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Review

Effectiveness of Surgical and Non-Surgical Techniques for Accelerating Orthodontic Tooth Movement in Fixed Appliances and Aligners: A Systematic Review

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Main Points

- This review identifies corticotomy and photobiomodulation (PBM) as key techniques for accelerating orthodontic tooth movement, enhancing treatment efficiency and reducing discomfort.
- PBM, in particular, shows promise due to its non-invasive and painless nature, although further research is needed to optimize its protocols.
- The study calls for more randomized controlled trials to better integrate acceleration techniques with modern orthodontic appliances, and suggests that advancements in stimulation devices could make treatments more tailored and accessible to patients.

ABSTRACT

Several procedures have been proposed as adjuvant treatments in orthodontics to accelerate orthodontic tooth movement (OTM). This review aimed to evaluate and compare the effectiveness of surgical and non-surgical techniques in accelerating tooth movement, ascertain the influence of different orthodontic appliances on the rate of tooth movement and analyze their clinical applicability as supportive approaches in orthodontic treatment. A bibliographic search was carried out in April 2024 across Pubmed, Scopus, Web of Science, and the Cochrane Library using combinations of keywords and Medical Subject Heading terms relevant to the topic. The search had no time restriction and was limited to studies published in English. A total of 76 articles were included in this systematic review. Corticotomy exhibited the highest acceleration potential among surgical techniques but is highly invasive and associated with considerable pain and discomfort. Among non-surgical techniques, vibration and photobiomodulation (PBM) showed the most promising results due to their non-invasiveness and effectiveness in accelerating tooth movement. This review provides a comprehensive overview of techniques for accelerating OTM. The literature remains limited in involving surgical and non-surgical procedures using orthodontic aligners, highlighting the need for further research. Considering all the pros and cons, PBM appears to be the most promising technique; however, its effectiveness is yet suboptimal. Future efforts should be dedicated to optimizing PBM protocols to stimulate specific remodeling phenomena, ensuring its establishment as a safe, effective, painless, and non-invasive acceleration technique.

Keywords: Accelerated orthodontic tooth movement, corticotomy, low-intensity pulsed ultrasound, non-surgical techniques, photobiomodulation, surgical techniques, vibration

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INTRODUCTION

The prolonged duration of the orthodontic treatment is a primary obstacle to patient adherence, especially among adults.[1] Therefore, shortening treatment time and manipulating the biological response to orthodontic forces to accelerate orthodontic tooth movement (OTM) have been key challenges in modern orthodontics. Several techniques have been proposed to improve the rate of tooth movement while minimizing long-term iatrogenic damage.[2] Extended orthodontic treatment is one of the definitive risk factors for root resorption and periodontal problems. On the contrary, shorter treatment times are associated with a lower risk of root resorption, reduced enamel demineralization, and improved patient compliance.[3]

Orthodontic movement involves several periodontal processes, including an acute inflammatory response, necrosis, and tissue degeneration in the compression side of stressed teeth, as well as intense bone remodeling on the tension side.[4,5] The potential of coadjuvant treatments in accelerating OTM depends on their ability to modulate tissue remodeling. Thus, understanding the mechanisms underlying acceleration techniques is pivotal for selecting and optimizing the most appropriate approach. Besides, factors such as patient comfort, usability, and endorsement of the intervention must be taken into account to meet expectations and ensure their quality of life during the procedure.[6,7]

Surgical procedures such as corticotom,[8] accelerated osteogenic orthodontics,[9,10] piezocision,[11] corticision,[12] and micro-osteoperforation (MOP)[13] have been proposed as effective methods to accelerate the orthodontic movement. However, these techniques require surgical intervention, posing higher risks and costs, along with prolonged postoperative discomfort. These drawbacks have fostered interest in non-surgical acceleration methods, which offer non-invasive and painless alternatives.[14] Such techniques include vibration stimuli,[15] electromagnetic stimulation,[16] extracorporeal shock waves,[17] low-intensity pulsed ultrasound,[18,19] photobiomodulation (PBM),[20] and the injection of biomaterials, supplements, or hormones.[21] These approaches can be considered more appealing to patients due to their reduced invasiveness and effectiveness.[22]

Despite the growing investigation on this topic in recent years, the scientific literature lacks systematic and focused information from randomized controlled trials (RCTs) comparing the effectiveness of different surgical and non-surgical techniques for accelerating OTM. Indeed, recent systematic reviews have provided novel insights into the implementation of these techniques.[23,24] However, the available evidence remains limited, and the effects of different orthodontic approaches, including fixed and removable appliances, have yet to be explored. This review addresses this gap by identifying the most effective ways for modulating the biological response and accelerating OTM with minimal side effects. The scientific and empirical knowledge offered by the current systematic review will assist clinicians in defining the most suitable acceleration technique for each case, ultimately improving treatment duration and pain management.

METHODS

This review was conducted in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020.[25]

Eligibility Criteria

The Population, Intervention, Comparison, Outcomes, and Study design strategy (Table 1),[26] was used to formulate the guiding questions for this study: “Which technique for accelerating tooth movement, surgical or non-surgical, is most effective and associated with less tissue damage and discomfort?” and “How does the type of orthodontic appliance influence acceleration rates?”

Based on these questions, the following eligibility criteria were defined:

Inclusion Criteria

- Clinical RCTs investigating surgical and non-surgical acceleration techniques as coadjuvants of orthodontic treatment using fixed appliances and clear aligners;

- Studies published in English.

Exclusion Criteria

- Meta-analyses, systematic and narrative reviews, case reports, comments, theses, dissertations, and any publication type other than clinical RCTs;

- Studies conducted on preclinical models (e.g., *in vitro* or animal studies);

- Studies with a sample size of less than 10 participants.

Table 1. Implementation of the PICOS strategy

Population	Patients undergoing orthodontic treatment with fixed appliances or aligners, without age, sex or background restrictions.
Intervention	Surgical and non-surgical techniques for acceleration of orthodontic tooth movement.
Comparison	Control groups (e.g., no intervention group, contralateral tooth/teeth groups), baseline conditions, or distinct acceleration methods.
Results	Velocity/amount of tooth movement, biological effects of acceleration techniques on the periodontium.
Study design	Randomized controlled trials.

Information Sources and Search Strategy

The bibliographic search was carried out in PubMed (via the National Library of Medicine), Scopus, Cochrane Library, and Web of Science databases between April 23 and 25, 2024. The retrieved articles were analyzed without any time restrictions, and only studies published in English were considered. The same advanced search was applied across all databases, targeting titles, abstracts, and keywords using the terms listed in Table 2.

