EFFECT OF LOW-LEVEL LASER THERAPY ON STABILITY DURING RETENTION PHASE AFTER ORHODONTIC TREATMENT: A RANDOMIZED CONTROLLED TRIAL

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by

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Three years have passed by like the wind. In a few months, I will finish my master's degree at USM School of Dental Science. Unwillingness and anticipation are intertwined in my heart, symbolizing the new journey that is about to begin. Through these three years of study in Kelantan, my own academics, abilities, and state of mind have improved greatly, and my progress could not have been achieved without the help of all my teachers, friends, and family. At the end of my three years of study, I would like to express my gratitude to my mentor, Dr. Norma, for all the hard work and teaching she has done for me. Three years have passed by in a hurry, you have led me to climb up the ladder in clinical work and scientific research, and it is difficult to express my feelings of gratitude. Your exquisite professional knowledge and profound academic attainments are the glittering lighthouse on my way to the sea of learning and will be the clear starlight on my long road of life. As I approach graduation, I can't help but think of Dr. Arif's guidance and patience in statistics during my three years of study, and I sincerely thank you for guiding me to dive deeper into data analysis. You were not only my mentor, but also a wise and warm friend. In the face of academics, you are rigorous, focused and meticulous; in the face of life, you have the wisdom of gold, which are the most valuable gains in my life. Finally, I would like to thank my parents and relatives for your silent support and encouragement, as well as your concern for me in every way. You are the warmest sunshine, and your love will warm me in every struggle of my life, accompanying me to ride the waves and surpass the past. This work was supported by a Universiti Sains Malaysia, Bridging with Project No: R501 - LR - RND003 - 0000000969 - 0000.

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LIST OF ABBREVIATIONS

AL	Arch length
CCD	Charged coupled device
CG	Control group
CW	Continuous wavelength
ICW	Intercanine width
IMW	Intermolar width
LG	Laser group
LII	Little's Irregularity Index
LLLT	Low-level-laser therapy
OB	Overbite
OJ	Overjet
OTM	Orthodontic tooth movement
PDL	Periodontal ligament
VFR	Vacuum formed retainer

LIST OF APPENDICES

KESAN TERAPI LASER PERINGKAT RENDAH TERHADAP KESTABILAN SEMASA FASA PENGEKALAN SELEPAS RAWATAN ORTODONTIK: PERCUBAAN TERKAWAL RAWAK

ABSTRAK

Laser tahap rendah, juga dikenali sebagai laser intensiti rendah biasanya menghasilkan kesan merangsang pada pembentukan semula tulang alveolar, mendorong peningkatan osteoblas dan osteoklas yang mengakibatkan peningkatan kejadian pergerakan gigi ortodontik (OTM). Matlamat kajian ini adalah untuk menyiasat kestabilan pada gigi maksila selepas penggunaan terapi laser tahap rendah (LLLT) semasa peringkat meratakan dan penjajaran gigi dengan pendakap gigi tetap. Dalam eksperimen ini, 20 peserta yang layak telah dipilih daripada sampel persampelan rawak eksperimen sebelumnya, dan Indeks Ketakteraturan Little (LII), lebar antara gigi geraham (IMW), lebar antara gigi kacip (ICW), panjang gerbang arkus (AL), overbite (OB), dan overjet (OJ) gigi maksila diukur mengikut nisbah kumpulan laser: kawalan = 1;1. Hasil pengukuran telah dianalisis dengan SPSS versi 26. Ujian Friedman dan ANOVA ukuran berulang digunakan untuk perbandingan statistik. Keputusan LII, ICW, OB, dan OJ adalah tidak signifikan ($P > 0.05$). Walau bagaimanapun, IMW ($P = 0.038$) dan AL ($P = 0.019$) adalah signifikan secara statistik. Walaupun kesan keseluruhan LII, ICW, OB dan OJ tidak ketara, nilai purata dalam kumpulan laser secara amnya lebih kecil berbanding kumpulan kawalan. LLLT tidak mempunyai kesan yang ketara terhadap LII, ICW, OB dan OJ. Disimpulkan bahawa LLLT hanya mempunyai kesan kestabilan ke atas IMW dan AL semasa tempoh pengekalan 12 bulan. Walau bagaimanapun, perbandingan di dalam kumpulan, LLLT mempunyai nilai purata yang lebih kecil yang menunjukkan kestabilan dari semasa ke

semasa untuk kumpulan laser yang jelas lebih baik daripada kumpulan kawalan untuk mengekalkan kestabilan.

