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Review Article

Pain perception and sEMG of masticatory muscle in clear aligners vs. conventional orthodontics: A systematic review and meta-analysis

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ABSTRACT

Background: Clear aligner therapy (CAT) has gained popularity as an alternative to Conventional Orthodontic Treatments (COT) for its potential to reduce pain and discomfort. This systematic review and meta-analysis aimed to compare pain perception and surface electromyography (sEMG) in masticatory muscles between CAT and COT groups.
Materials and Methods: A comprehensive search of multiple electronic databases was conducted to identify relevant studies. The PRISMA guidelines were employed to ensure transparency and completeness in reporting and was registered in PROSPERO (CRD42024556800).
Results: Nine studies were considered for inclusion. The meta-analysis revealed a nonsignificant difference in Visual Analog Scale scores between CAT and COT groups, with a mean difference (MD) of –2.77 (95% confidence interval [CI]: –7.25, 1.71), $P = 0.23$. The heterogeneity test revealed significant heterogeneity among studies ($I^2 = 100\%$). In contrast, the sEMG activity scores showed a nonsignificant difference between CAT and COT groups (MD = –0.80, $P = 0.60$). In addition, the odds ratio for patients requiring analgesics was 0.23 (95% CI: 0.08, 0.65), $P = 0.005$, suggesting a significant difference between CAT and COT groups.
Conclusion: The results suggest that CAT may be associated with improved patient outcomes, including reduced pain and discomfort, as well as lower analgesic consumption. However, the evidence is not conclusive, and further research is needed to fully understand the differences between CAT and COT.

Key Words: Clear aligner therapy, conventional orthodontic treatments, masticatory muscles, pain perception, surface electromyography

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INTRODUCTION

Maintaining ideal oral function, articulation, and general quality of life depends critically on the stomatognathic system, a complex neuromuscular entity encompassing the masticatory muscles, temporomandibular joint (TMJ), and dental occlusion.[1,2] A careful balance of brain inputs, proprioceptive feedback, and mechanical forces – all sensitive to disturbances caused by orthodontic treatments – coordinates the complex interaction among these components.[3]

The field of orthodontics has seen a dramatic change in recent years as clear aligner therapy (CAT) has become

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a preferred substitute for conventional orthodontic treatments (COT) for the repair of malocclusions and restoration of ideal tooth alignment.[4] Although both modalities have as their common goal achieving optimal occlusion, the different biomechanical characteristics, treatment approaches, and mechanical stimuli inherent in each approach may differently affect the masticatory muscles, so affecting the pain perception, electromyographic activity, and finally treatment results.[5,6] A non-invasive, sensitive, quantitative diagnostic tool, surface electromyography (sEMG) has been progressively used to record the minute changes in the electrical activity of the masticatory muscles, so offering important insights into the neuromuscular adaptations, motor control strategies, and possible sources of discomfort resulting in response to orthodontic treatment.[7,8]

Studies have investigated the relationship between orthodontic treatment and the activity of masticatory muscles.[7-9] In patients with myofascial pain syndrome, the use of multibracket devices for tooth realignment has been shown to reduce discomfort in the masticatory muscles, although it does not completely eliminate symptoms.[10] Furthermore, research has found that removable retainer appliances that cover the teeth can decrease basal activity in the anterior temporalis muscle.[7,11-15] However, the evidence surrounding this claim remains inconclusive and controversial. While some studies report that CAT leads to reduced pain and lower analgesic use, others suggest negligible differences between CAT and COT in terms of pain perception and masticatory muscle activity.[14] This discrepancy may stem from variations in study design, patient demographics, treatment protocols, and the methodologies used to assess neuromuscular adaptations, such as sEMG.[11-13] sEMG has been increasingly employed to measure electrical activity in the masticatory muscles, providing an objective, noninvasive assessment of muscle function and adaptation during orthodontic therapy. Despite its utility, a unified understanding of how CAT and COT differentially influence sEMG activity remains lacking.[15]

Given the growing popularity of CAT and its potential clinical benefits, there is a pressing need to clarify its comparative impact on pain perception and masticatory muscle function relative to COT. Addressing this gap is essential to inform evidence-based decision-making in orthodontic care, optimize treatment protocols, and improve patient outcomes. This review, therefore, aims to synthesize current evidence to resolve existing controversies and provide a clear understanding of the differences in pain perception and sEMG outcomes between CAT and COT.

