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Lasers In Orthodontics – A Comprehensive Review

[1]Nanthini G , [2] Bhaskar V , [3]Mohamed Shamsudeen A I , [3]Pavithra P, [3]Ouma Maguesvary S
[1]Postgraduate, [2]Professsor, [3]Postgraduate
Department of Orthodontics And Dentofacial Orthopaedics
Government Dental College and Hospital, Cuddalore Dt, Chidambaram, Tamilnadu – 608002

***Corresponding Author:**
Dr. Bhaskar V
Professor, Department of Orthodontics And Dentofacial Orthopaedics
Government Dental College and Hospital, Cuddalore Dt, Chidambaram, Tamilnadu – 608002

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Abstract

Lasers have become valuable tools in modern orthodontics due to their precision, minimally invasive nature, and diverse clinical applications. They are used for three-dimensional imaging, enamel etching, bonding and debonding, adhesive removal, welding, soft-tissue procedures, and exposure of impacted teeth. Low-level laser therapy and photobiomodulation show potential for accelerating orthodontic tooth movement, reducing pain, enhancing bone remodeling, improving mini-implant stability, and promoting post-treatment stability. Emerging integration of artificial intelligence with laser-based imaging may further improve diagnosis, treatment planning, monitoring, and personalized orthodontic care. Despite their advantages, factors such as cost, thermal effects, technique sensitivity, and lack of standardized protocols remain limitations. Lasers therefore represent a promising adjunct to contemporary orthodontic practice, with further research required to establish standardized and evidence-based clinical protocols.

Keywords: Lasers, Orthodontics, Low-level laser therapy, Accelerated orthodontic tooth movement, Soft tissue lasers, Artificial intelligence

Introduction

Lasers (Light Amplification by Stimulated Emission of Radiation) was introduced by Theodore Maiman in 1960, is a major advancement in dentistry due to their precision and minimally invasive nature. LASER produces a coherent, monochromatic and highly directional beam for precise interaction with biological tissues. In dentistry and orthodontics, lasers are used for diagnosis, soft tissue procedures, bonding/debonding, enamel etching and acceleration of tooth movement. Despite limitations such as high cost and potential tissue damage, lasers enhance patient comfort, improve clinical outcomes and continue to expand their applications in modern practice(1).

Application In Orthodontics

Laser Scanning

Laser scanning (triangulation/time-of-flight) creates accurate 3D digital dental models while Confocal Laser Scanning Microscopy(CLSM) provides high-resolution, distortion-free images for detailed dental analysis(2).Laser scanners with CCD cameras and rotating platforms generate precise 3D models, GeoDigm, OrthoCAD and e-Plan enable analysis of tooth alignment, arch form, overjet/overbite, treatment planning, tooth movement simulation and orthognathic surgery(3). 3D facial laser scanning is a non-invasive, highly reproducible method (0.5–2 mm resolution) for evaluating facial soft tissue changes and treatment outcomes from multiple views(4). Holography (Dennis Gabor, 1947) and digital holography with CCD cameras produce 3D orthodontic records for analyzing incisor extrusion, centres of resistance/rotation, force systems, maxillary expansion and Class II mechanics, improving diagnosis and treatment planning(5).

Laser Etching

Laser etching creates 10–20 µm enamel microporosities by thermo-mechanical ablation improving resin penetration, acid resistance and patient comfort compared with conventional acid etching.Er:YAG provides the highest bond strength with minimal thermal damage combining Er:YAG/diode lasers with acid etching enhances bonding although acid etching remains the gold standard(6).

Laser Bonding

Laser bonding shortens chair time and improves comfort through rapid adhesive curing; diode and argon lasers effectively activate camphorquinone while maintaining adequate bond strength. Argon lasers enhance enamel resistance and reduce enamel fracture while riboflavin-mediated PDT and ceria nanoparticles improve bonding, antibacterial effects, and remineralization; Er,Cr:YSGG may show inconsistent adhesion(7).

