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Accelerated orthodontics (AO): The past, present and the future

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ABSTRACT

Accelerated orthodontics (AO) is emerging as a revolutionary approach in achieving desired orthodontic results in a shorter timeframe. AO modalities, both invasive and non-invasive promise to bring about rapid orthodontic tooth movement (OTM) transformations through targeted bone remodeling. From micro-osteoperforations facilitating bone remodeling to photobiomodulation enhancing cellular activity, the armamentarium of accelerated orthodontics promises to not only shorten treatment times but also potentially unlock novel therapeutic avenues for complex malocclusions. This burgeoning field, however, necessitates rigorous scientific scrutiny to optimize protocols, mitigate potential iatrogenic effects, and ultimately deliver on the promise of a faster, more efficacious, and patient-centric orthodontic experience. This paper offers a comprehensive review of AO, exploring its potential benefits and drawbacks, analysing the effectiveness of popular techniques, and providing insights for informed decision-making by delving into the science behind AO, evaluating clinical evidence, such as, transient pain, root resorption, and periodontal considerations. Also, this paper aims to equip patients and Orthodontists with a deeper understanding of this evolving field.

Introduction

Over a millennium, orthodontic treatment has been synonymous with extended timelines, often spanning numerous years. This can be a significant deterrent for individuals seeking to improve their malocclusion. Fortunately, the landscape of orthodontics is undergoing a remarkable transformation with the advent of accelerated orthodontics (AO). This innovative approach utilizes various techniques to expedite tooth movement, offering patients the potential to achieve the desired results in a considerably shorter duration.

The AO developments both invasive and pharmacological agents undoubtedly hold the potential to increase the overall efficiency of orthodontic treatment, a significant challenge persists for orthodontists and researchers' alike—namely, (1) safety, and (2) overall clinical significance of AO treatment modality in comparison to the conventional orthodontic treatment (does AO modalities really impact orthodontic treatment efficiency in a meaningful manner?). Despite advancements, there is an ongoing effort within the field to address the above factors and find ways to streamline orthodontic procedures further. Therefore, with any novel approach comes a responsibility for thorough evaluation. This paper aims to critically analyze the effectiveness and safety of AO, providing a balanced perspective on its potential benefits and drawbacks. By exploring the scientific evidence supporting popular AO techniques, assessing their impact on treatment time and patient experience, and addressing ethical considerations. Also, this comprehensive review seeks to empower patients and healthcare professionals to make informed decisions regarding this evolving field of AO, hence, we discuss the same in the following sections.

- What is the scope and need for accelerated orthodontics?
- Various modalities of accelerated orthodontics: Invasive and non-invasive
- Biological responses to accelerated orthodontics: Tissue, cellular and molecular responses.
- What are the clinical implications and current level of evidence of accelerated orthodontics?
- Future of accelerated orthodontics and conclusion

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What is the scope and need for accelerated orthodontics?

The expanding field of accelerated orthodontics seeks to revolutionize tooth movement, leveraging cutting-edge biomolecular and biomechanical strategies to expedite the traditionally journey. This urgency stems from a confluence of factors: burgeoning patient demand for rapid results, evolving esthetic expectations, and the recognition that protracted treatment durations can exacerbate biomechanical challenges and patient compliance issues. Table 1 explains the scope and need for accelerated orthodontics.

Various modalities of accelerated orthodontics: invasive and non-invasive

Researchers have explored numerous methods for speeding up tooth movement, ranging from non-invasive approaches like pulsed electromagnetic fields, mechanical vibration, and low-level laser therapy to invasive surgical techniques like osteotomies and corticotomy.

The following flowchart (Fig.1)[1] explains the various modalities of accelerated orthodontics, both Invasive and non-invasive.[1]

Surgical intervention to accelerate orthodontic tooth movement.

The concept of surgery-assisted accelerated orthodontics traces back to 1931 when Bichlmayr introduced a surgical technique for the correction of severe maxillary protrusion.[2] This approach involved the removal of bone wedges to facilitate the retraction of anterior teeth. Subsequently, in 1959, Kole built upon this corticotomy method, using it for space closure and correction of crossbites. Corticotomy, osteotomy piezoincision, micro-osteoperforations (MOP), periodontally assisted osteogenic orthodontics (PAOO), corticotomy-accelerated osteogenic, orthodontic treatment (CAOOT) and dental distraction (dentoalveolar distraction osteogenesis are some of the proposed surgical interventions to accelerate orthodontic tooth movement (Table 2).

Micro-osteoperforations (MOPs)

Propel Orthodontics introduced a device called Propel to minimize the invasiveness of bone surgery in orthodontic procedures, employing a technique known as alveocentesis, involving bone puncturing. This device showcased increased inflammatory markers during Orthodontic Tooth Movement (OTM), leading to heightened osteoclast activity and accelerated tooth movement. A study by Alikhani et al. applied this procedure on humans using a Ni-Ti closed coil spring anchored to a Temporary Anchorage Device (TAD) for maxillary canine distalization after premolar extraction (Table 3).[3]

Gingival crevicular fluid (GCF) samples collected before and after tooth movement revealed an enhanced inflammatory response, recruiting osteoclast precursors and stimulating osteoclast differentiation through increased infiltration of cytokines and chemokines. Micro-osteoperforations (MOPs) demonstrated a 2.3-fold increase in the rate of canine retraction compared to the control group, with patients reporting mild local discomfort.

We conducted a trial to test the effects of micro-osteo perforations (MOP) on root resorption. Using the Propel appliance (Propel Orthodontics, San Jose, Calif), MOP were applied at a depth of 5 mm and the contralateral side served as the control. Experimental side premolars showed greater root resorption than controls.[4]

The mechanism behind MOP involves increased expression of inflammatory mediators present during OTM, like other interventions enhancing RAP. Research on MOP protocols has yielded mixed results, with conflicting outcomes in studies and systematic reviews. Some studies demonstrated accelerated tooth movement, while others found no significant difference. Systematic reviews by Sivarajan et al. and Shahabee et al. presented conflicting evidence regarding the effectiveness of MOP, with varying levels of tooth movement observed.[5,6]

Factors like the number and frequency of MOP applications, as well as patient perception and discomfort, play a role in the overall assessment of MOP efficacy. While some studies suggested a correlation between the extent of surgical insult and increased tooth movement, others failed to find a significant difference. It is essential to consider these factors alongside patient comfort and quality of life scores. Notably, the duration and bias risks of studies also impact the interpretation of results.[7-10]

Non-mechanical/non-physical (drugs)

The quest for faster orthodontic tooth movement has led to the exploration of various pharmacological agents including, calcium, vitamin D3, parathyroid, prostaglandin, corticosteroids, osteocalcin, cytokines, and relaxin with the potential to accelerate treatment timelines. However, a cautious and evidence-based approach is paramount. Rigorous research is crucial to elucidate the mechanisms of action, address potential side effects, and optimize delivery systems for safe and effective clinical application of these agents. Only then can we unlock their true potential for faster, yet safe, orthodontic treatment, ultimately benefiting patients seeking a more streamlined journey towards a confident smile.