EFFECT OF LOW-LEVEL LASER THERAPY ON STABILITY DURING RETENTION PHASE AFTER ORTHODONTIC TREATMENT: A RANDOMIZED CONTROLLED TRIAL

ABSTRACT

Low-level laser, also known as weak laser and low-intensity laser normally produce stimulating or positive effects on alveolar bone remodeling, inducing an increase osteoblasts and osteoclast resulting increased the incidence of orthodontic tooth movement (OTM) and inhibitory effects depending on the dose. The aim of this study is to investigate the stability in maxillary dentition after application of low-level laser therapy (LLLT) during leveling and alignment stage of fixed appliances. In this experiment, 20 eligible participants were selected from the random sampling samples of the previous experiments, and the Little's Irregularity Index (LII), intermolar width (IMW), intercanine width (ICW), arch length (AL), overbite(OB), and overjet(OJ) of the maxillary dentition were measured according to the ratio of the laser group: control group = 1;1. The results of the measurements were analyzed by SPSS version 26. Friedman's test and repeated-measures ANOVA were used for statistical comparison. The results of LII, ICW, OB, and OJ were not significant ($P > 0.05$). However, IMW ($P = 0.038$) and AL ($P = 0.019$) was statistically significant. Although the overall effects of LII, ICW, OB and OJ were not significant, the mean values in the laser group were generally smaller compared to control group. LLLT has no significant effects on LII, ICW, OB, and OJ. It was concluded that LLLT only had a subsequent effect on IMW and AL during 12 months of retention period. However, within group changes, LLLT has smaller mean values which indicate the stability over time in the laser group was clearly better than control group to prevent relapse.

CHAPTER 1

INTRODUCTION

1.1 Background to Research

During orthodontic treatment, effective retention and stability are key factors in preventing relapse. According to the literature, in animal experiments with rats, the average relapse rate on day 1 after removal of orthodontic appliances ranged from 62.6% to 73.1% (T. J. Franzen et al., 2014; Tanya J. Franzen et al., 2013) . In relevant human experiments, relapses were mainly within 1-2 years of the retention phase. (Edman Tynelius et al., 2013; Kuijpers-Jagtman, 2002) The reason for such a complex phenomenon as orthodontic relapse is often due to incomplete remodeling of the alveolar bone and periodontal ligament (PDL) (Krishnan et al., 2021a). The periapical tissues generally take several months to remodel, during which time the teeth tend to revert to their initial position.

Although the use of retainers has become an indispensable part of orthodontic retention, it is still plagued by long treatment cycles and limited results. To better address this tendency to relapse, many relevant studies have emerged in recent years.

Orthodontic tooth movement (OTM) is influenced by biomolecules, and the forces exerted on the teeth trigger changes in the blood flow and microenvironment of the PDL, leading to the secretion of inflammatory mediators in the PDL and inducing bony remodeling(Santonocito et al., 2022). Therefore, alteration of the PDL microenvironment by local and systemic administration of drugs, such as simvastatin (Han et al., 2010), bone morphogenetic proteins (Hassan et al., 2010), bisphosphonates

(T.-W. Kim et al., 1999), relaxin (Hirate et al., 2012) and osteoprotegerin (Hudson et al., 2012; Zhao et al., 2012), aims to shorten the retention time and reduce relapse.

Low-level laser therapy (LLLT) is a physical therapy with positive effects on alveolar bone remodeling, inducing an increase in the number of fibroblasts (Matthias Kreisler et al., 2003), preosteoblasts (Angela Dominguez et al., 2012), osteoblasts (Delma R. Cruz et al., 2004) and osteoclasts (A. R. Coombe et al., 2001). In a literature review of the effects of LLLT on OTM in animal and human studies, Torri and Weber (Torri & Weber, 2013) found that most authors reported that LLLT increased the incidence of OTM. However, Kim et al. (S.-J. Kim et al., 2013a) concluded in animal studies that LLLT contributed to retention only if a retainer was placed during radiotherapy, otherwise it accelerated relapse rates.

1.2 Problem statement & Study rationale

The biggest problem in the orthodontic process is the pain and the long duration of treatment, which is also generally divided into 2 phases, namely the orthodontic tooth movement (OTM) and the retention phase (Krishnan et al., 2021a). In recent decades, low-level-laser therapy has gained attention because it is non-invasive, inexpensive, relieves pain and has no significant adverse effects. Low-level-laser therapy (LLLT) has been proved to effectively induce and accelerate the remodeling process of alveolar bone by increasing the number of osteoblasts and osteoclasts. Therefore, LLLT is widely used in OTM to accelerate tooth displacement, but there are few studies and limited evidence on the stability whether it can strengthen and shorten the retention stage to avoid relapse. Thus, the purpose of this study is to investigate the stability after orthodontic treatment by observing the substantial influence of low-level-laser as during retention phase.