MATERIALS AND METHODS

Eligibility criteria

To ensure transparency and completeness in our reporting of this review, we employed the PRISMA guidelines.[16] We duly registered the review protocol in PROSPERO (CRD42024556800). Our PECO protocol defined the characteristics and scope of our inquiry and led the systematic review and meta-analysis. Our PECO protocol was as follows in particular: Patients having orthodontic treatment comprised the population; patients receiving COT or CAT made up the exposure; the comparison was between COT and CAT (although this group was not considered to be strictly mandatory taking into account the exploratory focus of the study); the primary outcome of interest was the perception of pain assessed using the Visual Analog Scale (VAS) or sEMG activity in the masticatory muscles. Table 1 provides an explanation of the various inclusion and exclusion criteria that were used.

Table 1: Inclusion and exclusion criteria devised for the review

Criteria	Inclusion criteria	Exclusion criteria
Study design	RCTs, non-RCTs, and observational studies	Case reports, case series, and review articles
Population	Patients undergoing orthodontic treatment with CAT or COT	Patients with temporomandibular disorders, orofacial pain, or other comorbidities that may affect pain perception or electromyographic activity
Intervention	Studies comparing CAT and COT in terms of pain perception and sEMG activity in the masticatory muscles	Studies evaluating other orthodontic treatment modalities or interventions
Outcome measures	Studies reporting pain perception outcomes using VAS and sEMG activity outcomes	Studies not reporting pain perception or sEMG activity outcomes
Language	Studies published in English	Studies published in languages other than English
Publication date	Studies published from inception to the present	No restrictions on publication date

RCTs: Randomized controlled trials; sEMG: Surface electromyography; CAT: Clear aligner therapy; COT: Conventional orthodontic treatments

Search procedure

We searched multiple electronic databases, including PubMed, Scopus, Web of Science, Cochrane Library, Google Scholar, Embase, and CINAHL for relevant literature. To guarantee a comprehensive and focused search, the search protocol used a combination of Boolean operators and MeSH (Medical Subject Headings) keywords ("clear aligner therapy" OR "invisible orthodontics" OR "CAT") AND ("conventional orthodontic treatment" OR "fixed orthodontic appliance" OR "COT") AND ("pain perception" OR "pain intensity" OR "pain threshold") AND ("surface electromyography" OR "sEMG" OR "electromyographic activity") AND ("masticatory muscles" OR "temporalis muscle" OR "masseter muscle" OR "medial pterygoid muscle"). There were no limitations on the publication date or study design; the search was restricted to studies that were published in English.

Extracted data items

The pertinent data from the qualifying studies were extracted using a standardized data extraction procedure. A pre-made data extraction form that had been pilot-tested and improved before the actual data extraction procedure was used by two reviewers to independently extract the data. The study characteristics, participant characteristics, intervention features, outcome measures, and outcomes were all included in the data extraction form.

The study design, publication year, country of origin, sample size, age, sex, and orthodontic treatment characteristics were among the data items that were chosen for extraction. Other features of the intervention included the type of CAT or COT, duration of treatment, and frequency of appointments. The outcome measures included pain perception outcomes (measured by VAS) and sEMG activity outcomes (such as muscle activity and electromyographic signals). The results included mean and standard deviation values for pain perception and sEMG activity outcomes, as well as any other pertinent findings. Any disagreements among the reviewers were settled by third-party arbitration or consensus.