Vitamin D

Vitamin D, beyond its role in calcium absorption, plays a pivotal role in bone remodeling, a process crucial for orthodontic tooth movement. Its active metabolite, 1,25-dihydroxyvitamin D3 (1,25D), directly stimulates osteoclast activity, the bone-resorbing cells that drive tooth movement. This opens a tantalizing avenue for faster treatment timelines. Preclinical studies using local 1,25D administration into the periodontal ligament (PDL), the dynamic tissue surrounding the tooth root, demonstrate significant acceleration in tooth movement. However, this potent modulator presents a double-edged sword. Local injections have been shown to elevate enzyme levels suggesting cellular stress and tissue damage. Additionally, long-term systemic effects on organs like kidneys and bones remain largely unexplored. Controlled-release systems offer a promising solution by targeting the PDL with pinpoint precision. Encapsulation technologies and biocompatible matrices hold the key to achieving this targeted delivery, minimizing systemic exposure, and

Table 1
Scope and need for accelerated orthodontics.

Scope and need for accelerated orthodontics	
Need	Scope
Patient expectations: Increasing awareness of shorter treatment options and desires for faster results.	Minimizes the impact of treatment on lifestyle and improves patient satisfaction.
Complex cases: Cases requiring extensive tooth movement may benefit from faster treatment to reduce overall time in braces.	Reduces chair time for both patient and orthodontist, allowing for increased patient volume.
Compliance issues: Some patients struggle with adhering to orthodontic treatment plans for extended periods. Acceleration can improve compliance and treatment outcomes.	Expands the scope of orthodontic care to address more challenging clinical situations.
Periodontal concerns: For patients with periodontal disease, early correction of malocclusions can be crucial to prevent further damage.	Provides orthodontists with more tools to achieve optimal results in less time.
Social and professional demands: Some patients may need faster treatment due to upcoming social events or professional commitments.	Promotes positive patient experiences and enhances overall satisfaction with orthodontic care.
Technological advancements: The development of new technologies and techniques allows for more targeted and controlled stimulation of bone remodeling, leading to faster tooth movement.	