1.3 The Rationale for Focusing on the Maxillary Dentition

The focus of this study is on the maxillary dentition because of the differences between the maxillary and mandibular dentition in terms of visibility and relapse patterns in terms of anatomy, physiological function and force characteristics (Kawamura et al., 2021).

In terms of visibility, the unique position of the maxillary dentition provides a natural advantage over the mandibular dentition (Orejas-Perez et al., 2022): when the patient opens his or her mouth, the maxillary teeth are naturally exposed externally, allowing the dentist to directly observe the state of the teeth and surrounding tissues, which allows for the accuracy of impressions and scans. The interference of the tongue and mandibular soft tissue ties also increases the difficulty and error of manipulating the lower jaw.

The stability of maxillary dentition after orthodontic treatment is influenced by several factors and it plays an important role in facial aesthetics and occlusal function. According to other research (Klaus et al., 2020), the pattern of tooth movement and relapse in the maxillary dentition is different from that of the mandibular dentition, and the stability of the maxillary dentition is more susceptible to interference by a variety of factors during the retention phase after orthodontic treatment, and unwanted tooth movements occurred more frequently with maxillary retainers than with mandibular retainers (20.9%).

Therefore, according to this characteristic of the maxillary dentition, good and poor stability can be presented more clearly, changes can be detected and observed more easily, and the effect of the study of stability after orthodontic treatment can be more highlighted.

1.4 Justification of the study

This trial exploring the role of LLLT on stability in the retention period of maxillary dentition after orthodontic treatment, the key significance of this study is demonstrated through the following elements：

Expanding the application of LLLT in orthodontics: It contributes to the growth of research on LLLT in orthodontics. By investigating its potential use and benefits, this study paves the way for future research to improve orthodontic retention.

Enhanced orthodontic treatment results: The use of LLLT during the retention period may lead to potentially better results. This can provide patients with long-lasting, stable treatment results by minimizing the risk of relapse.

Improved retention methods: The insights provided by this study could help orthodontists develop more effective retention strategies. Integrating LLLT into post-treatment management programs may reduce the reliance on long-term use of retention appliances and even thereby reduce overall treatment costs.

Furthering scientific knowledge: Being a randomized controlled trial, the results of this study strengthen the evidence base for the use of LLLT in orthodontics. By providing valuable insights into treatment efficacy, this investigation will inform and support future research work on the topic.

1.5 Research questions

This study explores whether there are subsequent effects during maxillary dentition retention based on previous laser applications during orthodontic process, which are demonstrated through 3 aspects:

1.Is there any difference in the Incisor Irregularities Index between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT?

2.Is there any difference in the interarch dimension: intercanine width, intermolar width, arch length between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT?

3.Is there any difference in the overjet and overbite between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT?

1.6 Research hypotheses

1.There is a significant difference in the Incisor Irregularities Index between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT.

2.There is a significant difference in the interarch dimension: intercanine width, intermolar width, arch length between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT.

3.There is a significant difference in the overjet and overbite between laser and control group at debond (0), 6 and 12 months of retention due to previous application of LLLT.

1.7 Objective

1.7.1 General:

The goal of this study is to investigate the stability in maxillary dentition during retention phase after application of LLLT during levelling and alignment stage with fixed appliances.

1.7.2 Specific:

1.To compare the Incisor Irregularities Index between laser and control group at debond (0), 6 and 12 months of retention after application of LLLT during levelling and alignment stage of fixed appliances.

2.To compare the interarch dimension: intercanine width, intermolar width, arch length between laser and control group at debond (0), 6 and 12 months of retention after application of LLLT during levelling and alignment stage of fixed appliances.

3.To compare the overjet and overbite between laser and control group after at debond (0), 6 and 12 months of retention after application of LLLT during levelling and alignment stage of fixed appliances.