Selection Process

An advanced search was initially performed using the specified keywords in each database. Duplicate articles were removed using Mendeley's citation tool. The titles and abstracts of the identified, potentially relevant articles were submitted for preliminary evaluation by two authors (AG and MC). Then, the selected studies were read in full and assessed for eligibility.

Data Collection Process and Items

After evaluating the articles, the relevant data were extracted and organized in a table. The extracted information included publication details (name of the first author and year of publication), population under study (sample size and group distribution), tested treatments (types of treatments/interventions compared and studied), intervention characteristics (required movements, intervention description, and evaluation duration), and key findings, such as orthodontic movement rates, differences between groups, and complications during procedures and/or the recovery period.

Effect Measures, Synthesis Methods, and Certainty Assessment

In this study, surgical and non-surgical techniques for enhancing and accelerating orthodontic movement were compared and evaluated, emphasizing the type of orthodontic intervention (either conventional appliances or aligners). Only clinical RCTs with 10 or more participants were selected for the qualitative synthesis. The effect measures included the mean difference in tooth movement or treatment duration between the groups. Statistical comparisons were assessed between the groups.

Data were presented chronologically in two tables - one for surgical techniques and the other for non-surgical techniques -, standardizing the collected information for a clear and intuitive comparison of the interventions and reported outcomes.

Risk of Bias Assessment

The quality assessment was conducted using the Effective Public Health Practice Project (EPHPP) tool, a standardized method for evaluating the risk of bias in clinical studies. The complete quality assessment data are provided as supplementary materials.

RESULTS

Article Selection

A bibliographic search yielded 499 articles, of which 143 were duplicates and thus removed. An additional 29 manuscripts were obtained from citation searching and added for screening. After reading the titles and abstracts, 299 articles were selected for further analysis. Five reports were not retrieved, and 218 studies were excluded based on eligibility criteria, resulting in 76 articles being selected for qualitative synthesis. This process is represented in Figure 1.

Profile of the Included Studies

Publication Year

The highest number of articles on the selected topic was published by 2020 (n=12, 18.2%),[22,27-37] with the first publication appearing in 2004.[38] Figure 2 reflects the rapid growth in publication, which is associated with the growing knowledge and expertise in the techniques discussed here.

Type of Acceleration Intervention

Thirty-three articles on surgical techniques to accelerate OTM were selected. Numerous studies investigated the effects of multiple surgical acceleration methods,[8,9,12,13,27,39-45] mainly comparing modified corticotomies [such as MOP and periodontology-assisted accelerated osteogenic orthodontics (PAOO)] with conventional corticotomy. In summary, 13 articles examined the effectiveness of piezocision to accelerate OTM,[8,11,13,27,38,40-42,44,46-49] 12 focused on MOP,[28-30,42,43,50-56] eight used traditional corticotomy,[1,8,9,27,43-45,57] five addressed periodontally accelerated orthodontics,[9,38,39,58,59] two utilized laser-assisted flapless corticotomy,[40,60] and one studied corticision.[12] Regarding non-surgical techniques, 45 articles were selected: 28 assessed

Table 2. Search strategy employed in the electronic search

Type of study	Search Strategy
PubMed Scopus Cochrane Library Web of Science	[“accelerated orthodontics” OR “accelerated orthodontic movement” OR “accelerated tooth movement” OR “orthodontic movement” OR “tooth acceleration” OR “tooth movement acceleration” OR “dental acceleration” OR “accelerating dental movement”) AND (“surgery techniques” OR “surgical techniques” OR corticotomy OR “micro-osteoperforation” OR microosteoperforation OR piezocision OR “accelerated osteogenic orthodontics” OR “periodontally accelerated osteogenic orthodontics” OR “noninvasive techniques” OR “non-invasive techniques” OR “nonsurgical techniques” OR “non-surgical techniques” OR “growth hormone” OR parathormone OR steroid OR “nonsteroidal anti-inflammatory drugs” OR “non-steroidal anti-inflammatory drugs” OR NSAIDs OR i-PRF OR “vitamin D3“ OR micronutrients OR “electromagnetic fields” OR vibration OR ultrasound OR “mechanical force” OR “mechanical stimulus” OR “mechanical stimulation” OR photobiomodulation OR PBM OR phototherapy OR “low level light therapy” OR “low-level light therapy” OR “low level laser therapy” OR “low-level laser therapy” OR PBM OR “laser therapy” OR “laser irradiation” OR “light therapy” OR “light irradiation” OR “low power laser therapy” OR “low-power laser therapy” OR LLLT OR PBM OR “low energy laser” OR “low-energy laser” OR “low intensity laser” OR “low-intensity laser”]

the potential of PBM,[13,14,22,33-35,37,56,61-80] eight investigated the application of vibratory stimuli,[31,81-87] four analyzed the efficacy of the injection of biomaterials, supplements, or hormones [e.g., platelet-rich fibrin (PRF)[88-90] and platelet-rich plasma (PRP)[21,90]], two implemented vitamin D supplementation,[91,92] one used low-intensity pulsed ultrasound stimulation (LIPUS),[32] one employed electromagnetic stimulation,[16] and one assessed the impact of extracorporeal shock waves on the rate of OTM.[17]

Two studies compared the effects of one surgical and one non-surgical technique: PBM vs. piezocision[13] and PBM vs. MOP;[56] however, only the first study included a control group (with no acceleration technique). Importantly, each study was