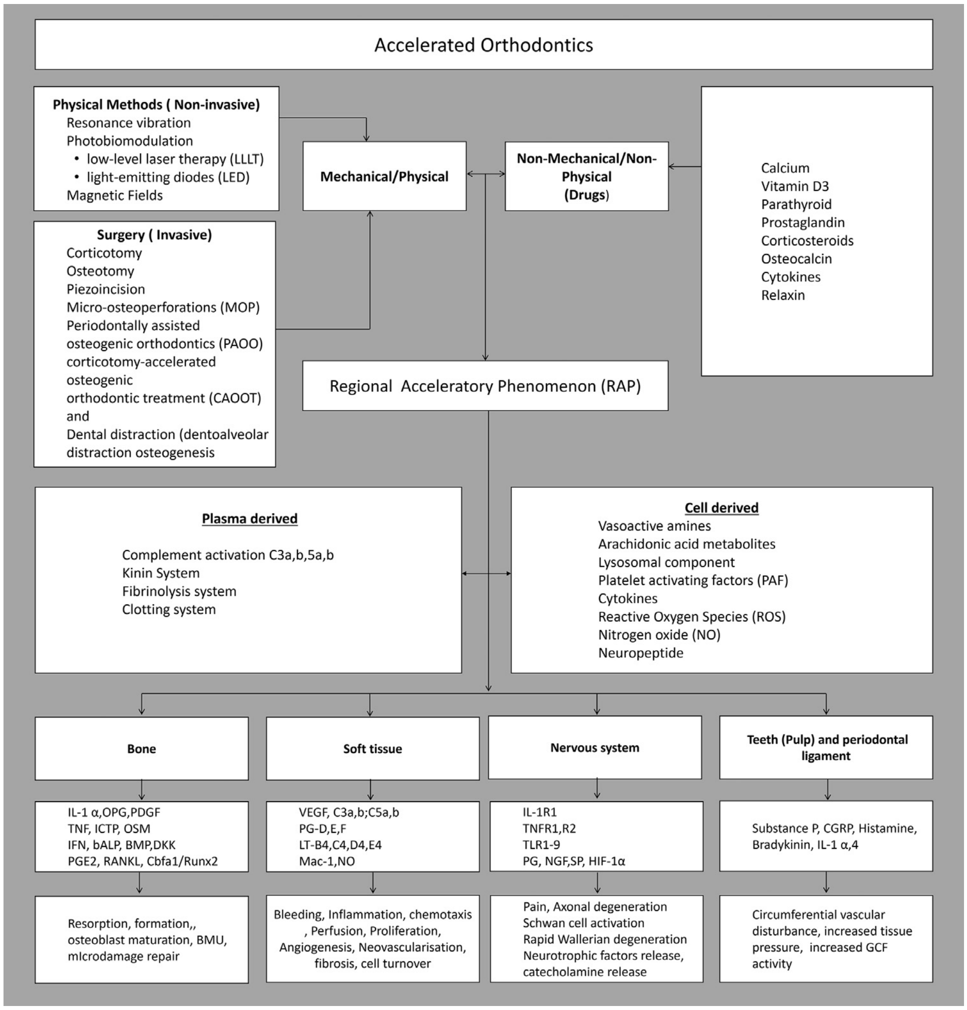

Fig. 1. Accelerated orthodontics − modalities of treatment. RAP is a ubiquitous phenomenon that not just solely occurs in the skeletal system, but also in the soft tissue, nervous system, dental and periodontal ligament too, which is mediated by various plasma and cell derived mediators. Several mediators have been identified that play a direct or indirect role in the local and systemic acceleration of healing process. IL, interleukin; OPG, Osteoprotegerin; PDGF, Platelet-derived growth factor; TNF, Tumor necrosis factor; ICTP, C-terminal telopeptide of type I collagen; OSM, Oncostatin M; INF, Interferon; bALP, bone alkaline phosphatase; BMP, Bone morphogenetic proteins; DKK, Dickkopf homologue; PG, prostaglandin; RANKL, Receptor activator of nuclear factor kappa-B ligand; RUNX, Runt-related transcription factor; Cbf, core binding factor; VEGF, Vascular endothelial growth factor; LT, leukotriene; Mac, Macrophage-1; NO, nitrogen oxide, IL, interleukin; TNF, Tumor necrosis factor; TLR, Toll-like receptors; NGF, Nerve growth factor; HIF, Hypoxia-inducible factor; SP, specificity protein; CGRP, Calcitonin Gene-Related Peptide. (Figure modified with permission from; Chng, C.K., Gandedkar, N.H. and Liou, E.J., 2019. Biological Principles and Responses to Surgery-First Orthognathic Approach. Surgery-First Orthodontic Management: A Clinical Guide to a New Treatment Approach, pp. 15−21.)

mitigating side effects. Despite its exciting potential, 1,25D is not a panacea. A comprehensive understanding of both its benefits and risks, including potential long-term effects on bone health and organ function, is crucial. The quest for a completely safe and effective agent for orthodontic acceleration demands further research.[11-13]

Prostaglandins

Prostaglandins (PGs), particularly PGE2, act as potent paracrine lipid mediators with complex roles in bone metabolism. Their ability to directly stimulate osteoclasts makes them intriguing candidates for accelerating tooth movement. Pioneering work by Yamasaki et al. demonstrated that local PGE2 administration significantly accelerated tooth movement in animal models. However, this benefit came at a cost: root resorption, a detrimental side effect, directly correlated with the PGE2 dosage and frequency. Interestingly, co-administration of calcium with PGE2 mitigated root resorption while maintaining the acceleration effect.

These findings paved the way for human trials, with split-mouth experiments showing a 1.6-fold faster rate of canine retraction using localized PGE2 injections. However, concerns regarding long-term systemic effects, including potential impacts on kidney function and overall bone health, warrant further investigation. The quest for a safer PGE2 delivery system continues, with research exploring controlled-release technologies and calcium co-administration to minimize side effects while maintaining efficacy.[14-16]

Relaxin

Relaxin has sparked curiosity for its potential to accelerate tooth movement due to its presence in the periodontal ligament (PDL). However, its impact remains a complex and enigmatic puzzle. Early preclinical studies suggested that human relaxin administration might accelerate tooth movement in rats. This effect was attributed to its ability to modulate collagen deposition within the PDL, potentially facilitating tooth movement. However, subsequent studies, including a randomized controlled trial in humans, failed to demonstrate a

Table 2
Surgical intervention to accelerate orthodontic tooth movement.

Modality	Definition	Invasive/Non-invasive	Application Method	Claimed Advantages	Potential Disadvantages	Indications	Contraindications	Potential Risks	Current Level of Evidence
Micro-osteoperforations (MOPs)	Creation of micro-holes in alveolar bone to stimulate localized bone remodeling and accelerate tooth movement.	Minimally invasive	Drilling micro-holes with specialized burs under local anesthesia.	Increased blood flow, bone turnover, faster tooth movement	Pain, potential nerve damage, infection, limited long-term data.	Mild to moderate crowding, anchorage issues, complex cases with careful planning.	Active infection, severe bone loss, thin gingiva.	Infection, nerve damage, bone resorption.	Limited (primarily pre-clinical studies, promising pilot clinical trials).
Periodontal Accelerated Orthodontic Tooth Movement (PAOO)	Disruption of the periodontal ligament with piezoelectric scalers or lasers to stimulate localized bone remodeling and accelerate tooth movement.	Minimally invasive	Piezoelectric scaler or laser treatment of periodontal ligament under local anesthesia.	Increased bone remodeling, faster tooth movement, potentially less appliance wear.	Potential gingival recession, root damage, periodontal complications, technique sensitivity.	Severe crowding, anchorage issues, complex cases with careful planning.	Active periodontal disease, thin gingiva, compromised immune system.	Gingival recession, root damage, periodontal complications.	Moderate (positive clinical evidence, long-term effects and optimal protocols need further research).
Corticotomy	Creation of cuts in the alveolar bone cortex to facilitate faster tooth movement.	Minimally Invasive (compared to Osteotomy	Surgical micro-saw or piezoelectric device under local anesthesia.	Significant reduction in treatment time, Increased tooth movement predictability, Effective for complex cases, impacted teeth	Pain, swelling, potential for infection, Risk of nerve damage, bleeding, and bone resorption, Requires specialized training and technical expertise	Severe crowding, anchorage issues, Impacted teeth • Complex malocclusions with limited bone flexibility	• Active infection • Medical conditions affecting bone healing • Thin gingiva, smoking	Infection, nerve damage, bleeding, bone resorption	Moderate – established technique with good clinical evidence, but potential complications require careful patient selection and technique.
Osteotomy	Surgical creation of complete cuts through the alveolar bone to achieve rapid tooth movement and repositioning.	Invasive	Surgical saw or chisel under local or general anesthesia.	Most significant reduction in treatment time, Effective for major jaw discrepancies and complex malocclusions, High degree of tooth movement control	Increased risk of complications compared to corticotomy, more extensive surgery and longer healing time, Requires advanced surgical skills and expertise	Severe skeletal discrepancies, Facial asymmetries, Cases requiring significant tooth repositioning	Active infection, Medical conditions affecting bone healing, Limited mouth opening, compromised immune system	Infection, nerve damage, bleeding, bone resorption, jaw joint complications	Moderate – established technique with good clinical evidence, but potential complications require careful patient selection and extensive training.
Piezocision	Bone disruption with ultrasonic vibrations to stimulate localized bone remodeling and accelerate tooth movement.	Minimally invasive	Application of ultrasonic device to alveolar bone under local anesthesia.	Increased bone remodeling, faster tooth movement, less appliance wear compared to PAOO.	Pain, potential root damage, technique sensitivity, limited long-term data.	Moderate crowding, anchorage issues, complex cases with careful planning.	Active periodontal disease, thin gingiva, compromised immune system.	Root damage, periodontal complications.	Moderate (growing body of clinical evidence, long-term outcomes and optimal protocols need further research).
Dental Distraction	Gradual separation of two bone segments with a distraction device and subsequent bone regeneration in the gap.	Minimally Invasive (requires implant placement)	Placement of distraction device and activation with external key under local anesthesia.	Precise, controlled tooth movement. Less pain and faster healing compared to osteotomies. Effective for anterior open bites and crossbites	Requires specialized equipment and longer treatment time compared to corticotomies. Higher cost due to device and additional appointments. Potential for device complications and gingival recession	Anterior open bites and crossbites. Distalization of molars. Correction of midline diastema	Active infection. Compromised immune system. Thin gingiva, smoking	Pain, device complications, gingival recession, infection	Moderate – growing body of clinical evidence, but long-term outcomes and optimal protocols require further research.

