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Technologies for Accelerating Orthodontic Tooth Movement: Clinical Efficacy and Biological Mechanisms – A Literature Review

Katarzyna Cybulska*

ABSTRACT

Introduction and Literature Review: This literature review clinically assesses the development of orthodontic tooth movement (OTM) technology and discusses the shift in force-delivery mechanisms from mechanical means to biological stimulation, bone conditioning, photobiomodulation, and mechanotherapy. Treatment duration is a clinically important issue for adult patients, leading to the introduction of various accelerated treatments. The classic mechanical approach relies solely on mechanical forces, which often require long-term treatment and carry a high risk of tooth root resorption and periodontal problems. Over the last twenty years, there has been a shift toward biological and physical acceleration methods. Surgical techniques use corticotomy, piezocision, and micro-osteoperforations (MOPs). These methods apply the Regional Acceleratory Phenomenon (RAP) principle to dramatically increase bone remodeling rates. Concurrently, non-invasive approaches—such as low-level laser therapy (LLLT)/photobiomodulation and high-frequency acceleration (HFA) devices—stimulate cellular activity, mitochondrial ATP production, and cytokine release without significant surgical morbidity. Moreover, novel biochemical and pharmacological approaches, including localized cytokine regulation and vitamin D therapy, have emerged as alternative routes to enhance bone metabolism. *Conclusion*: The above review highlights the effectiveness of accelerated orthodontic treatment methods along with their scientific basis, stressing the necessity to shift from mechanical principles of teeth movement to biophysical principles.

Keywords: orthodontic tooth movement; orthodontic tooth acceleration; regional acceleratory phenomenon; micro-osteoperforation; piezocision; photobiomodulation; vibration.

1. INTRODUCTION

Orthodontic treatment time is one of the most important factors influencing patient compliance and acceptance, which usually takes from 18 months to 36 months with the use of traditional orthodontic brackets or aligners. Long-term use of the orthodontic forces is known to lead to increased cases of root resorption, white spot lesions, gingival recession, and periodontal destruction. Hence, the main goal of

modern orthodontics includes not only the achievement of static position of the teeth but also the acceleration of orthodontic tooth movement (OTM) (Proffit et al., 2018; Roberts et al., 2004).

Mechanical forces involved in the traditional OTM cause cellular stress in the periodontal ligament (PDL) and alveolar bone, resulting in ischemia and inflammatory mediator release. The latter leads to bone resorption on the compression side performed by osteoclasts and new bone formation on the tension side through osteoblasts (Meikle, 2006). However, there are natural physiological limitations to this process, related to the metabolic rate and density of the alveolar bone (Yaffe et al., 1994; Amit et al., 2022).

To overcome physiological limitations, many techniques have been developed over the last decades (Zafar et al., 2020). The following can be mentioned as the types of modern methods:

- Surgical interventions: Utilizing controlled bone trauma, such as alveolar corticotomy, piezocision, and flapless micro-osteoperforations (MOPs), to induce the Regional Acceleratory Phenomenon (RAP) (Alikhani et al., 2013; Dibart et al., 2009; Wilcko et al., 2001).
- Physical and biostimulatory methods: Applying non-invasive energy sources, including low-level laser therapy (LLLT) / photobiomodulation and high-frequency mechanical vibrations (HFA), to stimulate cellular proliferation and metabolic turnover (Alikhani et al., 2018; Cheung et al., 2021; Darendeliler et al., 2010; Fujita et al., 2018).
- Studies related to biochemical and pharmacological approaches for the understanding of role of cytokines, prostaglandins, and systemic effect of vitamin D on the regulation of osteoclast formation (Babu et al., 2021; Kale et al., 2004; Seyedzadeh et al., 2019).

This review combines the clinical and biological background of advanced orthodontic systems in terms of their evolution from basic bone physiology knowledge to current evidence-based surgical, mechanical, and pharmacological methods aiming at reducing treatment time (Frost, 1989; Proffit et al., 2018; Domínguez et al., 2023).

2. REVIEW METHODS

The literature review included articles published in the appropriate databases that are considered peer-reviewed such as PubMed, Scopus, Web of Science, and Google Scholar, up to January 2026. The search terms used were “orthodontic tooth movement,” “accelerated orthodontics,” “regional acceleratory phenomenon,” “corticotomy,” “piezocision,” “micro-osteoperforations,” “photobiomodulation,” “low level laser therapy,” and “high-frequency vibration”.