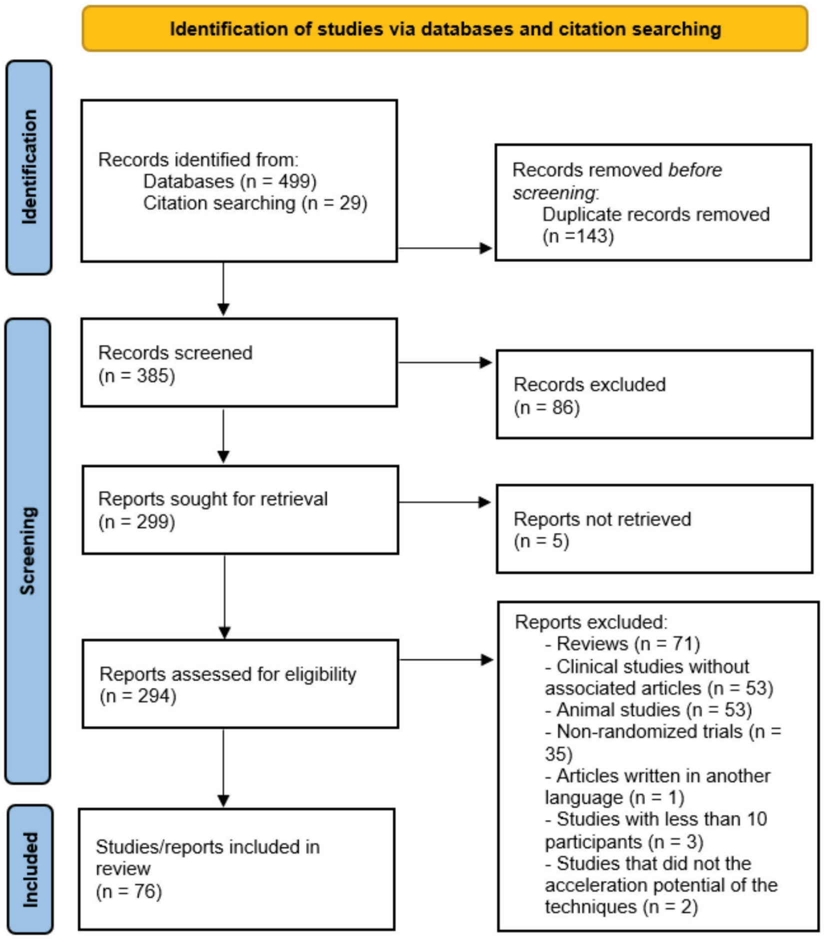

Figure 1. PRISMA flowchart of the studies identified through electronic search

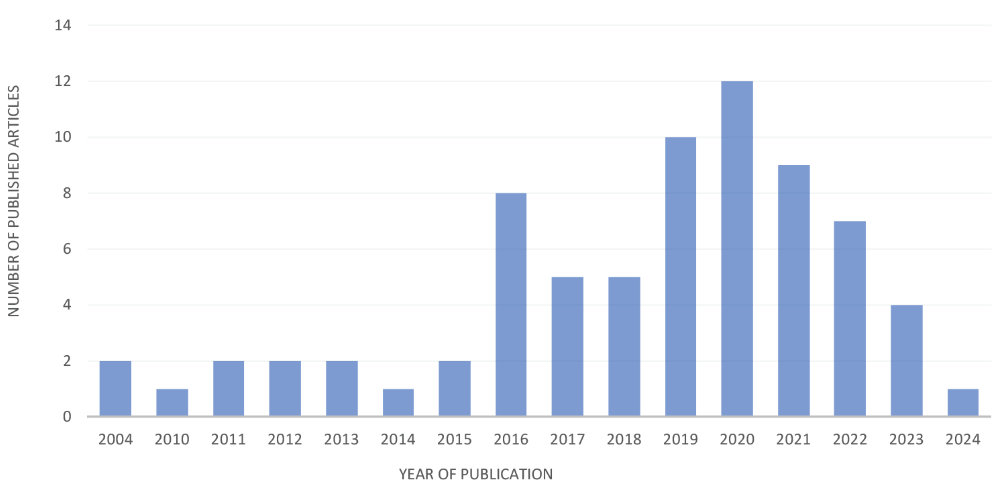

Figure 2. Distribution of the included articles by year of publication

presented only once in Supplementary Tables 1 or 2, including the experiments in which multiple techniques were assessed. Nevertheless, studies comparing two acceleration methods are further discussed below.

Type of Orthodontic Intervention

Conventional treatment with fixed appliances was the preferred orthodontic intervention, with no aligner interventions being registered among the studies describing surgical techniques. In contrast, three studies investigated the efficacy of non-surgical techniques for accelerating tooth movement with aligners - two focused on vibration[85,86] and one on PBM.[69]

Data Extraction, Systematic Synthesis, and Certainty of Evidence

The most relevant features from the revised studies were extracted and organized into tables for a more dynamic, easy-to-read, and systematic analysis. This approach enables the reader to efficiently compare protocols and results obtained from studies using surgical (Supplementary Table 1) and non-surgical (Supplementary Table 2) acceleration techniques.

Each study associated orthodontic procedures with movement-related variables, serving as proxies for the accelerating abilities of each technique (i.e., amount of tooth movement, treatment duration, and movement rate). In some cases, unit conversions were performed to uniformize the stimulation parameters across studies, facilitating comparison (e.g., mechanical vibrational forces presented in gf were converted into Newton). Movement-related values were statistically compared between groups, typically with conventional orthodontic treatment (control) vs orthodontic treatment with acceleration techniques. A few studies compared two or more acceleration approaches. Occasionally, biological outcomes, such as cytokine expression and root resorption signals, were monitored and compared between groups.

For statistical analysis, the majority of studies assessed the magnitude of difference between groups with a significance level of 5% (95% confidence interval).

Results of Syntheses

Supplementary Tables 1 and 2 present the compiled data from the studies investigating the accelerating potential of surgical and non-surgical techniques, respectively.

Results of Individual Studies

Traditional Corticotomy

The traditional alveolar corticotomy is a surgical technique involving an intentional lesion of the cortical bone that consists of reflecting full-thickness flaps to expose buccal alveolar bone, followed by a series of interdental cuts through the cortical bone, which scarcely penetrate the medullary bone. It has been previously shown that corticotomy can increase the rate of OTM two to four times in the first days compared to the single use of a conventional appliance alone.[1] Initially, corticotomies were believed to accelerate tooth movement through alveolar bone segmentation, mass tooth movement, and an associated bone block. However, the regional accelerator phenomenon (RAP) is now the most widely accepted explanation, involving a complex regional mechanism encompassing both soft and hard tissues, and is characterized by the acceleration of normal vital tissue remodeling processes, enhancing tissue healing and defensive reactions.[93] This phenomenon causes a reduction in bone density due to increased remodeling space, which starts within a few days after the procedure, peaks between one and two months, and lasts for two to four months.[57]

Shoreibah et al.[57] conducted one of the early RCT studies on surgical acceleration techniques, demonstrating that corticotomy can decrease the total time of orthodontic treatment. However, the procedure was associated with a slight (non-significant) decrease in bone density and root resorption post-intervention.

A few years later, Al-Naoum et al.[1] showed that while corticotomy was highly effective in accelerating the OTM, it was accompanied by increased pain, discomfort, and swelling compared to conventional orthodontic treatment, thereby highlighting the primary drawbacks of traditional corticotomy from the patients' perspective. By 2023, Gopalakrishnan et al.[45] compared the effects of a soft tissue flap-only procedure and a single-cut corticotomy on the rate of canine retraction, revealing no significant differences between the two surgical methods.

At the time of this review, no relevant studies were found that combined corticotomy with orthodontic treatments using aligners.

Although corticotomy is highly effective in accelerating OTM, it is also invasive and aggressive for patients. As a result, minimally invasive surgical techniques with high acceleration efficiency have been developed, known as flapless corticotomies, which do not require flap elevation.[27] Consequently, all other surgical acceleration methods are modified corticotomies, including MOP, PAOO, corticision, piezocision, and laser-assisted corticotomy.