Laser Debonding

Laser-assisted debonding removes brackets by thermal softening, thermal ablation and photoablation, reducing debonding force, enamel damage, bracket fracture and patient discomfort with controlled heat delivery. Diode and Er:YAG lasers are preferred for metal brackets whereas Er:YAG and super-pulse CO_2 lasers are most effective for ceramic brackets minimizing enamel cracks and pulpal temperature rise(8)(9).

Laser-Assisted Adhesive Removal

Er:YAG/CO_2 lasers selectively remove adhesive with minimal thermal effects, preserving enamel better than conventional methods although enamel may be slightly rougher; carbide burs are fastest and composite burs produce the smoothest surface. Er:YAG conditioning preserves bracket morphology and bond strength, improves mechanical properties and enhances porcelain surface conditioning and bracket–ceramic bonding, though improper settings may reduce bond strength(10)(11).

Laser Welding

Nd:YAG laser welding (1064 nm) enables precise metal joining with minimal heat-affected zones for appliance fabrication and intraoral repair but is limited by high cost, shallow penetration and operator skill requirements. Laser welding provides strength comparable to soldering with improved biocompatibility, preserves NiTi shape memory under optimal settings and laser specular reflectance helps assess wire roughness and friction for better wire select(12).

Accelerated Orthodontics

Low-level laser therapy (LLLT/PBM, 450–850 nm) is a non-thermal modality that accelerates tooth movement, reduces pain and enhances bone remodeling by increasing ATP, angiogenesis, IL-1β, RANKL and osteoblast/osteoclast activity(13)(14). Studies showed 34% faster canine retraction, improved mini-implant stability and 30–40% shorter aligner treatment with less pain and no root resorption although standardized protocols are still lacking(15).

Functional Treatment

LLLT (especially 650 nm diode lasers) stimulates condylar growth, chondroblast activity and mandibular development while remaining safe near the TMJ.
Clinical evidence is mixed: Amer et al. found no added skeletal benefit, Taher et al. reported modest improvements whereas Aghili et al. demonstrated significant mandibular growth and skeletal correction(16)(17).

Rapid Maxillary Expansion

LLLT (Ga-Al-As diode lasers, 660–940 nm) enhances osteoblast activity, collagen synthesis, bone regeneration and mid-palatal suture healing, potentially reducing relapse. Abreu et al. reported complete bone regeneration in 3 months, Lai et al. confirmed improved ossification whereas Abdelwassie et al. found no significant additional skeletal benefit(18)(19).

Laser-Assisted Corticotomy

Flapless Er:YAG/Er,Cr:YSGG laser corticotomy is a minimally invasive technique that significantly accelerates orthodontic tooth movement especially early canine retraction and incisor intrusion without compromising pulp or periodontal health. Salman &

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Ali and Shaadouh et al. confirmed safe short-term acceleration although evidence remains low–moderate and adjunctive LLLT offers no clear additional benefit(20)(21).

Mini-Implants

Er:YAG lasers improve mini-implant site preparation with precise, contact-free osteotomy and minimal thermal damage increasing implant stability and pull-out strength. LLLT enhances primary and secondary mini-implant stability by reducing mobility and peri-implant inflammation. Costa et al.'s meta-analysis confirming greatest benefits during the first 3 months after placement(22).

Orthodontically Induced Inflammatory Root Resorption

Photobiomodulation (PBM/LLLT) reduces inflammation, enhances ATP production and regulates bone remodeling showing moderate potential in preventing OIIRR caused by cementoblast damage and odontoclast activation. Yang et al. reported significant reduction with LEDs (≥850 nm, >10 J/cm²)(23) whereas Shahid et al. found no significant benefit with a 940 nm diode laser, highlighting the need for standardized protocols(24).