Table 3
The table explains the low-level laser therapy (LLLT), Pulsed electromagnetic fields (PEMF), and mechanical vibration's mechanism of action, application method, potential benefits, and current level evidence.

Feature	Low-Level Laser Therapy (LLLT)	Pulsed electromagnetic fields (PEMF)	Mechanical Vibration
Mechanism of action	Photochemical and photobiological effects	Interaction with charged particles	Micro-osteoperforations and mechanosensitive pathways
Application method	Non-invasive laser irradiation	Non-invasive application of magnetic fields	Direct application of vibrations
Potential benefits	Increased cellular activity, improved blood flow, reduced inflammation	Increased osteoblast activity, reduced osteoclast activity, enhanced blood flow, pain relief	Micro-osteoperforations, osteoblast activation, accelerated bone turnover
Current evidence	Promising results with some inconsistencies	Initial promising results, requiring further research	Early promising results, requiring long-term studies

significant effect on tooth movement. Furthermore, concerns have emerged regarding potential drawbacks. Relaxin might negatively impact the PDL, reducing its organization and mechanical strength, and potentially increasing tooth mobility. These findings raise questions about long-term consequences and potential relapse after treatment. The underlying mechanism of relaxin's influence on tooth movement remains elusive. Unraveling this puzzle and determining the true potential and safety of relaxin for orthodontic applications requires further rigorous research, including larger, well-designed clinical trials and investigations into its potential for mitigating side effects.[17-19]

Parathyroid hormone (PTH)

Parathyroid hormone (PTH), a cornerstone of calcium homeostasis and bone remodeling, has ignited a spark of intrigue in the realm of orthodontic tooth movement (OTM). Its ability to directly orchestrate osteoclast activity, the bone-resorbing cells vital for tooth movement, presents a tantalizing avenue for expedited treatment timelines. Preclinical studies, led by Soma et al.,[20] paint a promising picture. Continuous PTH infusion in rats, delivered via dorsocervical implantation, yielded a remarkable 2−3-fold increase in molar movement compared to controls. This remarkable acceleration can be attributed to PTH's potent ability to induce localized bone resorption, as corroborated by other studies. However, wielding PTH's power requires a delicate balancing act. While daily injections demonstrate efficacy, their cumbersome nature and potential for systemic and local adverse effects raise concerns. Researchers are actively exploring controlled-release systems, such as PTH-enriched gel matrices, achieving a 1.6-fold faster movement rate compared to conventional saline injections. Despite these promising initial steps, several uncertainties linger. The long-term systemic effects of PTH, particularly on bone density and kidney function, necessitate thorough investigation. Additionally, the optimal dosage and delivery method for safe and effective clinical application remain elusive. To date, only a handful of animal studies have ventured into the realm of PTH for OTM, highlighting the critical need for larger, well-designed clinical trials. Furthermore, exploring PTH in synergy with other agents, such as calcium supplements or bisphosphonates, to mitigate potential bone loss holds significant promise for future research.[11,20,21]

Biological responses to accelerated orthodontics: tissue, cellular and molecular responses

The AO invasive methods rely on deliberately injuring the bone to activate the "regional acceleratory phenomenon" (RAP), a localized series of healing events occurring after bone injury. RAP involves increased bone turnover and remodeling, accompanied by decreased local bone density (osteopenia) due to heightened osteoclastic activity. In orthodontic tooth movement (OTM), early recruitment of macrophages during RAP is also thought to shorten the hyalinization period by facilitating the removal of hyalinized tissue, ultimately leading to faster tooth movement.

Harold M. Frost's pioneering work on RAP and basic multicellular units (BMUs) has significantly contributed to our understanding of bone biology, providing a framework for studying the complex processes involved in bone growth, repair, and remodeling.[22-25] The regional acceleratory phenomenon (RAP) is a concept proposed by Frost to describe a tissue reaction to various noxious stimuli, with a specific focus on the accelerated remodeling process in both hard and soft tissues at a fracture site. According to Frost, this accelerated remodeling facilitates the transformation of impaired bone structure to a new state within a relatively short period. Frost introduced the idea of BMUs to better define the remodeling process at perturbed sites. BMUs are groups of cells that respond to biochemical and biomechanical stimuli, undergoing distinct phases in a cyclical manner. These phases include the activation phase, resorption phase, resting (or reversal) phase, and formation phase. These phases represent successive events involved in the induction of bone healing, contributing to the acceleration of regional reparative reactions, formation of granulation tissue, and eventual reconstruction of the perturbed structure to restore its original biomechanical strength. Researchers following Frost's work have delved into evaluating bone biology through the lens of RAP. The study of growth, repair, and remodeling processes has led to the establishment of a 'new paradigm' for bone biology, offering insights into the rate of remodeling in the region of a bone defect and how ordinary tissue activity can potentiate tissue healing in response to various local tissue defense reactions. RAP can be triggered by different noxious stimuli, and once initiated, the BMU sets off a biologically coupled, directly proportional, cyclical sequence of events known as the 'ARF sequence'—comprising activation, resorption, and formation. This sequence plays a crucial role in bone healing under the influence of specific stimuli.[26,27]

Tissue, cellular and molecular responses are further explained in each section as deemed essential.

What are the clinical implications and current level of evidence of accelerated orthodontics?

The clinical implications and current level of evidence of accelerated orthodontics is discussed in following subsections. Also, table shows important systematic review and meta-analysis on accelerated orthodontics (Table 4).