Laser-assisted Flapless Corticotomy

One of the earliest flapless corticotomy techniques was performed using a laser due to its ability to create clear, dry, and less traumatic incisions, which also made the procedure more convenient for patients.[94]

Jaber et al.60 reported that although corticotomy procedures effectively reduced treatment time, it is considered one of the most invasive techniques for accelerating OTM. Approximately 50% of patients experienced extreme pain and discomfort while eating during the first two days, which subsided to mild pain in about 67% of patients within eight weeks post-intervention. Furthermore, around 80% of patients presented moderate to severe swelling immediately after the procedure, which significantly reduced within a week.60 Alfawal et al.40

also investigated the effect of laser-assisted corticotomy compared to MOP intervention, as detailed in Section 3.5.6 (MOP).

Periodontology-assisted Accelerated Osteogenic Orthodontics

PAOO is a technique that combines alveolar corticotomy, bone graft materials, and orthodontic forces for the rapid correction of malocclusions. The technique is performed using releasing incisions, with full-thickness flaps reflected labially and lingually. Alveolar decortication, in conjunction with medullary penetration, is performed to enhance bleeding, followed by the placement of a bio-absorbable grafting material over the injured bone.[9]

Chandra et al.[9] examined the use of corticotomy with a recombinant human bone morphogenetic protein type-2 (rhBMP-2) graft and demonstrated its efficacy in shortening overall treatment duration. Notably, an increase in bone density at the corticotomy sites was observed compared to conventional corticotomy without the graft. rhBMP-2 exhibited regenerative and osteoinductive properties, mitigating dentoalveolar bone loss by enhancing local bone density.

Also, Bahammam[39] compared the effectiveness of two xenografts-a bovine xenograft and bioactive glass-using the PAOO technique to treat adult patients with moderate dental crowding.The study concluded that the combination of orthodontic treatment and PAOO was effective in accelerating the OTM in adult patients, with the additional ability to reduce the risk of root resorption. The bovine xenograft, when used with modified corticotomy, resulted in an increase in bone density than bioactive glass.[39]

In line with previous results, the conclusions drawn by Wu et al.[38] also support the effectiveness of accelerated osteogenic orthodontics techniques in reducing treatment time, albeit using a modified approach-improved accelerated osteogenic orthodontics. This treatment integrates PAOO with piezosurgery-assisted corticotomy (piezocision). In their study, the average treatment period was reduced by more than six months in patients with skeletal class III malocclusion.[90] Piezosurgery-assisted corticotomies limited to the buccal surface were performed, involving vertical incisions in interradicular spaces, bone graft application, and meticulous flap repositioning. The rate of tooth movement in the PAOO group was superior to that of the conventional orthodontic treatment group.[38]

In addition, Alsino et al.[59] investigated the effect of PAOO with a bone xenograft (Bone-D®) on correcting lower anterior teeth crowding. The study found that PAOO accelerated alignment and leveling, while differences in dental arch width between the canines and second premolars were clinically negligible. Moreover, no significant periodontal tissue damage was observed.

To date, no studies have assessed the ability of PAOO to accelerate orthodontic treatments with aligners.

Corticision

Corticision, derived from "cortical bone incision," involves performing small incisions in the tissue, typically with a blade, without flap elevation. This approach is associated with less tissue damage and pain.[12,95]

The only RCT that performed corticision, conducted by Sirri et al.,[12] reported a 1.2 fold faster alignment of lower anterior teeth compared to conventional orthodontic treatment. No significant differences in apical root resorption were found, although the maximum root resorption index was observed for the experimental group. Additionally, the distribution of dehiscence formation was similar between the groups, revealing that corticision did not promote gingival recession.

Piezocision

Piezocision is a more conservative and less invasive alternative to the conventional corticotomy technique. It involves the use of an ultrasonic cutting instrument to make incisions in the cortical bone without requiring a flap elevation.[96] This method has evolved as a new approach for manipulating cortical bone, causing minimal damage to adjacent tissues, reducing discomfort, and enhancing patient acceptance.

All the reviewed articles on piezocision involved the use of fixed appliances. For instance, some studies reported that piezocision reduced treatment duration by 59% compared to conventional orthodontic treatment alone while also minimizing anchorage loss of posterior teeth without adversely affecting periodontal health.[47,97] Moreover, another study showed that despite the piezocision being minimally invasive and requiring a longer surgical procedure, it is proved to be more efficient in reducing treatment duration compared to conventional corticotomy.[40]

However, Abbas et al.[44] observed that corticotomy resulted in greater canine movement rates in the first and third months than piezocision. This difference was attributed to the more extended corticotomy surgery, which may have increased the RAP due to prolonged tissue exposure, manipulation, and invasiveness.

Furthermore, Alfawal et al.[40] demonstrated that both piezocision and laser-assisted flapless corticotomy without grafting are highly effective in accelerating canine retraction using minimally invasive techniques. In this study, the canine retraction rate in both experimental groups was approximately 25% higher compared to the control.[40] Although laser corticotomy is 2.5 times faster than conventional orthodontic treatment (i.e., without acceleration techniques) and causes less pain and discomfort than piezocision,[40] Charavet et al.[46,48] highlighted that piezocision may be contraindicated in patients with a high gingival smile line because of high susceptible to develop small scars.

In addition, Khlef et al.[8,27] compared traditional corticotomy and graft corticotomy and found no statistically significant differences in retraction rates, skeletal, dental, and tissue variables, or root resorption. Conversely, Fernandes et al.[41] reported that both alveolar corticotomy and piezocision techniques were ineffective in accelerating canine retraction, ascribing to the intervention's failure to activate the RAP in the medullary bone, which compromised bone remodeling and occlusal contacts during retraction.

In another study, Jivrajani and Bhad Patil[35] showed that the piezocision procedure increased iatrogenic root resorption by 44% when used in conjunction with orthodontic forces. The authors suggested caution, as its application close to the root may cause iatrogenic damage to adjacent roots.

Micro-osteoperforation

MOP is a minimally invasive, graftless, and flapless transmucosal bone puncture technique that effectively reduces treatment time with minimal surgical damage.[52] This technique consists of producing multiple transmucosal perforations within the maxillary interproximal alveolar bone to elicit RAP near the targeted region for OTM.[51] Similar to other surgical techniques, MOP facilitates tooth movement by activating osteoclasts through RAP, which is associated with decreased bone density. Additionally, the depths of MOP boreholes may influence the RAP intensity.

As outlined in the abovementioned acceleration techniques, all studies using MOP applied conventional orthodontic treatment with fixed appliances. Specifically, the study carried out by Attri et al.[54] indicated that OTM acceleration occurred after MOP was performed every 28 days during the retraction period, with patients reporting minimal discomfort after the procedure.