CHAPTER 2

LITERATURE REVIEW

2.1 Low-level laser and its characteristics

In contemporary orthodontic treatment, orthodontists are striving to provide a painless environment and to reduce the treatment time for patients. Low-level lasers, also known as weak lasers and low-intensity lasers, are less likely to cause damage to biological tissues and produce stimulating or inhibitory effects depending on the dose. Early researchers have used low-level lasers on the body surface to inhibit bacterial growth, promote inflammation, reduce pain, accelerate tissue healing, promote blood circulation, and enhance the body's immune function (Jian-hua, 2003). Low-level laser systems mainly consist of laser emitters, laser delivery systems, and laser controllers. Nowadays, the laser instruments we mostly see in clinical practice are semiconductor lasers, and the wavelength range of this semiconductor laser can be varied, and the output intensity is usually between 10 and 50 mw, but the laser consumes a lot during its action on the tissue. Since semiconductor lasers are mostly powered by batteries, there will inevitably be times when the power is insufficient, which affects the actual output power of the laser (Mansouri et al., 2020). Therefore, current study usually need to use a power meter to determine the actual power before use. The output of the diode laser is basically controlled by electricity, and the manual can only control the irradiation time, or in the case of a controller can adjust the laser power and emission frequency and other factors. During use, the operator must wear protective eyewear because the laser can have an adverse effect on strength. Different wavelengths of laser light on soft and hard tissue penetration are different, the absorption rate is not the same, the process of penetrating the tissue in the consumption of great, even the irradiation of the laser emitting end of the distance from the tissue also greatly affects the actual power of the laser (Maheswari & Sathiyamoorthy, 2016).

The biological stimulation of low-level laser is manifested in several ways: firstly, the dose of laser has two opposite effects on the body, when the laser is not too intense it produces a stimulation of the body, on the contrary, when the laser is too intense it may cause inhibition of some functions of the body. Secondly, the laser will accumulate energy when it acts on the tissue, for example, 10 exposures to 1 joule of laser light will have the same biological effect as one exposure to 10 joules of laser light. In addition, the biological stimulation of the body is parabolic with increasing dose, and when the dose reaches its maximum, the positive effect of laser light on the body will slowly decrease until it becomes a negative effect (Cios et al., 2021).

Low-level laser parameters also have a significant impact on the biostimulation effect. The wavelength, exposure time, energy density, and pulse frequency of low-level lasers can all have an effect on the biostimulatory effect. This actually adds many difficulties to the study of low-level laser therapy and requires extensive experiments to determine an optimal range of treatment parameters for all of them (Migliario et al., 2018).

Usually, people are familiar with the laser is the use of its thermal effect, can be cutting, destruction, etc. This type of laser is often relatively high energy, but when we control the laser energy in a smaller range, the characteristics and effects produced by the laser is not familiar to most people. The low energy laser acts directly in the body tissues without producing unnecessary tissue damage, but it can have a better biological effect on the body and improve the physiological functions of the body, such as blood function, nerve impulse transmission, immunity, metabolism, enzyme activity and other functions, and by improving these functions, the purpose of treating the disease can be achieved. In general, the biological effects of low-level lasers are broadly photothermal, photochemical, and photobiostimulatory (Xavier et al., 2023). Many scholars have studied the mechanism of biological effects of low-level laser, represented by Inyushin's bioelectric field model and Mseter's conception of polarization stimulation, in addition to the absorption theory of the photosystem and the concept of biological electromagnetic field absorption (Freitas & Hamblin, 2016).

Many scholars have used theoretical analysis to investigate the biological effect of low-level-laser upon bodily tissues, and Xu Lin applied quantum mechanics theory to investigate the microscopic mechanism of the effect of low-level-laser irradiation on blood properties, and the results showed that laser can dissolve fibrin clots and low-level laser can also promote the dissolution of cholesterol in blood, thus improving blood rheological properties (Arjmand et al., 2021). Theoretically, different tissues in living organisms have different components and different physical properties, and the interaction between laser and biological tissues is different due to the different penetration and absorption rates of different types of lasers to the body tissues, and when laser irradiates the body tissues, the body tissues will absorb some laser energy and the temperature of biological tissues will rise, and different types of lasers can only produce certain biomolecular biologic effects (Jacques & Patterson, 2021).

2.2 Factors affecting the outcomes of orthodontic treatment

2.2.1 Factors affecting tooth movement, stability and retention

Individual factors: The movement of teeth during orthodontic treatment for adults will be slower than that of growing children, because adults have higher bone density and growing children have more active physiological metabolism, which will affect the movement speed and retention time of teeth (Bagga, 2010). In addition, hormonal factors in women may result in different rates of tooth movement and retention times depending on gender (Haruyama et al., 2002). Pre-lab x-rays are performed to avoid abnormalities in the periodontal tissues or problems with the teeth themselves that may affect tooth movement, such as root and bone adhesions that can prevent tooth movement and post-orthodontic stability. The teeth between the upper and lower jaws also have a different impact on the teeth due to issues such as bone density and blood flow.