- Potential Effects of Accelerated OTM on Root Resorption
- Energy transfer to periodontal tissues
- Effect on pain reduction
- Effect on orthodontic tooth movement

Potential Effects of Accelerated OTM on Root Resorption

While accelerated OTM techniques aim to reduce treatment time, it is crucial to ensure they do not exacerbate root resorption. Current evidence suggests that LLLT, when applied judiciously, may not significantly increase root resorption compared to conventional orthodontic forces. However, further research is needed to assess the long-term impact of other acceleration methods on root integrity. The increased forces employed in accelerated OTM techniques have raised concerns about potentially exacerbating root resorption. However, the research findings on this topic remain diverse and often inconclusive. This section examines the impact of accelerated OTM techniques on the extent and

Table 4
Table showing important systematic review and meta-analysis on accelerated orthodontics.

Accelerated orthodontics	Authors	Year	Study Type	Purpose of study	Conclusion
Physical Methods (Non-invasive) • Resonance vibration • Photobiomodulation ◦ low-level laser ◦ therapy (LLLT) ◦ light-emitting ◦ diodes (LED) • Magnetic Fields	Ge, M. K., et al.[65]	2015	SR* & MA†	Efficacy of low-level laser therapy for accelerating tooth movement during orthodontic treatment	LLLT might speed up the tooth movement in orthodontic treatment
	Sousa, Marinês Vieira S., et al.[66]	2014	SR & MA	Evaluate the influence of low-level laser (LLL) on orthodontic movement and pain control in humans, and what dose ranges are effective for pain control and increased speed of orthodontic movement	further studies are warranted to determine the best protocols with regard to energy and frequency.
	Carvalho-Lobato, Patricia, et al.[67]	2014	SR & MA	Tooth movement in orthodontic treatment with low-level laser therapy	Studies that do not demonstrate any benefit according to their values.
	Imani, M.M., et al.[68]	2018	SR & MA	Effect of low-level laser therapy on orthodontic movement of human canine	LLT can speed up the rate of tooth movement of human canine
	A.Aljabaa., et al.[69]	2018	SR	Effects of vibrational devices on orthodontic tooth movement	No advantage from the use of vibrational devices during orthodontic treatment
	C. Lyu et al.,[70]	2019	SR	Effectiveness of supplemental vibrational force (SVF) on enhancing orthodontic treatment	Insufficient evidence to support the claim that SVFs have positive clinical advantages
	M. A. Abd Elmotaleb et al.,[71]	2019	SR &MA	Evaluate the efficiency of the vibrating devices in accelerating orthodontic tooth movement.	No significant difference between vibrating devices group and control group
	D. Jing et al.,[50]	2017	SR	Effectiveness of vibrational stimulus to accelerate orthodontic tooth movement	Evidence indicates that vibrational stimulus is effective for accelerating canine retraction but not for alignment
	M. F. García Vega., et al[72]	2021	SR	Mechanical vibrations an effective alternative to accelerate orthodontic tooth movement in humans	No evidence that vibratory stimuli can increase the rate of dental movement
	A. Akbari et al.,[73]	2022	SR & MA	Vibrational force on accelerating orthodontic tooth movement	The results are inconsistent in clinical studies
	M. Cronshaw ET AL.,[74]	2019	SR	Treatment management with photobiomodulation therapy	Insufficient studies at present to make an evidence-based determination
	Olmedo-Hernández, O. L., et al[75]	2022	SR & MA	Effect of the photobiomodulation for acceleration of the orthodontic tooth movement	No evidence to support the use of LLL and LED to accelerate the orthodontic movement
	Alam, M. K.,[76]	2023	SR & MA	Effects of static magnetic fields (SMF) on orthodontic tooth movement	Limited evidence to suggest that there is any effect of SMF on orthodontic tooth movement.
Surgical procedures • Corticotomy • Osteotomy • Piezoincision • Micro-osteoperforations	Mheissen, Samer, et al.[77]	2021	SR & MA	Effectiveness of surgical adjunctive procedures (SAPs) in accelerating orthodontic tooth movement (OTM)	Acceleration is minor and transient
	R. Gasparro., et al.[78]	2022	SR & MA	Effectiveness of surgical procedures in the acceleration of orthodontic toothmovement	Surgical procedures in accelerated orthodontic is extremely variable
	J. Yi., et al.[79]	2017	SR	Efficacy of piezocision on accelerating orthodontic tooth movement	Weak evidence supports that piezocision is a safe adjunct
	Viwattanatipa, N and Charnchairerk, S[80]	2018	SR	Evaluate effectiveness of corticotomy and piezocision on canine retraction	Corticotomy and piezocision increased the rate of orthodontic canine retraction
	R.-G. Houara., et al.[81]	2019	SR	Effects of piezocision in orthodontic tooth movement	No high-quality evidence to confirm that Piezocision results in significant OTM acceleration
	E. Afzal., et al.[82]	2021	SR & MA	Comparison between conventional and piezocision-assisted orthodontics in relieving anterior crowding	shortage of high-quality randomized controlled trials lack of standardization of piezocision protocol. Existing evidence suggests piezocision is effective accelerates OTM
	S. Mheissen., et al.[83]	2020	SR & MA	Effect of piezocision in accelerating orthodontic tooth movemen	effect appears to be clinically insignificant
	T. Fu., et al.[84]	2019	SR & MA	Effectiveness and safety of minimally invasive orthodontic tooth movement acceleration	No evidence to support single use of MOP could accelerate tooth movement

(*continued*)

Table 4 (*Continued*)

Accelerated orthodontics	Authors	Year	Study Type	Purpose of study	Conclusion
Non-Mechanical/Non-Physical (Drugs) • Calcium • Vitamin D3 • Parathyroid • Prostaglandin • Corticosteroids • Osteocalcin • Cytokines • Relaxin	Al-Attar, A., et al[85]	2021	SR & MA	Impact of the active form of vitamin D3, calcitriol (CTL), on the tooth movement caused by orthodontic forces (OTM	Scarce data and supported by a low level of evidence and lack of meaningful evidence of its impact on OTM in humans
	Bartzela, T., et al[86]	2009	SR	Medication effects on the rate of orthodontic tooth movement	well-designed clinical studies were scarce
	Khurshid, Z., & Asiri, F. Y.[87]	2021	SR	Influence of Intermittent Parathyroid Hormone (PTH) Administration on the Outcomes of Orthodontic Tooth Movement	long-term clinical studies are needed to ascertain the efficacy of intermittent PTH administration
	Eltimamy, A., et al[88]	2019	SR	Effect of Local Pharmacological Agents in Acceleration of Orthodontic Tooth Movement	Below moderate evidence showing no effect of Relaxin and Prostaglandinon orthodontic tooth movement

* SR, systematic review
ǂ MA, meta-analysis.

severity of root resorption. Here's a closer look at the potential effects of different acceleration techniques:

Low-Level Laser Therapy (LLLT): Some studies suggest that LLLT, when applied judiciously, may not significantly increase root resorption compared to conventional orthodontic forces. This may be attributed to the biostimulatory effects of LLLT, which could promote bone healing and regeneration alongside tooth movement.