Lasers In Impacted Teeth

Diode lasers (808–980 nm) provide minimally invasive exposure of impacted teeth with less bleeding, pain, faster healing and immediate bracket bonding. Vitale, Ahmed and Borzabadi-Farahani reported favorable outcomes while Alashbal et al. demonstrated significantly less postoperative pain and bleeding particularly with dual-wavelength (810 + 980 nm) lasers(25)(26).

Retention

LLLT/PBM improves orthodontic retention by enhancing bone density, periodontal ligament maturation, BMP-2 expression and post-treatment stability thereby reducing relapse and retainer wear time. Abo Ayach, Othman, Swidi, An, and Zhao demonstrated reduced relapse and improved stability (especially with MSCs, green laser PBM, or fulvic acids + LLLT) although further clinical validation is required(27)(28).

Other Applications

Argon laser irradiation reduces enamel solubility by 30–50% and increases acid resistance up to fivefold; combined with fluoride significantly decreases lesion depth while allowing safe resin curing. Laser fluorescence (~488 nm) enables non-invasive detection of white spot lesions, argon laser whitening (450–500 nm) accelerates peroxide bleaching and photoactivated dye (PAD) disinfection with toluidine blue effectively destroys bacterial, fungal and viral cells without thermal damage(29).LLLT (GaAlAs diode lasers 500–1200 nm, commonly 30 mW) effectively reduces orthodontic pain by decreasing PGE_2 and IL-1β modulating nerve activity and providing prolonged analgesia without thermal injury. It also improves TMJ dysfunction, accelerates healing of traumatic ulcers, reduces dentinal hypersensitivity and enhances papillary fill and soft-tissue healing to minimize open gingival embrasures (black triangles)(30).

Soft Tissue Lasers

Diode lasers (800–980 nm) provide precise, minimally invasive soft tissue ablation with excellent hemostasis making them ideal for routine orthodontic soft tissue procedures. They are effective for gingival recontouring, frenectomy (810 nm diode/2940 nm Er:YAG), gingivectomy and operculum removal, improving esthetics, enabling immediate bonding of unerupted teeth, facilitating eruption, and reducing bleeding, pain, treatment delays and anesthesia requirements(31).

Synergy Between Ai And Lasers In Orthodontics

Diagnostic Enhancement through Laser Imaging and AI Analysis- AI analyzes laser-based imaging (OCT, laser scanners, CBCT and 3D scans) with 92% accuracy for cephalometric landmark identification, malocclusion detection and bone/soft tissue assessment, improving diagnosis and treatment planning(32)(33).

Predictive Analytics and Laser-Guided Treatment- AI predicts tooth movement and optimizes LLLT and laser-assisted soft tissue procedures by individualizing laser timing, dosage and wavelength, improving treatment efficiency while minimizing adverse effects.

Smart Monitoring: AI with Laser Sensors-AI combined with laser sensors and smartphone-linked intraoral scanners enables real-time monitoring of tooth alignment, bracket integrity and tissue healing,

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allowing early detection of complications and reducing clinical visits.

Enhanced Aligner Fabrication-AI processes laser-acquired 3D intraoral scans to fabricate highly accurate clear aligners, reducing fabrication errors, minimizing mid-course corrections and shortening treatment time by 20%.

Surgical Simulation and Laser Planning- AI-assisted CBCT and laser scan analysis supports virtual osteotomy planning while laser-guided surgery enables precise, minimally invasive bone cutting with improved healing and esthetic outcomes.

Post-Treatment Relapse Monitoring and Laser Interventions- AI analyzes serial laser scan data to detect early relapse and recommends retainer modifications or minor laser-guided corrections improving long-term orthodontic stability and reducing relapse risk.

Conclusion

Lasers have transformed orthodontics by improving diagnostic accuracy, soft tissue management, accelerated tooth movement and minimally invasive treatment while reducing pain, bleeding and swelling. Advances in laser technology continue to expand clinical applications but effective use requires knowledge of laser physics and safety and wider adoption depends on further research, standardization, and overcoming current technical and clinical limitations.

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