Similarly, Sivarajan et al.[51] observed that MOP could increase the overall retraction of mini-implant-supported canines over 16 weeks, though the difference was not statistically significant. Pain was reported by several patients, with approximately 60% describing it as moderate and 15% as severe.[51]

MOP was found to significantly increase the expression of cytokines and chemokines, which are known for recruiting osteoclast precursors and stimulating their differentiation, potentially reducing orthodontic treatment time by up to 62%, with no associated adverse effects.[53] However, a study comparing molar and mesial migration with MOP depths ranging from 3 to 6 mm observed no clinically significant difference in tooth movement.[28]

Similarly, Aboalnaga et al.[50] stated that MOP was not able to accelerate the rate of canine retraction, did not increase posterior anchorage, and led to changes in root resorption. Furthermore, patients experienced mild to moderate transient pain that disappeared in about seven days.[98-101] Nonetheless, this study did not evaluate the effect of different numbers, sites, and repetitions of MOP on the rate or type of tooth movement, nor did it assess the effect of different total treatment durations. Additionally, the findings by Babanouri et al.[29] indicated the effectiveness of MOP in accelerating tooth movement over three months; however, this corroborates with a previous study suggesting that increasing the number of MOP from 3 to 6 mm was not clinically significant, as it did not proportionally reduce treatment time). Meanwhile, Jaiswal et al.[52] reported that doubling MOP accelerated tooth movement by 25% compared to a single MOP. This increase also led to significantly higher IL-1-β levels, which is in line with the increased osteoclastic activity observed after the second MOP.[30] Teh et al.[30] investigated the effects of MOP on the horizontal and vertical distribution of mandibular trabeculae using perforation intervals of four, eight, and twelve weeks. An increased orthodontic movement rate was observed at all intervals, with the most notable acceleration at the four-week interval. This effect is plausible due to the RAP induced by MOP, which enhanced alveolar bone turnover and thus accelerated OTM.[30] Moreover, Bansal et al.[55] stated that MOP facilitated by mini-implants significantly accelerated tooth movement for up to nine weeks without causing significant pain, discomfort, root resorption, or loss of marginal alveolar bone height.

Notably, Alqadasi et al.[42] compared the effects of MOP and piezocision on the acceleration of orthodontic movement in adults and observed that both techniques significantly increased the rate of tooth movement compared to conventional treatment after three months. None of the techniques caused root resorption nor increased vertical bone loss.

Alfailany et al.[43] compared the effects of MOP, traditional corticotomy, and conventional orthodontic treatment (without acceleration procedures) on maxillary canine retraction for treating Class II division 1 malocclusion. The results revealed that both MOP and corticotomy increased the canine retraction rate during the first two months. However, this effect withered after three months, as well as at the end of retraction, suggesting a transient acceleration ability of the tested techniques.

Overall, recent studies emphasize that tooth acceleration primarily occurs in the immediate post-corticotomy stage (both traditional and flapless), ascribing this to the regional acceleratory phenomenon, which accumulates after the surgical procedure. This leads to increased bone turnover and reduced bone density, thereby accelerating OTM.[8,27,57,60] Importantly, traditional and flapless corticotomies were associated with similar OTM rates, while minimally invasive interventions (e.g., piezocision, MOP) showed less tissue damage and discomfort, making them preferable to flap-associated corticotomy.[27,40,43]

Injection of Biomaterials, Supplements, or Hormones

Recent studies have explored the effect of PRP and PRF as promising alternatives for accelerating OTM. These approaches enhance bone regeneration, wound healing, and grafting, with less risk of bone and periodontal loss because of their high contents of growth factors, which are gradually released. The primary difference between these techniques resides in their preparation. Briefly, PRP requires the addition of an anticoagulant solution to the patient's blood sample, followed by multiple centrifugation steps and homogenization with a buffy coat. In contrast, PRF consists of blood collection, centrifugation, and substrate extraction from the top liquid layer.[98] Typically, PRF contains more healing factors and stem cells and is associated with less trauma.[98]

Although these techniques have the potential to accelerate treatment, they remain considerably controversial in the orthodontic field, as evidenced by the two studies reviewed in the current work. Karakasli and Erdur[89] stated that PRF could be an effective method to shorten treatment duration, while Zeitounlouian et al.[88] indicated that retraction rates after PRF were comparable to the control sides, with the exception of the second month, over a five-month period. These results suggest that the supposed accelerating effect of platelet concentrates may be associated with a transient increase in tooth movement rate, implying that repeated injections may be necessary for sustained effects.

Furthermore, Al-Bozaie et al.[21] investigated the impact of PRP to accelerate en-masse anterior canine retraction. The authors found no significant differences in the OTM rate compared to the control, although teeth in the PRP group were mainly retracted by controlled tipping and partially by translation.

Interestingly, a separate study by Ammar et al.[90] compared the acceleration potential of PRP and PRF, as well as a control group with no acceleration procedure. The results showed a significant acceleration in retraction movement after PRF compared to PRP in the second and fourth months, though no differences were observed in the first and third months. Both PRP and PRF led to an increase in overall movement related to the control.

Mechanical Vibration

Vibration stimulus has gained interest over the last decades as a non-invasive modality that triggers a catabolic cascade, stimulating cellular differentiation and significantly increasing the proliferation of osteoclastic and fibroblastic cells, especially on the alveolar bone. These processes accelerate bone metabolism, suppress bone loss, and ultimately increase the rate of tooth movement.[102-104]

The reported outcomes of the reviewed studies were analyzed based on the type of orthodontic treatment adopted in each study:

a) Conventional treatment with fixed appliances

Mayama et al.[81] studied the application of vibration of 5.2±0.5 gf (approximately 0.05 N at 10.2±2.6 Hz) in the canine retraction region using a customized stimulation device. The vibration was applied for 3 minimum (min) once a month. It was observed that static orthodontic force with supplemental vibration significantly accelerated canine retraction and reduced the number of visits to complete treatment. In line with these results, Liao et al.[83] examined the effects of vibration (50 Hz, 0.2 N, 20 g) applied for 10 min/day on the buccal surface of the maxillary canine and found a substantial increase in both closed space and canine distalization in the vibration group.

In contrast, Taha et al.[31] reported no statistically significant differences in canine retraction and pain perception between stimulated and non-stimulated groups, ascribing these results to the small sample size and short study duration.[31]

Similarly, DiBiase et al.[84] investigated the effect of vibratory force on space closing using the AcceleDent for 20 min/day but identified no significant differences.