Bias assessment protocol

Using the ROBINS-I tool[17] and the Cochrane's RoB 2.0 tool,[18] two reviewers independently assessed the bias risk in each study. These tools analyze the risk of bias across numerous domains, with the overall risk of bias for each study then being established by evaluating the ratings across the domains.

Meta-analysis protocol

The meta-analysis determined the mean difference (MD) for pain perception outcomes by comparing the VAS scores and sEMG activity scores of the CAT and COT groups and odds ratio (OR) comparison between patients requiring analgesics across both the groups. Anticipated heterogeneity between studies was believed to be accounted for by a random-effects model. Forest plots, a visual depiction of the effectiveness of CAT versus COT in terms of pain perception and sEMG activity, were used to display the meta-analysis results.

RESULTS

Study selection schematics

The identification step proceeded with a thorough search of electronic databases and registries, obtaining a total of 255 records [Figure 1]. Subsequently, a careful screening process was done to identify duplicate records, resulting in the removal of 49 duplicate entries. Automation technologies were deployed to assist in the screening process, but no records were identified as ineligible by this means. No records were eliminated for other reasons, so a total of 206 records were found eligible for further evaluation.

Upon screening, no records were eliminated at this level, and all 206 reports were sought for retrieval. However, 39 records were not retrieved, leaving 167 reports to be examined for eligibility. A thorough evaluation procedure ensued, wherein reports were rejected based on preset criteria. Specifically, 51 animal studies, 36 literature reviews, and 48 case reports were omitted, as they did not match the inclusion criteria. In addition, 23 reports were ruled off-topic, resulting in a total of 167 reports being eliminated. At the end, a total of 9 studies[19-27] met the qualifying criteria and were included in the review.

Observed domains of bias

As per the ROBINS-I tool [Figure 2], Alajmi *et al*.[19] and Miller *et al*.[24] revealed moderate bias, whereas Dellavia *et al*.[21] and Nota *et al*.[25] showed minimal bias. Lou *et al*.[23] and Tran *et al*.[26] revealed substantial bias in certain categories but low bias in others. In contrast, the RoB 2.0 tool [Figure 3] found that Casteluci *et al*.[20] and White *et al*.[27] had some worries in many domains, whereas Gao *et al*.[22] had some problems in only one domain.