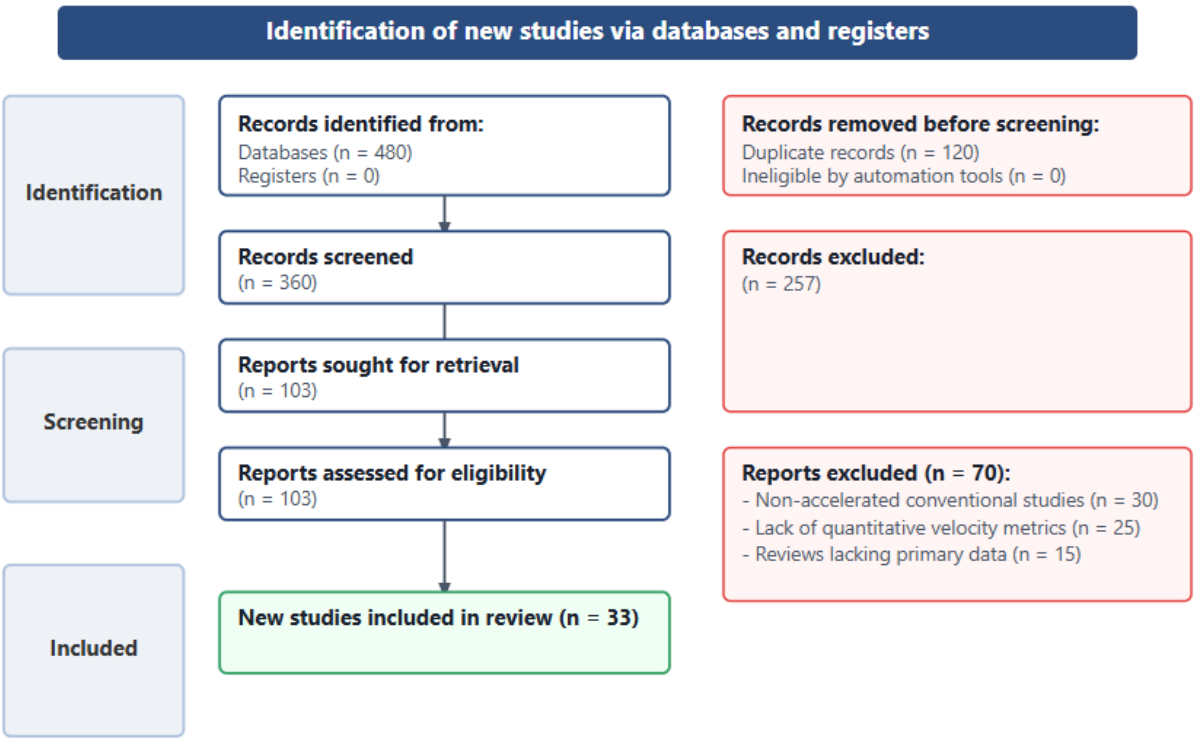

Figure 1. PRISMA 2020 flow diagram for the process of literature search and selection.

A total of 480 articles were identified through literature searches (PubMed: 200; Scopus: 160; Web of Science: 120). Out of the 480 articles, 120 duplicates were eliminated, leaving 360 articles for title and abstract review, in which 257 articles were excluded. Next, 103 articles underwent full-text review. Of the 103 articles, we excluded 70 based on the orthodontics inclusion criteria: non-accelerated conventional orthodontics research (n = 30); no velocity or time reduction (n = 25); and no original methodological data (n = 15). In conclusion, 33 peer-reviewed papers satisfied all inclusion criteria for qualitative review, in line with the bibliographic review. Figure 1 illustrates the screening and selection process according to the PRISMA protocol.

3. RESULTS AND DISCUSSION

Biological Foundations and the Physiology of Orthodontic Tooth Movement

Classical principles of OTM depend on the periodontium's biological response to mechanical loading. The application of orthodontic force causes PDL compression and leads to ischemia and inflammation in the area of applied force. This inflammatory process includes synthesis of various cytokines and mediators such as interleukin-1β, interleukin-6, TNF-α, and prostaglandin E2. They signal the migration of osteoclast precursors, leading to alveolar bone resorption (Gao et al., 2020; Gonçalves et al., 2025).

Nevertheless, the natural speed of remodeling depends on the density of the cortical bone in the alveolar socket. A critical paradigm change in rapid orthodontics relates to the Regional Acceleratory Phenomenon (RAP) theory of Frost (1989). Frost showed that regional tissue injury or surgery temporarily accelerates bone remodeling at the lesion site, leading to regional bone rarefaction and heightened tissue responsiveness to changes within it. Exploiting this biological response became the key concept behind modern surgical acceleration methods (Jaiswal et al., 2021).

Surgical and Invasive Acceleration Methods: Induction of Regional Acceleratory Phenomenon

Among surgical acceleration methods, some of the most effective treatments that reduce the total treatment time of orthodontic procedures are surgical interventions, which have been found to reduce treatment time by an average of 50% to 70%. The concept was defined by Wilcko et al. (2001) using periodontally accelerated osteogenic orthodontics (PAOO), which involves the combination of selective alveolar corticotomy and bone grafting techniques. Though these techniques were effective in reducing the time needed for treatment and bone volume, the traditional corticotomy required significant flap reflection and presented high levels of morbidity for patients (Kalemaj et al., 2015).

Dibart et al., (2009) developed Piezocision to minimize invasiveness; it uses piezoelectric micro-incisions of the gingiva without raising full-thickness flaps, preserving local blood supply while still generating the necessary RAP response. Later innovations produced Micro-Osteoperforations (MOPs), according to Alikhani et al., (2013). MOPs are tiny, flapless perforations of the attached gingiva and bone made using special instruments designed to perform this procedure in a single sitting. Randomized clinical trials have shown that MOPs significantly expedite tooth movement and increase local chemokine expression without causing root resorption or pain (Khlef et al., 2020).