Since LLLT promoted wound healing and improve cellular metabolism, differentiation and proliferation of progenitor cells, osteoblasts, and cementoblasts.[28,29]A two-arm-parallel split-mouth trial was conducted to investigate the effect of low-level laser therapy (LLLT) on the repair of orthodontically induced inflammatory root resorption (OIIRR). The maxillary first premolars were subjected to 150 g buccal tipping force for 4 weeks, followed by retention period of 6 weeks. LLLT was applied using a continuous beam 660 nm, 75 mW aluminum-gallium-indium-phosphorus laser. No difference in the amount of root resorption crater volume was detected at the end of this period.[30]

(LED)-mediated photobiomodulation (PBM)

The effects of (LED)-mediated photobiomodulation (PBM) on orthodontic root resorption and pain was investigated by Sambevski et al. [31]in a randomised clinical trial. Patients were provided with the OrthoPulse device (Biolux Research Ltd, Vancouver, British Columbia, Canada) and asked to use it for 5 min/day. This was a split mouth trial, therefore the control side of the device was blocked by tape. There was no statistically significant difference in the volume of root resorption between sides at the end of 4-week period. There was less pain 24 h after the application of orthodontic force, but no difference thereafter.[31]

Ng et al., double-blind, single-center, 3-arm parallel split-mouth randomized controlled trial investigated the effect of low-level laser therapy (LLLT) on orthodontic root resorption. The study also compared the difference between pulsed and continuous LLLT on OIIRR. Laser was applied on days 0, 1, 2, 3, 7, 14, and 21, using AlGaAs diode laser of 808 nm wavelength for 9 min. They showed LLLT resulted in 23 % less root resorption compared to the placebo.[32]

Pulsed Electromagnetic Fields (PEMF): Similar to LLLT, the evidence on the impact of PEMF on root resorption remains unclear. While some studies report no significant increase in resorption, others suggest potential risks. Further research is needed to determine the long-term effects of PEMF on root integrity.

Mechanical Vibration: The potential effects of mechanical vibration on root resorption are still under investigation. Initial studies have not reported significant increases in resorption, but more research is required to assess the long-term impact and establish safe protocols for application.

The effects of mechanical vibration on root resorption were tested in 2 split mouth trials, using the Acceledent (30 Hz) and Humminbird (50 Hz) devices. The Acceledent device produces vibration of 30 Hz and 20 gs. Acceledent device was cut in half to enable the control side teeth to not receive direct vibration. The subjects were then instructed to use the Acceledent 20 mins/day. Compliance was monitored using the inbuilt software of the device. The response was highly variable, however failed to show significant difference in the amount of root resorption. This was different when the Hummingbird device was used, which creates 50 Hz vibration and was applied every day for 10 mins. All but 2 subjects showed less overall resorption on the vibration side.[33]

Surgical Procedures: Surgical interventions like corticotomies and interseptal bone reduction, while accelerating OTM, carry a higher risk of root resorption due to the direct manipulation of the bone. A trial was conducted to test the effects of micro-osteo perforations (MOP) on root resorption. Using the Propel appliance (Propel Orthodontics, San Jose, Calif), MOP were applied at a depth of 5 mm and the contralateral side served as the control. Experimental side premolars showed greater root resorption than controls.[4] One of the most striking findings regarding accelerated tooth movement and root resorption was in the paper by Patterson et al., that showed that piezocision carries the risk of iatrogenic damage to the roots by the piezocision blade. Furthermore, even without the damaged areas, there was a significantly greater root resorption seen on the piezocision side when compared to control, with 44 % average increase. In 5 patients, there was noticeable piezocision-related iatrogenic root damage[34] Careful consideration of the potential benefits and risks is crucial before implementing these techniques.

Energy transfer to periodontal tissues

This section delves into the current understanding of the energy transfer mechanisms, focusing specifically on low-level laser therapy (LLLT), pulsed electromagnetic fields (PEMF), and mechanical vibration. By exploring their distinct advantages and limitations, we gain valuable insights into the future of orthodontic treatment, paving the way for faster, more patient-friendly experiences.

Low-level laser therapy (LLLT)

LLLT delivers low-energy photons (typically in the red and near-infrared spectrum) to targeted tissues. These photons interact with cellular components, primarily mitochondria, leading to various photochemical and photobiological effects.[35] These effects include:

- Increased cellular activity: LLLT can stimulate the activity of osteoblasts, the bone-forming cells, and osteoclasts, the bone-resorbing

cells. This enhanced activity can lead to faster bone remodeling and potentially accelerate OTM.
- Improved blood flow: LLLT can promote vasodilation, leading to increased blood flow to the treated area. This increased blood flow delivers essential nutrients and oxygen, facilitating the healing and repair processes necessary for OTM.
- Reduced inflammation: LLLT has anti-inflammatory properties that can help suppress the inflammatory response associated with orthodontic tooth movement. This reduced inflammation can potentially alleviate pain and discomfort during treatment.

Multiple studies have investigated the use of LLLT in accelerating OTM, with varying results. Some studies have reported significant reductions in treatment time, ranging from weeks to months, while others have found no significant effect. The inconsistent findings may be attributed to differences in laser parameters, treatment protocols, and study methodologies. Nonetheless, the potential of LLLT to enhance OTM warrants further investigation, particularly with standardized protocols and larger study populations.[36-41]

Pulsed electromagnetic fields (PEMF): PEMF therapy utilizes pulsed electromagnetic fields to stimulate cellular activity and promote tissue healing. These fields interact with charged particles within cells, inducing intracellular signaling pathways and potentially influencing various biological processes relevant to OTM. The proposed mechanisms of action of PEMF in OTM include:[42,43]

- Increased osteoblast activity: PEMF can stimulate the proliferation and differentiation of osteoblasts, leading to enhanced bone formation.
- Reduced osteoclast activity: PEMF may suppress the activity of osteoclasts, the bone-resorbing cells, potentially minimizing root resorption during OTM.
- Enhanced blood flow: PEMF can promote vasodilation and blood flow to the treated area, like LLLT.
- Pain relief: PEMF is thought to have analgesic effects through the stimulation of endorphin release, potentially reducing pain associated with orthodontic tooth movement.