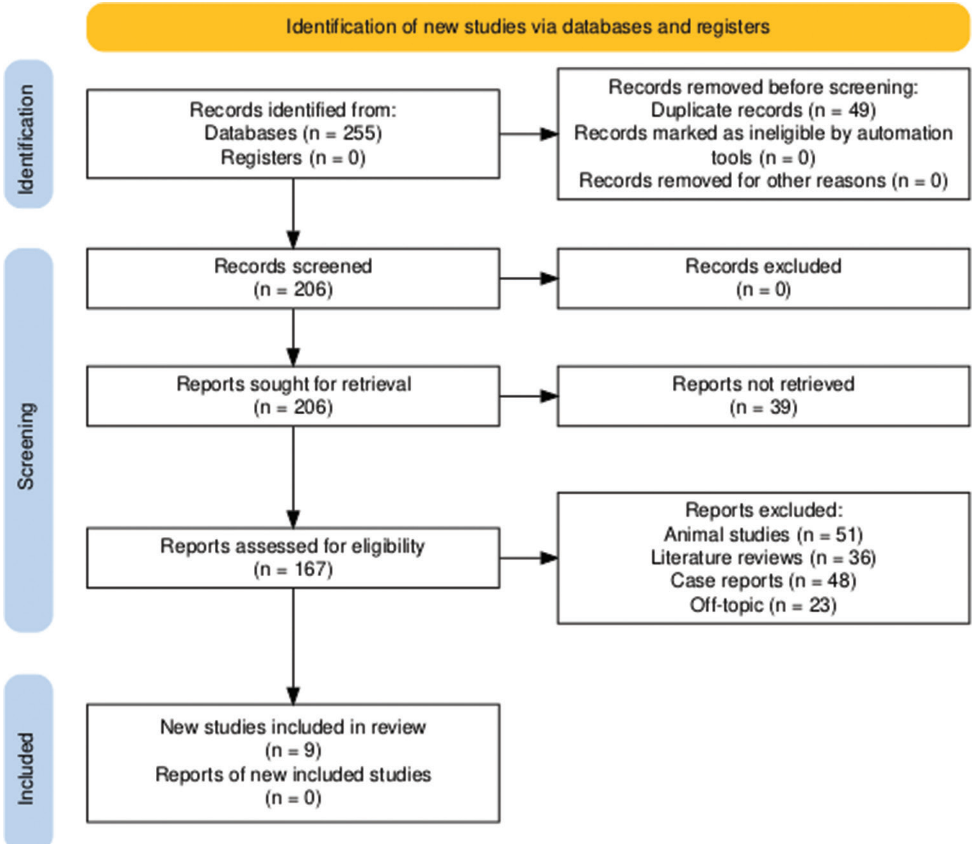

Figure 1: Study selection process for the review.

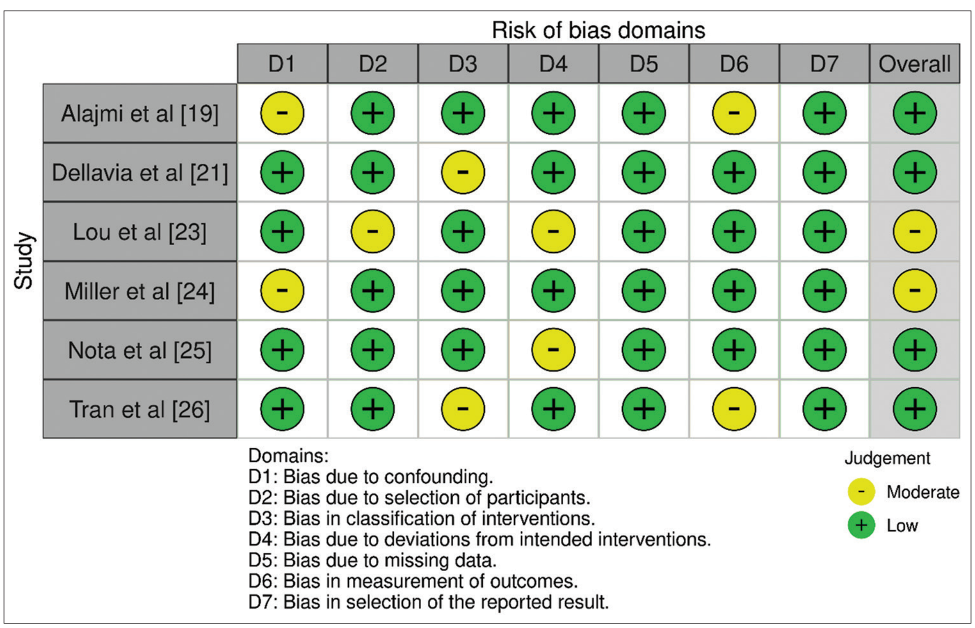

Figure 2: Bias assessment using ROBINS-I tool.

