to fixed buccal and lingual appliances, which have been found to produce up to 50 mm[13,14] and 60 mm of tooth pain on VAS,[12] the peaks of pain in the current study were around 20 mm. This maximum reported tooth pain is similar to that reported by White et al in 2017,[14] who utilised the newest generation multilayer thermoplastic material SmartTrack, as performed in the present

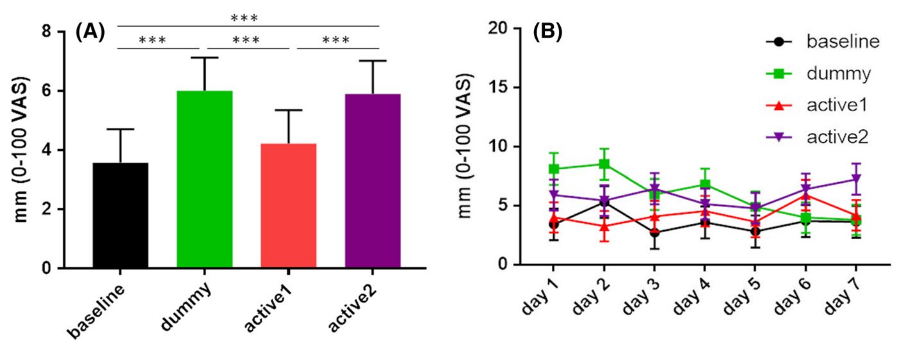

FIGURE 4 Visual analogue scales (VAS) scores for masticatory muscle soreness. A, Mean estimated marginal means of masticatory muscle soreness (±SEM) for each condition. ***Pairwise comparisons statistically significant at *P* < .001. B, Mean estimated marginal means of masticatory muscle soreness trajectories (±SEM) over 7 d. All pairwise (between conditions) comparisons within each day were not statistically significant (all *P* > .05) [Colour figure can be viewed at wileyonlinelibrary.com]

study. In an earlier study, using the Exceed-30 material, tooth pain was reported to be greater with aligners than fixed appliances.[12] Therefore, it seems that the change of the aligner material could have contributed to improve patient pain experience with Invisalign.

Masticatory muscle soreness resulting from CAT has been minimally investigated. Brien[19] demonstrated that CAT with Invisalign produces transient symptoms of TMD in the form of muscle soreness within the first 2 weeks of treatment and subsides to baseline levels over time. This finding was not consistent with the current results. Indeed, in the present study, masticatory muscle soreness did not subside to baseline levels after 4 weeks. However, it was mild and likely of limited clinical significance as no patients developed TMD. Of importance, pressure pain thresholds did not significantly change after 4 weeks. Yet, it might be questioned what the effects of CAT in patients with TMD, or a previous history of, could be different. Indeed, as CAT results in a mild increase in masticatory muscle soreness, it may exacerbate TMD symptoms, although further studies are needed to address this hypothesis. Similar to conventional orthodontic treatment, it is advisable to stop active treatment in patients reporting TMD symptoms during CAT and manage symptoms prior to continue treatment.[41]

It has been reported that orthodontic pain reduces the electromyographic activity of the masseter.[17,18,42] Also, masticatory muscle soreness is infrequently reported by patients commencing orthodontic treatment with edgewise fixed appliances. Conversely, CAT determined mild muscle soreness in the current sample. Hence, patients' masticatory muscle adaptation to CAT may differ from that to fixed orthodontic appliances. It is possible that patients with CAT may engage in tooth clenching to alleviate the perception of tooth pain. This repetitive behaviour could induce a temporary displacement of the teeth and promote blood flow through the compressed areas of the periodontal ligament, thus preventing accumulation of pro-algesic mediators in the periodontal ligament space and promoting pain relief.[23] Of interest, masticatory muscle soreness had a moderate correlation with OBC scores (waking-state oral behaviours), supporting the hypothesis that masticatory muscle soreness is related to increased oral behaviours.[43] However, further investigations which could monitor the activity of the masticatory muscles during CAT are needed to address this hypothesis. Similarly, it is also possible that the increase in muscle soreness is the result of masticatory muscle hyperactivity related to the introduction of occlusal interferences,[45] rather than to tooth pain. However, experimental studies have demonstrated that the application of occlusal interferences leads to an avoidance behaviour and reduction of masseter muscle activity in the short term.[16] Also, occlusal interferences produced by 2-week treatment with aligners are clinically negligible. Therefore, the latter proposed mechanism is not supported by the available evidence and the current research method.