Like LLLT, the effectiveness of PEMF in accelerating OTM remains under investigation. While some studies have reported positive results,[44-48] including faster tooth movement and reduced treatment times, others have shown no significant effect.[49] The inconsistency in findings highlights the need for further research with robust methodologies and standardized protocols.[50]

Mechanical vibration

Mechanical vibration is a relatively new concept in accelerated orthodontics. This technique involves applying low-frequency vibrations directly to the teeth or surrounding tissues. Proposed mechanisms of action include:

- Vibration, in combination with orthodontic pressure, amplified inflammatory signals and receptor activator of nuclear factor kappa-B ligand (RANKL) production in human periodontal ligament cells grown in a lab.[51]
- Osteoblast activation: Mechanical vibration can stimulate osteoblastic activity through mechanosensitive pathways, leading to increased bone formation.
- Accelerated bone turnover: Vibrations may promote faster bone turnover by stimulating both osteoblasts and osteoclasts, potentially leading to faster tooth movement.

Initial studies investigating mechanical vibration in OTM have yielded promising results. These studies have reported significant reductions in treatment time and enhanced tooth movement compared to conventional orthodontic forces. However, the research is still in its early stages, and larger, long-term studies are needed to confirm the efficacy and safety of this approach. Table 2 provides LLLT, PEMF, and mechanical vibration's distinct advantages and disadvantages in transferring energy to periodontal tissues and compares energy transfer methods.

Different modalities, such as low-level laser therapy (LLLT), pulsed electromagnetic fields (PEMF), and vibration, are investigated for their ability to deliver energy to periodontal tissues and potentially stimulate cellular activity and bone remodeling.

Low-level laser therapy (LLLT): LLLT delivers low-energy photons to tissues, promoting cellular processes like mitochondrial activity and protein synthesis. Evidence suggests that LLLT may slightly accelerate OTM, but the results are not statistically significant, and the clinical relevance remains unclear. We investigated the percentage loss of laser energy when transmitted through the periodontium to the extraction socket. A specifically designed photodiode ammeter was used to detect the percentage energy loss of an 808 nm diode laser through the periodontium in 27 tooth sockets. It was seen that for each millimeter of increased bone thickness, there was 6.81 % reduction in laser energy.[52]

Pulsed electromagnetic fields (PEMF): PEMF utilizes pulsed magnetic fields to stimulate tissue healing and bone regeneration. While some studies show promise for PEMF in accelerating OTM, the evidence remains limited, with further research needed to confirm its efficacy.

Vibration: Recent studies have explored the application of vibrational forces in OTM. Initial results suggest that vibration may enhance tooth movement, potentially by stimulating osteoblastic activity and bone remodeling. However, long-term studies and larger sample sizes are necessary to draw definitive conclusions.

Effect on pain reduction

Orthodontic treatment often causes discomfort and pain, impacting patient compliance. Studies investigating the effect of LLLT report a potential decrease in pain perception during orthodontic tooth movement. Similarly, PEMF therapy is proposed to alleviate pain by stimulating the release of endorphins. However, more robust evidence is required to confirm the pain-reducing effects of these interventions.

Effect on orthodontic tooth movement

Surgical procedures: Surgical interventions like corticotomies and interseptal bone reduction aim to create microfractures in the alveolar bone, potentially facilitating faster tooth movement. Studies report a tendency for OTM acceleration with corticotomies, but the quality of evidence remains low. Interseptal bone reduction also shows potential, but further research is needed to assess its long-term efficacy and safety.

To investigate the effects of MOPs on tooth movement a split-mouth, randomized controlled trial was undertaken by Li et al.[53] Patients requiring canine distalisation following maxillary premolar extractions were included in the study. Distalisation was applied with coil springs applying 150 g of force. On the experimental side, two 5 mm deep MOPs in vertical alignment on distal aspect of the maxillary canine mid-root region were performed prior to space closure. At the end of 12 weeks there was 0.69 mm more tooth movement on the experimental side, which is not clinically significant.

Another trial was conducted to test the effects of micro-osteo perforations (MOP) on root resorption. Using the Propel appliance (Propel Orthodontics, San Jose, Calif), MOP were applied at a depth of 5 mm and the contralateral side served as the control. Experimental side premolars showed greater root resorption than controls.[4]

Non-surgical interventions: LLLT, PEMF, and vibration are non-invasive approaches to accelerate OTM. While initial findings are promising, the evidence for their effectiveness remains inconclusive. Larger, well-designed trials are needed to determine the true impact of these methods on the rate of tooth movement and overall treatment duration.

There were a few studies that reported some increase in the rate of tooth movement with different LLLT protocols.[41] However, the frequency of visits required in those protocols, may not be feasible for neither the patient nor the orthodontist. Therefore, we aimed to investigate if a clinically more feasible application protocol helped improve the rate of tooth movement during canine retraction.[54] LLLT was applied to 8 points on the buccal and palatal sides of the canine root for 10 s per point, on days 0, 28, and 56. Control sides received sham laser. Our results showed similar amount of tooth movement for both sides.

Even though there were some positive reports on LLLT improving rate of tooth movement, for it to show if any effect, the patients need to attend the orthodontists' office too frequently. LED modulated PBM was introduced to overcome this short coming, as patients can apply it at home. We wanted to investigate, if using LED mediated PBM could provide outcomes like LLLT, as described by others. Split mouth randomised clinical trial protocol was used. After premolar extractions, leveling, and alignment, canines' retraction started with coil springs delivering 150 g of force to each side. Sides were randomised into experimental or control. The experimental side received 850 nm wavelength, 60 mW/cm^2 power, continuous LED with OrthoPulse device (Biolux Research Ltd, Vancouver, British Columbia, Canada) for 5 min/d. For the control side, the device was blocked with opaque black film. At the end of 12 weeks there were no significant differences in amount of canine movement, rotation, or anchorage loss.[55]

Balancing benefits and risks

While the potential for accelerated OTM techniques to improve treatment efficiency is undeniable, it is crucial to weigh the potential risks of increased root resorption. Here are some key considerations:

- Individual variability: The extent of root resorption varies significantly among individuals, influenced by factors like age, genetics, and bone quality. Therefore, a personalized approach is essential, carefully evaluating each patient's risk factors before implementing acceleration techniques.
- Treatment protocol optimization: Optimizing the application parameters and timing of acceleration techniques can potentially mitigate the risk of root resorption. For instance, judicious use of LLLT or PEMF, with intermittent application or lower energy levels, might be safer alternatives.
- Monitoring and risk assessment: Regular monitoring of root resorption throughout treatment is essential for identifying potential risks and adjusting treatment protocols as needed. This can involve radiographic examinations and specialized techniques like cone-beam computed tomography (CBCT).