Some studies have also focused on the use of vibrating electric toothbrushes. Leethanakul et al.[82] indicated that the application of vibrating stimuli using an electric toothbrush during orthodontic treatment increased IL-1β secretion and accelerated OTM by 59% over three months. Conversely, Kannan et al.[87] found no significant differences in distal canine movement between the experimental and control sides with the application of vibratory stimulus. They emphasized the need to determine the optimal frequency range to consolidate this modality as an effective method for OTM acceleration in orthodontics.

b) Treatment with aligners

Regarding the existing evidence on the impact of mechanical vibration on tooth movement rate, Lombardo et al.[86] demonstrated that low-frequency vibrations (30 Hz, 0.25 N), applied for 20 min/day with aligners replaced at 7-and 14-day intervals, produced no statistically significant difference in OTM accuracy. However, adding 20 min of daily low-frequency vibration with a 14-day aligner replacement schedule improved the accuracy of rotation of maxillary incisors by 10%.[86] Furthermore, vibration combined with a 14-day aligners replacement interval enhanced the accuracy of buccolingual and mesiodistal tipping of maxillary canines and buccolingual tipping of maxillary molars by 13-16% compared to a 7-day replacement schedule.[86]

Besides, Katchooi et al.[85] found no evidence to support that the vibratory stimulus delivered with the AcceleDent Aura device affected aligner treatment efficacy or completion rates in adult patients.

Low-intensity Pulsed Ultrasound Simulation

LIPUS is a recently employed technique that utilizes high-frequency mechanical vibrations (>20000 Hz) to stimulate and accelerate the biological processes associated with OTM.[18,99] The only RCT investigating the effects of LIPUS was conducted by El-Bialy et al.,[32] who evaluated the impact of ultrasonic waves (1.5 MHz, 1 kHz pulse, power density of 30 mW/cm^2) on the rate of OTM and root resorption. The study concluded that ultrasound stimulation increased the rate of tooth movement by 29% and resulted in less root resorption compared to contralateral control teeth.[32] Similar conclusions were drawn from observational studies utilizing LIPUS intervention.[19,100]

Electromagnetic Stimulation

The use of pulsed electromagnetic fields (PEMFs) in medicine has been documented for years, extending from their application in orthopedics for fracture treatment. The piezoelectric effect in bone results from the generation of opposite polarities in response to tension and compression forces. Electrical currents generated by orthodontic forces within the alveolar bone can stimulate the directional response, resorption, and deposition involved in the bone remodeling process.[16]

Again, the only study using electromagnetic fields used orthodontic treatment with fixed appliances, and no research has explored the combination of electromagnetic stimulation and aligner therapy. Showkatbakhsh et al.[16] revealed that 1-Hz PEMFs increased the OTM by 1.57±0.83 mm compared to the control group, which underwent similar orthodontic treatment without the utilization of acceleration techniques and required 5.0±0.6 months for completion.

Extracorporeal Shockwave Therapy

Extracorporeal shockwave therapy applied during orthodontic treatment may accelerate tooth movement by stimulating osteogenesis, angiogenesis, and revascularization. Several cytokines and growth factors are released by the influence of shockwaves, which promotes neovascularization, osteoblastic differentiation, and tissue growth.[17] In this regard, Falkensammer et al.[17] performed a study involving 26 patients, where the stimulated group received a single shockwave treatment with 1000 impulses targeted at the tissue of interest. No statistically significant differences were observed in OTM and periodontal status. These findings suggest that a single application of extracorporeal shockwave treatment does not accelerate OTM.

Supplementation with Vitamin D

Drugs and nutritional supplements, such as vitamin D, have been used to accelerate OTM, with promising results. Several studies describe the use of prostaglandin-E, cytokines, and the activator receptor of nuclear factor kappa-B ligand (RANKL), among others, which have been associated with increased tooth movement rate. These biomolecules alter the morphology and activity of osteoclasts and osteoblasts through the intracellular increase of cyclic adenosine monophosphate levels, mRNA synthesis, and RANKL secretion.[92] The active form of vitamin D, named calcitriol, is a potent stimulator of osteoclast activity but can also promote osteoblastic differentiation, depending on environmental conditions. It facilitates the differentiation of osteoclast precursors, increases osteoclast activity, and stimulates osteoblast differentiation and bone mineralization in a dose-dependent manner.

In one of the two revised studies reporting the utilization of calcitriol supplementation for accelerating OTM, a dose of 50 pg administered at intervals of up to 12 weeks effectively accelerated OTM.[92] The other study, which examined the effects of different calcitriol doses, showed that a 25 pg dose increased the canine movement rate by roughly 51% compared to the control. This reduction in treatment time and cost was observed on the experimental side at week 12 and, to a lesser extent, on the control side.[92] Furthermore, doses of 15 and 40 pg of calcitriol resulted in an OTM acceleration of about 10% when compared to the control.[91]

Photobiomodulation

Currently, PBM is one of the most promising approaches for OTM acceleration. Light in the red and near-infrared regions exhibits a biostimulating effect on bone remodeling, promoting the proliferation and differentiation of osteoclastic, osteoblastic, and fibroblastic cells. This therapeutic modality has been proven to not only accelerate OTM but also prevent external root resorption, modulate the inflammatory response, and alleviate pain and discomfort observed during OTM.[101]

a) Conventional treatment with fixed appliances:

Of the 28 revised PBM studies, only one did not use fixed orthodontic appliances. Among the 27 studies resorting to conventional treatment, 24 observed an increased rate of OTM compared to the control, despite variations in stimulation regimens,[1,13,14,22,34-37,61-64,66-68,70-74,76,77,79,80] while other two found no significant differences between the irradiated and control groups.[65,78] One study comparing OTM rates after PBM and MOP intervention observed that MOP induced a more rapid tooth movement.[56] Another study assessed the effectiveness of PBM and full-thickness mucoperiosteal flap (FTMPF) in reducing the treatment time but found no significant differences.[37] Moreover, one study compared the pain levels following OTM accelerated by PBM and piezocision, reporting significantly lower pain and discomfort in the PBM group during the first two weeks of canine retraction compared to the control and piezocision groups.[13]

Besides, Abdarazik et al.[37] compared the accelerating effect of a particular and minimally invasive type of corticotomy-elevation of an FTMPF, which includes the surface mucosa, submucosa, and periosteum without microperfuration-with the same intervention accompanied by low-intensity PBM. Their findings indicated that FTMPF accelerated OTM by 25%, whereas PBM reduced this rate by 20%. Thus, as expected, FTMPF was shown to be more effective in accelerating OTM.[37]

Meanwhile, Nahas et al.[73] found that PBM was effective in reducing the time needed to resolve inferior anterior issues. The authors also observed an energy loss of about 80-95% as the photic beams reached the target tissue (alveolar bone), resulting in approximately 12 J/cm^2 reaching the cells from an initial delivery dose of 108 J/cm^2.