Clear aligner therapy did not affect PPTs of the superficial masseter and anterior temporalis. This is contrary to what was found in previous studies[46] where orthodontic interventions resulted in significant sensory changes in trigeminal locations. These PPT findings confirm that masticatory muscle tenderness produced by CAT may be of limited clinical significance. A significant effect of sex on PPTs was found, with females having lower mean PPTs than males. Sex differences in clinical and experimental pain conditions have been previously described with females generally having higher pain sensitivity than males.[47]

It is well known that orthodontic pain can be affected by multiple factors including psychological traits such as somatosensory amplification, trait anxiety and stress.[27,31] Because in this study stress and anxiety were correlated with tooth pain and masticatory muscle soreness, it is possible to assume that they contributed to the pain experience during CAT. Yet, we did not find correlations between other psychological variables and tooth pain and masticatory muscle soreness. Of interest, increased somatosensory amplification has been reported to contribute to increased orthodontic pain in a previous study.[27] Therefore, it is possible that somatosensory amplification may have less impact on orthodontic pain and masticatory muscle soreness when the latter are of very limited magnitude.

This study has some limitations. First, it included adults of different ages. Although the effect of age on orthodontic pain is controversial, the biologic response to orthodontic forces is age dependent.[48] Therefore, for this study, we preliminarily tested whether age was correlated with tooth pain and masticatory muscle soreness. Because age was not significantly correlated with these variables in the current sample, we did not include it as a potential confounder in our analysis. Second, occlusal characteristics, such as crowding, were not considered in the models as potential confounders. A previous study showed no relationship between crowding and orthodontic pain.[49] Also, differences in crowding across participants likely did not affect the results, because the Invisalign technique produces controlled and very limited tooth movements in 2 weeks. Third, in this study we used paper-based diaries, which could have increased the chances of recall bias. The use of mobile apps for collecting data in real time could have minimised recall bias and, in turn, maximised the ecological validity of our data. Also, randomisation in sequence of dummy and active aligners was not performed, as it could have prolonged treatment duration and raised ethical concerns. Yet, this allowed us to determine that tooth pain was mostly determined by the fitting of the aligner rather than the active tooth movement. Finally, we evaluated the effects of CAT on masticatory muscle soreness only in the short term (ie, 4 weeks) in healthy individuals and we cannot draw conclusions on its long-term effects, and its potential effect on individuals with a former history of TMD, which limits the external validity of our study.

5 | CONCLUSIONS

In the short term, clear aligner therapy produces mild tooth pain and masticatory muscle soreness of limited clinical significance, which are related to the fitting of the aligners rather than orthodontic tooth movement. Daily stress contributes to tooth pain perception and masticatory muscle soreness during clear aligner therapy. Finally, trait anxiety and frequent oral behaviours may contribute to increasing experience masticatory muscle soreness during treatment with clear aligners. The medium- and long-term effects of CAT on the masticatory muscles should be further explored.

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CONFLICT OF INTEREST

Iacopo Cioffi received funding to conduct this research study from Align technology. Align technology produces Invisalign aligners. Tommaso Castroflorio received funding from Align Technology for previous research studies. Johnny Tran, Ali Tassi, and Bianca Nebiolo declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Johnny Tran and Tiantong Lou contributed to the study design, recruitment of participants, data collection, analysis and interpretation and drafting of the manuscript. Bianca Nebiolo contributed to the recruitment of participants and data collection. Tommaso Castroflorio and Ali Tassi contributed to the conceptualisation of the research study and study design, data interpretation and writing. Iacopo Cioffi contributed to the conceptualisation of the study and study design, data analysis and interpretation, and writing. He was the coordinator of the multi-site research.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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