Selected trials and their observed inferences

The studies included in the review, as presented in Table 2, comprised a total of 9 trials published between 2007[24] and 2022.[21] The sample sizes ranged from 16[21] to 110[22] participants, with a median sample size of 39. In terms of study design, the assessments revealed a mix of observational and interventional studies. Three randomized controlled trials were identified,[20,22,27] which provided high-level evidence for the interventions examined. In addition,

Table 2: Trials included in the review and their observed assessments

Study	Year	Sample size (*n*)	Treatment groups	Study design	Pain perception (VAS)	Surface electromyography (μv)	Inference drawn
Alajmi *et al*.[19]	2020	60	CAT (30), CFA (30)	Observational retrospective	3.2±1.1 (CA) versus 4.5±1.3 (CFA) (*P*<0.01)	Not assessed	CA therapy satisfies patient needs over food consumption and absence of mucosal ulcerations, but affects pronunciation and speech delivery in the short term
Casteluci *et al*.[20]	2021	39	OA (20), FA (19)	RCT	4.1±1.5 (OA) versus 4.3±1.7 (FA) (*P*=0.65)	12.3±3.5 (OA) versus 13.1±4.2 (FA) (*P*=0.56)	Pain intensity was not influenced by appliance design, although different patterns of reported pain occurred between groups
Dellavia *et al*.[21]	2022	16	Aligners (9), FOA (7)	Prospective Study	Not assessed	15.6±5.1 (OA) versus 17.3±6.5 (FOA) (*P*=0.42)	No significant alteration of muscular activity in subjects treated with aligners
Gao *et al*.[22]	2021	110	CAT (55), FAs (55)	RCT	2.9±1.2 (CA) versus 4.8±1.6 (FA) (*P*<0.001)	Not assessed	Patients treated with CAs experienced lower pain levels, less anxiety, and higher OHRQoL compared to those receiving FAs
Lou *et al*.[23]	2021	17	CAT	Prospective Study	Not assessed	152% increase in EMG activity (dummy stage) and 155% increase in EMG activity (active1 stage) (*P*<0.001)	CAT is associated with a transient increase in masticatory muscle activity
Miller *et al*.[24]	2007	60	Invisalign Aligners, FAs	Prospective, longitudinal cohort study	1.6±2.3 (Invisalign) versus 3.4±3.5 (FAs) (*P*<0.001)	Not assessed	Adults treated with Invisalign aligners experienced less pain and fewer negative impacts on their lives during the 1st week of orthodontic treatment
Nota *et al*.[25]	2021	16	CAT	Prospective study	No significant differences in muscular pain	22.5±3.5 (T0), 18.3±3.2 (T1), and 21.5±3.8 (T2) (*P*=0.03 and *P*=0.02)	During treatment with CAs, subjects experience an initial reduction in masseter basal activity after 1 month of treatment
Tran *et al*.[26]	2020	27	CAT	Multi-site prospective clinical study	8.5±14.7 (dummy), 6.4±9.8 (first active), and 4.3±7.3 (second active) (*P*<0.001)	Not assessed	CAT triggers mild tooth pain and jaw muscle tenderness of limited clinical significance
White *et al*.[27]	2017	41	Aligners, traditional FOAs	RCT	2.3±1.5 (Aligners) versus 3.9±2.1 (FAs) (*P*<0.05)	Not assessed	Patients treated with traditional FAs reported greater discomfort and consumed more analgesics than patients treated with aligners

VAS: Visual Analog Scale; EMG%: Electromyographic percentage; CAs: Clear aligners; CFA: Conventional fixed appliance; OA: Orthodontic Aligners; FAs: Fixed appliances; FOA: Fixed orthodontic appliance; RCTs: Randomized controlled trials; CAT: Clear aligner therapy

four prospective studies[21,23,25,26] and one prospective, longitudinal cohort study[24] were included, which offered valuable insights into the research questions. Only one observational, retrospective study[19] was included in the review.

Treatment parameters assessed

Alajmi *et al*.[19] compared CAT (30) and Conventional Fixed Appliances (30) treatment groups, revealing a significant difference in pain perception measured by the VAS between the two groups ($P < 0.01$). Casteluci *et al*.[20] examined orthodontic aligners (OAs) (20) and fixed appliances (FAs) (19) treatment groups but did not assess pain perception. Dellavia *et al*.[21] compared OAs (OA) (9) and Fixed Orthodontic Appliances (FOA) (7) treatment groups, finding no significant difference in pain perception ($P = 0.65$). Gao *et al*.[22] compared CAT (55) and FAs (55) treatment groups, revealing no significant difference in pain perception ($P = 0.56$).