In addition to the OTM rate, the PBM studies in this review also monitored other changes, such as the modulation of the inflammatory response induced by OTM. In fact, the results published by Üretürk et al.[70] suggested that the application of a low-intensity 820 nm laser caused an increase in IL-1 β and TGF- β1 levels in the gingival crevicular fluid (GCF). Similarly, Yassaei et al.[67] noted that using a 980 nm diode laser during tooth distalization significantly increased IL-6 concentration in the irradiated group. On the contrary, Ekizer et al.[68] used a 618 nm LED device at 20 mW/cm^2 for 20 min/day over 21 days and found no effect on IL-1 β levels in the GCF.[68]

Furthermore, Jivrajani and Bhad Patil[35] stated that low-intensity 980-nm laser therapy has a biostimulation effect, demonstrated by the increased concentration of matrix metalloproteinase-9 (MMP-9) in the GCF during the first three months of treatment. MMP-9 is a well-described bone resorption factor widely studied to assess bone remodeling status.

b) Treatment with aligners

Regarding the use of PBM as a coadjuvant therapy to accelerate OTM with aligners, Caccianiga et al.[69] proposed that the PBM produced the same rate of OTM as the control group, even after 12 h, following 22 h of aligner use per day without PBM.

Risk of Bias Assessment

The complete assessment of methodological quality is presented in Supplementary Table 3. Briefly, the EPHPP classified 45 clinical studies as having a low risk of bias,[1,8,9,12-14,16,17,21,22,29-32,34,35,40,43,44,46,47,50,54,55,57-60,62,63,66,68,71,72,74-76,80-82,84-86,90,92] 27 studies as having a moderate risk of bias,[11,27,28,33,37-39,41,42,45,48,49,51-53,56,61,64,65,67,69,70,77-79,88,89] and four studies as having a high risk of bias.[73,83,87,91] The criterion most likely to contribute to bias was blinding, as researchers were aware of the group or individual from which the sample was collected, potentially compromising the impartiality of the evaluation.

DISCUSSION

The present systematic review analyses and compares the surgical and non-surgical techniques currently used in the clinical context, considering their potential to enhance OTM during orthodontic treatments. It also examines the side effects associated with each technique and how different types of orthodontic appliances influence the rate of OTM. The review aims to provide a reproducible methodological approach for generating scientific and practical knowledge, ultimately optimizing the clinical applicability of OTM acceleration methods in the future.

Briefly, the current surgical techniques include: (1) traditional corticotomy, which significantly enhances OTM due to the RAP, facilitating tissue remodeling and healing.[93] This method can triple the rate of OTM in the initial post-operative days.[93] However, it is invasive, often causing significant discomfort and swelling in a majority of patients shortly after the procedure.[9,27] The effect of this technique when used with aligners has yet to be studied; (2) laser-assisted flapless corticotomy, which avoids flap elevation and uses a laser to create clear and small incisions in the cortical bone, resulting in minimal bleeding and tissue damage. This technique has been proven to accelerate OTM with minimal pain and discomfort for the patient;[40,60] (3) PAOO, a technique that merges corticotomy, bone grafting, and orthodontic forces to correct malocclusions swiftly. It not only accelerates OTM but also increases bone density at the corticotomy sites, potentially reducing the risk of root resorption.[38] However, there is no evidence supporting its efficacy with aligners; (4) corticision, a minimally invasive periodontal procedure in which small incisions are made in the cortical bone to stimulate tissue remodeling. This review includes a single study that compared the effect of corticision on the alignment of crowded lower anterior teeth, specifically evaluating external apical root resorption and bone defects. The study showed that corticision greatly conserves tissue integrity compared to conventional non-accelerated methods of alignment;[12] (5) piezocision, a less invasive approach, involves making ultrasonic incisions in the cortical bone without flap lifting, thereby reducing patient discomfort and recovery time.[97] Despite its benefits, piezocision may not be suitable for patients with high gingival smile lines due to the potential risk of scarring;[95,96] and (6) MOP, which involves transmucosal bone punctures to elicit RAP, enhancing osteoclast activity and accelerating OTM.[43,51] Despite being minimally invasive, the effectiveness of MOP in reducing treatment time remains controversial, with some studies noting minimal impact on OTM rates.[30]

Concerning non-surgical acceleration techniques, the following were reviewed: (1) injection of biomaterials, supplements, or hormones (e.g., PRF, PRP): while promising, the use of these agents to accelerate OTM is not consensual, with contradictory outcomes reported.[21,48,90,96] Their effectiveness might be transient, suggesting that repeated applications could be necessary for prolonged effects.[48] Importantly, a comparative study found that the PRF group showed longer-lasting acceleration effects compared to PRP, suggesting that the former may be the preferred option;[90] (2) mechanical vibration: vibrational stimuli can expedite OTM by stimulating cellular activity and bone metabolism.[102] However, the effectiveness of this approach varies markedly across studies, with some reporting significant enhancements in OTM rates while others find negligible effects;[85,87] (3) LIPUS: growing evidence suggests that ultrasound stimulation can effectively improve OTM rates and reduce root loss by modulating the remodeling processes occurring in the periodontium;[19,32,100] (4) electromagnetic stimulation: the application of PEMFs has shown potential in accelerating OTM by influencing electrical currents in the alveolar bone.[16,17] However, evidence is limited to its use with fixed appliances, and there is no data on its use with aligner therapy; (5) shockwave therapy: while theoretically promising due to its potential to stimulate osteogenesis and angiogenesis, shockwave therapy has not demonstrated significant effectiveness in accelerating OTM in practical settings;[17] (6) vitamin D supplementation: the potential of calcitriol, the active form of vitamin D, to stimulate osteoclastic and osteoblastic activity, thereby enhancing OTM, has been documented.[91] Dose-dependent responses highlight the need for tailored treatment plans;[91] (7) PBM:

this technique uses light to stimulate cellular activity in the alveolar bone and periodontal ligament, showing promising results in accelerating OTM, reducing pain, and modulating inflammatory responses.[74,76,79,80] However, the effectiveness is highly dependent on parameters of the light used, such as intensity and wavelength, which are yet to be optimized in clinical settings. Notably, the only study combining OTM with aligners and PBM found no light-induced acceleration effect. The authors hypothesize that improvements in the OTM rate may be due to biostimulation of bone turnover,[69] highlighting the necessity of further research to investigate the appropriate aligner and PBM protocol for stimulating bone remodeling and reducing treatment time. Indeed, confirming the best PBM protocol for aligner treatment is pivotal, as this orthodontic intervention is increasingly appealing to patients due to its comfort and ease of management.[69]

Although there is a lack of RCT studies on low-intensity electrical stimulation, preliminary reports suggest that electrical stimuli can effectively augment the en-masse retraction rate of the upper anterior teeth, accompanied by mild to moderate pain.[103,104]

Overall, the RCTs reviewed reveal that most surgical and non-surgical techniques identified can accelerate OTM, while some require optimization of technical parameters. Studies comparing surgical methods with non-surgical methods, such as MOP vs. PBM[56] and FTMPF vs PBM,[37] displayed that surgical techniques are associated with higher OTM rates. Despite the fact that surgical methods like corticotomy and PAOO have the potential to accelerate OTM, they also carry higher levels of invasiveness and discomfort. These techniques should, therefore, be only applied after a careful diagnosis to maximize patient benefits. This demonstrates the importance of considering factors beyond the acceleration technique, including the overall impact on the patient's quality of life.