Systematic reviews and meta-analyses indicate that surgery is associated with the most predictable reduction in time. Nonetheless, clinical factors cannot be ignored, namely the operator's skill and the patient's ability to tolerate surgery (Krishnan and Davidovitch, 2009).

Non-Invasive Photobiomodulation: Light's Function and Biostimulation of Cells

Whereas some patients are unsuited for surgery or may experience surgical complications, non-invasive biostimulation methods provide a viable alternative. Photobiomodulation (PBM), also known as Low-Level Laser Therapy (LLLT), uses low-power laser diodes or light-emitting diodes (LEDs) that emit specific wavelengths of light (600–940 nm) to affect mitochondrial cytochromes (Lim Pan et al., 2016).

Photobiomodulation (PBM), as described by Fujita et al., (2018), improves mitochondrial electron transport, resulting in ATP production and ROS generation in a controlled manner. It promotes PDL fibroblast proliferation, osteoclastogenesis, and osteoblast differentiation without causing thermal tissue damage. Many scientific experiments show that the application of LLLT therapy for canine retraction speeds up tooth movement while at the same time not causing orthodontic pain through the use of anti-inflammatory neural channels. However, modern treatment methods focus on the safe use of LED lights in transparent aligners (Mavropoulos et al., 2021; Miles et al., 2020).

Mechanical Stimulation, Vibrations, and Pharmacological Pathways

Another type of non-invasive acceleration therapy uses mechanical stimulation with vibration appliances (HFA), such as AcceleDent or VPro. Furthering the ideas of Rubin et al., (2001) pioneering study on mechanical loading and bone-density adaptation published in Nature, clinicians investigated the possibility of activating cellular signaling mechanisms in the periodontium via vibrations (Turk et al., 2024; Verna, 2016).

Although laboratory research yielded positive results, randomized controlled trials and multicenter studies did not prove that this technology leads to considerable acceleration of the process (Nobre et al., 2021). However, patients reported greater comfort and less pain during the initial stages of orthodontic tooth movement. Another chemical approach has also gained popularity. Systemic or local vitamin D supplementation and local application of prostaglandins and cytokines help stimulate osteoclast function. Biomarkers identified in gingival crevicular fluid serve as valuable indices of biological turnover during active acceleration stages (Pavlin et al., 2015; Sujith et al., 2021).

Technological Protocols Comparison

To contextualize the evolution of orthodontic acceleration approaches, Table 1 compares clinical and biological parameters across four main technical paradigms.

Table 1. Comparison of Orthodontic Acceleration Modalities across Technical Paradigms.

Feature / Paradigm	Surgical Methods (Corticotomy / MOPs)	Photobiomodulation (LLLT / LED)	Mechanical Vibrations (HFA)	Pharmacological & Biomarker Adjuncts
Primary Mechanism	Surgical trauma triggering RAP & bone density drop.	Mitochondrial biostimulation & ATP upregulation.	Micro-mechanical strain & cellular mechanotransduction.	Biochemical up-regulation of osteoclastogenesis.
Invasiveness	Moderate to High (Flapped or flapless puncture).	Non-invasive (External light irradiation).	Non-invasive (Daily bite device use).	Non-invasive to systemic administration.
Clinical Efficacy	High (Up to 50–70% time reduction).	Moderate (Consistent acceleration of 20–30%).	Variable / Mild (Primarily focused on alignment/pain).	Moderate (Adjunctive enhancement of turnover).
Patient Compliance	Low requirement (One-time or occasional clinic visits).	Requires strict daily/weekly patient adherence.	Requires daily self-administration by patient.	Requires careful systemic/local dosage control.
Primary Limitations	Surgical discomfort, risk of swelling or root damage.	Equipment calibration, strict adherence protocols.	Mixed consensus in independent clinical trials.	Systemic side effects, need for precise dosage control.
Periodontal Impact	Potential risk of transient recession if poorly executed.	Safe; promotes tissue healing and pain reduction.	Safe; minimal adverse periodontal effects.	Requires monitoring of root resorption risks.

4. CONCLUSION

The development of accelerated orthodontics has been moving away from classic mechanical forces towards biophysical methods which helps to circumvent the inherent constraints of the alveolar bone remodeling process. Surgical techniques, such as corticotomy, piezocision, and micro-osteoperforations provide the greatest temporal effects since they allow for triggering of the regional acceleratory phenomenon (RAP). In turn, non-invasive techniques of biostimulation, such as photobiomodulation (low-level laser

therapy, LLLT) represent a safer and more convenient alternative that helps to accelerate metabolic processes at a microscopic level without surgical procedures. Mechanical vibration and pharmacology represent other methods that are used in conjunction with accelerated orthodontics. Further research efforts must be concentrated on creating the standardized protocol of light exposure energies and studying the combination of therapeutic approaches, such as the use of aligners with micro-osteoperforations or LLLT.

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I have made a significant contribution to the manuscript, have approved the final version, and agree to its submission and publication in Medical Science (journal).

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Data and materials availability
All data associated with this study are present in the paper.

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