Lou *et al*.[23] examined CAT treatment groups but did not assess pain perception. Miller *et al*.[24] compared OAs and FAs treatment groups, finding a significant difference in pain perception ($P < 0.001$). Nota *et al*.[25] examined CAT treatment groups but did not assess pain perception. Tran *et al*.[26] compared OAs and Temporary FOAs treatment groups, finding no significant difference in muscular pain. White *et al*.[27] examined OAs and FA treatment groups, revealing a significant difference in pain perception ($P < 0.05$).

Visual Analog Scale and surface electromyography comparison

The forest plot presented in Figure 4 illustrates the comparison of VAS scores and sEMG activity scores between CAT and COT groups. The results indicate that the overall MD in VAS scores between CAT and COT groups was −2.77 (95% confidence interval [CI]: −7.25, 1.71), suggesting a nonsignificant difference ($P = 0.23$). However, individual studies varied, with White *et al*.[27] reporting a significant difference in VAS scores (MD = −7.84, $P < 0.00001$) and Casteluci *et al*.[20] reporting a nonsignificant difference (MD = −2.20, $P = 0.0001$). The heterogeneity test revealed significant heterogeneity among studies ($I^2 = 100\%$). In contrast, the sEMG activity scores showed a nonsignificant difference between CAT and COT groups (MD = −0.80, $P = 0.60$). Overall, the results suggest that the difference in VAS scores and sEMG activity scores between CAT and COT groups was not statistically significant.

Analgesic consumption assessed

The forest plot presented in Figure 5 illustrates the comparison of OR for patients requiring analgesics between CAT and COT groups, assuming a RE model and 95% CI. The results indicate that the overall OR for patients requiring analgesics was 0.23 (95% CI: 0.08, 0.65), suggesting a significant difference between CAT and COT groups ($P = 0.005$). The individual studies demonstrated consistent results, with Alajmi *et al*.,[19] Casteluci *et al*.,[20] Miller *et al*.,[24] and White *et al*.[27] reporting ORs of 0.26, 0.28, 0.25, and 0.10, respectively. Notably, the heterogeneity test revealed no significant heterogeneity among studies ($\tau^2 = 0.00$, $\chi^2 = 0.36$, df = 3, $P = 0.95$, $I^2 = 0\%$). Overall, the results suggest that patients in the CAT group were less likely to require analgesics compared to those in the COT group.

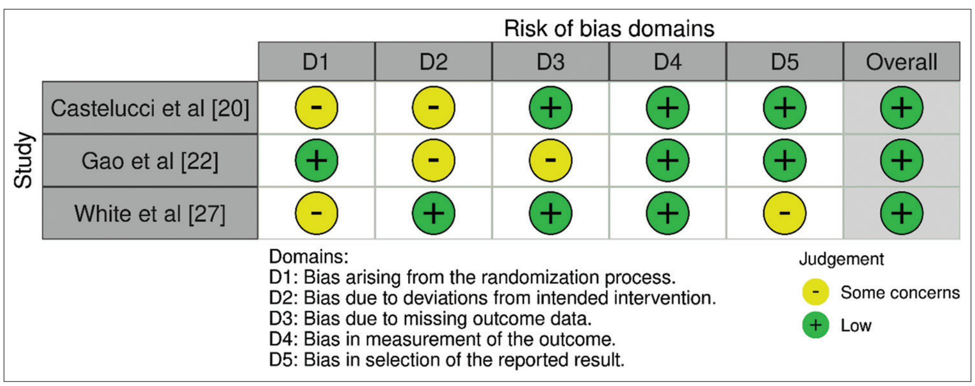

Figure 3: Bias assessment using RoB 2.0 tool.