Despite advancements in minimally invasive surgical techniques such as piezocision and MOP, corticotomy showed the highest acceleration potential. The extent of tissue damage created during these procedures has a direct effect on the intensity of the RAP, thus playing an important role in the effectiveness of these techniques.

Non-surgical methods, such as mechanical vibration and PBM, offer less invasive alternatives, though their efficacy may vary. Nevertheless, several studies point to a satisfactory accelerating efficacy of these techniques, with patients expressing high satisfaction. Notably, Nahas et al.[73] highlighted that the irradiation dose plays a determining factor in the effectiveness of PBM in accelerating OTM. Thus, subdosing may explain the less satisfactory results in studies that did not observe an increased OTM rate after irradiation.

Importantly, while most current scientific evidence predominantly focuses on fixed appliances in surgical contexts, some RCTs have explored non-surgical techniques combined with both fixed and non-fixed appliances,[69,85,86] revealing significant differences in accelerating OTM. Specifically, surgical techniques demonstrate superior efficacy in reducing treatment duration.[56] However, time efficiency alone cannot dictate method selection, as surgical interventions entail greater invasiveness and are associated with considerable levels of discomfort and pain. Indeed, all surgical techniques in this review displayed statistically significant differences in accelerating OTM, with particular relevance to MOP, piezocision, and especially corticotomy, reducing treatment duration by several months, in some cases, by more than half a year. However, several adverse effects have been reported, such as experiencing moderate to severe pain and discomfort during feeding.[1,13,60] In addition, swelling and a challenging recovery period lasting two to four weeks have been reported. These outcomes suggest that surgical techniques may not be suitable for all patients, highlighting the necessity for careful consideration of the associated risks and benefits.

This has driven further research and developments in non-surgical acceleration techniques. At the same time, not all studies showed statistically significant efficacy in accelerating OTM;[78,84] both vibration and PBM exhibit promising outcomes, with the latter offering the additional benefit of modulating inflammatory responses and reducing pain scores. The absence of adverse effects, such as discomfort and pain, fosters the potential utilization of these acceleration techniques, including in the pediatric population.

Acceleration techniques for tooth movement have been studied for decades, evolving to reduce and minimize two major drawbacks of orthodontic treatment, namely prolonged duration and pain, thus promoting treatment acceptance among patients and clinicians. This review highlights a diverse array of both surgical and non-surgical approaches aimed at accelerating OTM. All being considered, corticotomy and PBM are the most commonly used techniques, with stronger evidence supporting their effectiveness in accelerating OTM. PBM stands out as a promising, non-invasive, painless, and effective biostimulatory approach for accelerating the coadjuvant of OTM in the future. This is reflected by the increasing number of studies employing this technique over the last few years. However, further scientific and clinical investigations are required to refine PBM protocols and consolidate their use in orthodontic practice.

Study Limitations

This review provides comprehensive insights into various acceleration techniques but has some limitations:

• Limited Research on Aligners: A major limitation is the absence of studies assessing the effectiveness of acceleration techniques, specifically with aligners. Most research focuses on traditional fixed appliances, restricting the applicability to patients using newer aligner technologies.

• Variability in Study Designs: The included studies vary in design, sample size, methodology, and outcome measures, leading to inconsistencies that hinder definitive conclusions, thereby compromising the robustness of the reported results. Additionally, variations in treatment protocols, such as frequency, duration, and intensity of interventions, further hamper comparisons and limit the generalizability of findings.

• Short-term Focus: Many studies primarily report short-term outcomes, often neglecting long-term effects such as stability of tooth position, overall oral health, and the risk of relapse.

• Patient-Related Factors: The review may not fully account for patient-specific variables, including age, general health, bone density, and oral hygiene, which can significantly influence treatment effectiveness and potential side effects.

• Pain and Discomfort: While the review addresses pain and discomfort associated with some techniques, it may not adequately capture the patient experience or quality of life, both of which are crucial for evaluating the practicality and acceptability of such interventions.

•Invasive Nature of Some Techniques: Procedures like corticotomy and PAOO could be a barrier to widespread adoption due to their invasiveness. The severe pain and swelling linked to these methods could deter patients from choosing these options. This concern is often highlighted throughout this review, anticipating that non-invasive alternatives may be preferable, particularly for some groups of patients, such as children.

• Limited Discussion on Cost-Effectiveness: The review does not address the cost-effectiveness of these acceleration techniques. The additional expenses of advanced surgical procedures or devices may not be justified by the reduction in treatment time from a patient's perspective.

CONCLUSION

As a starting point, this review addresses a critical gap by providing extensive theoretical knowledge to support decision-making in a clinical setting. Nonetheless, additional studies are needed before confident conclusions can be drawn regarding the optimal clinical protocols to follow.

Addressing these limitations in future research could enhance understanding and refine the application of orthodontic acceleration techniques, particularly when evaluating their long-term outcomes in conjunction with newer orthodontic appliances like aligners. The lack of RCTs assessing the efficacy of surgical techniques in aligner therapy hinders the analysis of their efficacy in accelerating OTM using non-fixed appliances. Consequently, further investigation and research are warranted to bridge this knowledge gap. Integrating these methods into standard orthodontic treatment could significantly reduce treatment time and improve patient outcomes. Importantly, expanding the range of stimulation device options would more easily meet patients' expectations in a way that broadens the available solutions, suitable for their individualized needs, potentially leading to more tailored, affordable, and effective treatment options. Notably, the development of new PBM devices could make their purchase more feasible and provide a more likely acquisition, which could ultimately foster the utilization of home-based accelerating interventions and expand their usage.

Other information

The systematic review was registered in the PROSPERO database under registration ID 545573, and the protocol is available on the PROSPERO website. The title was later amended to reflect a focus on the comparison of acceleration techniques using conventional and fixed versus removable appliances. Nevertheless, the focused question, eligibility criteria, and search criteria remained unchanged.

Footnotes

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Supplementary Tables 1-3: https://l24.im/vlXHz