While AO techniques offer promising opportunities for faster orthodontic treatment, their potential impact on root resorption requires careful consideration. Understanding the mechanisms of action of different AO techniques and their potential influence on bone remodeling processes is crucial for optimizing treatment protocols and minimizing risks. By implementing evidence-based approaches, utilizing appropriate monitoring techniques, and individualizing treatment plans, clinicians can harness the benefits of AO while ensuring long-term oral health and optimal treatment outcomes for their patients.

However, two ultimate questions still loom from the Orthodontists' perspective, and they are; (1) whether orthodontic acceleration modalities, invasive and non-invasive, bring about any clinically significant OTM in comparison to conventional modalities, and (2) what it means regarding cost-benefit analysis.

The answers to the above questions are:

Surgery (invasive) procedures

- Corticotomy, and osteotomy studies showed mixed results with some cases showing faster movement, while others showing no significant difference in comparison to traditional orthodontics. Regarding the benefit-to-cost ratio the cost incurred with additional surgical procedures must be considered, along with surgery-related risk and morbidity should be weighed-in.[56,57]
- Micro-osteoperforations (MOP) and piezoincision (including micro-interseptal bone reduction, corticision, lasercision) have no significant difference in the rate of tooth movement in comparison to conventional OTM. Although, MOP did not significantly increase the level of pain, anchorage loss, and periodontal complications, however there is an increased risk of root resorption.[6,58-60]

Physical (non-invasive) procedures

- Resonance vibration, photobiomodulation, low-level laser therapy (LLLT), light-emitting diodes (LED), and magnetic fields evidence is weak to very weak in producing accelerated orthodontic tooth movement.[57,61,62] Also, the apparent increase of no more than about 0.5 mm/month from LLLT (average range of normal orthodontic tooth movement being 0–1 mm per appointment) does not justify the use of special equipment which would cost significantly more than the conventional orthodontics.[61,63]

Non-mechanical/non-physical (drugs)

- New local delivery methods for both drugs and genes show promise in controlled settings (animal studies), but their real-world use remains unproven. Cautious optimism is warranted until concerns about efficacy, side effects, and routine application are addressed. Currently, none of the chemicals (calcium, vitamin D3, parathyroid, prostaglandin, corticosteroids, osteocalcin, cytokines, and relaxin) have shown to be clinically effective in a human model.[21,64]

Understanding the factors that contribute to longer treatment times can help anticipate potential challenges and adjust the treatment plan accordingly, rather than looking for treatment modalities that accelerate the orthodontic treatment. We have enumerated factors contributing to longer orthodontic treatment during different stage of orthodontic treatment that must be considered to potentially reduce prolonging treatment (Table 5).

Future of accelerated orthodontics and conclusion

Despite the growing interest in accelerated OTM techniques, the current level of evidence remains limited. While some promising interventions show potential, more high-quality research is crucial to confirm their efficacy and safety before widespread clinical application. Future studies should focus on larger sample sizes, longer follow-up periods, and standardized protocols to provide conclusive evidence for the effectiveness of accelerated OTM methods. Additionally, investigating the long-term effects on root resorption and potential side effects is crucial to ensure patient safety and optimal treatment outcomes.

- Investigating the long-term effects of different AO techniques on root morphology and function.
- Developing standardized protocols for applying AO techniques to minimize root resorption.
- Exploring the potential of combined approaches with other treatment modalities to optimize tooth movement while minimizing potential risks.
- Conducting research on individual susceptibility to root resorption to develop personalized treatment strategies.

By addressing these research gaps, the field of orthodontics can further refine and optimize AO techniques, ensuring faster and safer treatment outcomes for patients.

Table 5
Table showing stage of orthodontic treatment and factors contributing to longer orthodontic treatment times.

Stage of Orthodontic treatment	Contributing factors for longer
Diagnosis and Treatment Plan	Wrong diagnosis: An inaccurate diagnosis of the malocclusion • inappropriate treatment plan, potentially requiring adjustments and extending treatment duration. • Failure to consider all aspects of the malocclusion and individual patient factors during treatment planning can lead to unforeseen complications and delays.
Mechanics and Appliance	Wrong appliance selection and incorrect mechanics • Applying inappropriate orthodontic forces can hinder tooth movement, slowing down progress and prolonging treatment. • Inadequate, or poorly designed appliances that are not customized to the patient's individual needs or are not well-maintained can lead to inefficient tooth movement and delays. • Improperly placed brackets can misdirect forces, leading to unwanted tooth movements and the need for additional adjustments, prolonging treatment.
Appointment Intervals	Long intervals between appointments and infrequent appointments • Result in missed opportunities to refine and optimize tooth movement, potentially extending treatment duration. • Unpredictable cancellations or missed appointments can disrupt the treatment plan and necessitate additional adjustments, leading to delays.
Patient Cooperation	Poor compliance with instructions, failure to wear appliances as instructed. • Inadequate oral hygiene practices, and dietary indiscretions can all hinder tooth movement and delay treatment progress. • Unforeseen medical complications and medications that affect bone metabolism or healing can also prolong orthodontic treatment.
Breakages and Appliance Issues	Broken brackets or wires occurrences • Necessitate additional appointments for repairs and adjustments. • potentially adding days or weeks to treatment time.

In summary, potential to revolutionize OTM by accelerating tooth movement is undeniable. However, a cautious and evidence-based approach is paramount. Rigorous research into both the benefits and risks, coupled with the development of targeted and safe delivery systems, is essential before integrating invasive, non-invasive, and pharmacological agents into routine clinical practice. Only then can we unlock the true potential of AO techniques for faster, yet safe, orthodontic treatment, ultimately benefiting patients seeking a streamlined journey.

Patient consent

Patient consent was obtained.

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