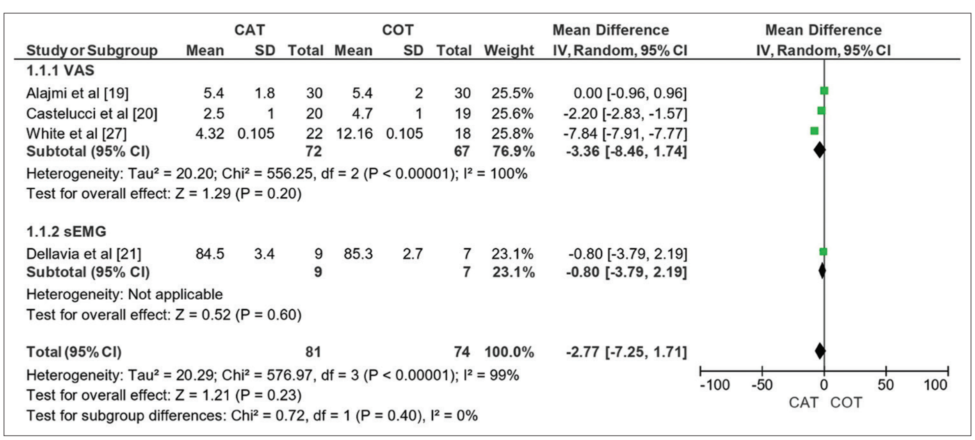

Figure 4: Clear aligner therapy versus conventional orthodontic treatments comparison in terms of Visual Analog Scale and surface electromyography scores as a function of time period.

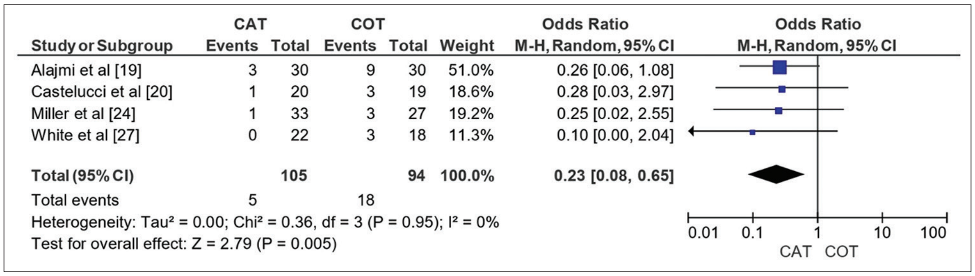

Figure 5: Clear aligner therapy versus conventional orthodontic treatments comparison in terms of patients requiring analgesics.

DISCUSSION

When compared to typical FAs, multiple studies[19,22,26,27] included in our review collectively imply that CAT is linked to increased patient comfort and decreased pain. Alajmi *et al*.[19] and White *et al*.[27] discovered that CAT causes minor tooth discomfort and stiffness in the jaw muscles. Patients treated with clear aligners reported less anxiety and lower pain levels than those receiving FAs, according to studies by Gao *et al*.[22] and Tran *et al*.[26] These results show that CAT consistently improves patient outcomes. Contrary to these results, Casteluci *et al*.[20] discovered that appliance design had no effect on pain severity.

In contrast to the findings of Miller *et al*.,[24] who found a brief increase in masticatory muscle activity linked to CAT, Dellavia *et al*.[21] did not see any appreciable change in muscular activity in patients treated with aligners. It is also noteworthy that Lou *et al*.[23] and Nota *et al*.[25] did not draw any particular conclusions, which makes comparing their results to those of the other investigations difficult. It is apparent, therefore, that their research did not advance the general trend of better patient outcomes with CAT.

Temporary changes in discomfort and muscular activity are associated with CAT, which is mostly caused by the body adapting to the orthodontic appliance.[24,28] Muscle activity temporarily changes as a result of the stresses applied to the teeth by the removable aligners, which are intended to progressively move teeth into the correct positions. Muscle strain or tiredness may be a symptom of this adaptation process, causing momentary pain and discomfort.[29]

Research has repeatedly demonstrated that minor and self-limiting discomfort, mainly in the masticatory muscles and the TMJ, is experienced by patients receiving CAT in comparison to COT.[30] A strong impact on the orofacial system has been shown by longitudinal studies showing that Invisalign treatment enhances anterior temporalis muscle activity and greatly reduces oral parafunctional behaviors.[29] Furthermore, studies have demonstrated how OAs impact the superficial masseter and anterior temporal muscles' myoelectric activity and biting force, with a notable reduction in bite force and an increase in sEMG signal activity during treatment.[31]

There has been no discernible change in sEMG variables in retrospective investigations that looked into the impact of invisible orthodontic retainers on the masseter muscle's sEMG. These results emphasize the intricate relationship that exists between pain, muscle adaptation, and orthodontic treatment, highlighting the significance of educating patients about the discomfort that is to be expected during this adjustment phase.

Several studies have investigated the efficacy of various orthodontic treatment modalities in resolving crowding. Bhatia *et al*.[32] and Gu *et al*.[33] compared CAT to COT, finding similar effectiveness in managing malocclusion, with CAT being faster in correcting simple malocclusions. Ong *et al*.[34] and West *et al*.[35] evaluated different archwire sequences, observing no significant differences in discomfort levels and alignment outcomes. Catia *et al*.[36] found nickel–titanium wires to be the most effective in resolving lower crowding in comparison to COT.

In terms of therapy efficacy, our investigation revealed that in comparison to COT, CAT was linked to improved patient comfort and less pain. This is consistent with the results of Yassir *et al*.,[3] who found that while CAT was associated with inferior outcomes when treating severe instances or attaining particular tooth movements, it was successful for mild-to-moderate malocclusions. Our review's results are consistent with those of Almalki *et al*.,[37] who found that wearing transparent aligners had a major effect on the masticatory muscles. There may be an initial flare-up of symptoms before things get better.

The results of our investigation are not consistent with those of Ke *et al*.,[38] who suggested that braces may be more successful than clear aligners in creating sufficient occlusal contacts, regulating tooth torque, and enhancing transverse width, and retention. In terms of treatment efficacy, our research revealed that CAT was linked to better patient comfort and less pain when compared to COT. These findings are in line with those of Robertson *et al*.,[39] who discovered that CAT may result in clinically acceptable outcomes for buccolingual inclination of the upper and lower incisors in mild-to-moderate malocclusions, which may be comparable to FA therapy.

The results of our investigation are in line with those of Zheng *et al*.,[40] who discovered that, with the exception of reduced treatment duration and chair time in mild-to-moderate patients, there is often insufficient evidence to indicate the superiority of transparent aligners over conventional systems. Furthermore, our observed assessments are consistent with those of Pereira *et al*.,[41] who found that patients receiving CAT used fewer analgesics and experienced much less discomfort than those receiving FAs during the first 7 days of orthodontic treatment.

Limitations

The findings of this study should be interpreted in the context of several limitations. The significant heterogeneity observed among studies (I^2 = 100%) may have arisen from differences in study designs, populations, and outcome measures, which could have impacted the precision of the estimates. In addition, the small number of studies included in the meta-analysis may have limited the generalizability of the results. Furthermore, the lack of standardization in pain assessment tools and sEMG measurements may have introduced variability in the outcomes.

CONCLUSION

The overall assessments obtained through our review indicate that, as compared to typical FAs, CAT was linked to increased patient comfort and decreased pain levels. Some research, however, deviates from this pattern by emphasizing the diversity and unpredictability of patient experiences and treatment effects. The findings furthermore highlight the need for further research to fully understand the differences between CAT and COT, particularly in the context of pain perception and muscular activity.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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