External factors, such as the amount of orthodontic force, the way the teeth are moved, the cooperation between the patient and the doctor, the method used to move the teeth, etc., all have an impact on the movement and retention phase of the teeth. Teeth move fastest and take less time to set when the orthodontic force is optimal, while too much or too little force can slow down tooth movement and increase the chances of relapse (Ren et al., 2004). When the teeth move, the forces are evenly distributed, and the teeth move quickly and with less damage to the teeth and periodontal tissue. The patient's regular follow-up appointments and cooperation with the doctor's orders also have a significant impact on the outcome of treatment.

2.2.2 Types of retainers

2.2.2(a) Vacuum form retainer (VFR):

VFR is made of colorless and transparent polyethylene phthalate film which is pressed and molded on a vacuum film press. It wraps around the entire dentition in three directions from the labial, buccal and lingual (alveolar) surfaces of the teeth, fixing all the teeth through a splint-type structure, which effectively prevents the teeth from twisting and shifting (Krämer et al., 2020). VFRs are relatively inexpensive, aesthetically pleasing and comfortable, easier to maintain oral hygiene (as they can be freely removed and worn for cleaning) and are simple and easy to fabricate, even after quick removal of the appliance on the same day. It has therefore become the most used retainer by orthodontists at home and abroad. The disadvantage of VFR is that during the wearing of VFR, the occlusal surfaces of the upper and lower teeth have gaps caused by the thickness of the retainer itself, therefore, high angle cases, temporomandibular joint disorders, and patients with a tendency to open bite are not suitable for the use of VFR (Lyros et al., 2023). Clinical studies have shown that VFRs are more prone to wear and fracture than Hawley retainers (Vagdouti et al., 2019). Hawley retainers tend to break between the cuspid and premolar, whereas VFRs tend to break in the midline. Studies on retention effects have shown that VFR are superior to conventional Hawley retainers in retaining maxillary and mandibular anterior teeth (Moslemzadeh et al., 2018). The VFRS is superior to the Hawley retainer for both retention options in terms of maintaining arch length and upper arch alignment (Vagdouti et al., 2019). There was no difference between the 1 mm and 1.5 mm VFRS and Hawley retainers in maintaining and stabilizing orthodontic treatment 6 months after the end of orthodontic treatment (Moslemzadeh et al., 2018).

2.2.2(b) Hawley Retainer:

It consists of a double curved labial arch, a pair of molar rings and a plastic abutment. The labial side of the double curved labial arch and the palatal side of the plastic abutment confine the teeth to a fixed position to ensure retention. The molar retainer serves as a retainer on the one hand, and on the other hand, it utilizes the advantages of the retainer to keep the molar teeth in position to close the gap between the retainers. Wearing this retainer has direct contact between the upper and lower posterior teeth, which is favorable for the vertical adjustment of the posterior region and increases the occlusal contact area of the posterior teeth. Some studies have shown that it allows the teeth to move more vertically to the right than VFRs, which is favorable for the adjustment of the occlusal relationship of the teeth in the later stages (Al-Moghrabi et al., 2018; Sauget et al., 1997). The Hawley retainer is far superior to VFRs in terms of retention for patients with deep overlapping and mouth breathing, but it is larger in size, has a strong foreign body sensation, and the palatal abutment affects the patient's articulation, while the labial wire in the anterior region affects the aesthetics of the anterior region, which may reduce the patient's adherence. Overseas studies have shown that there is no significant difference between the Hawley retainer and other removable retainers in terms of maxillary and mandibular arch measurements, arch relationships and occlusal contacts, phonological assessment, patient retention results, adverse reactions and economic aspects (Al Rahma et al., 2018).

2.2.2(c) Lingual Fixed Retainer:

It is made of resin and stainless-steel wire bonded to the lingual side of the upper and lower anterior teeth in the middle 1/3. Lingual fixed retainer can effectively prevent the relapse of the lower anterior teeth after crowding correction, and is good for occlusion and aesthetics. However, the way the teeth are bound together by the wire and resin can limit the physiological movement of the teeth, which is not conducive to periodontal health (Krämer et al., 2020; Storey et al., 2018).The study showed no significant difference in periodontal health between lingual fixed retainers and VFRs, with fixed retainers providing better compliance and maintenance of lower anterior stability (Al-Moghrabi et al., 2018). This retainer does not need to be fitted, but still has the potential to fall out. Lingual Fixed Retainers and Hawley Retainers have the longest history, followed by Combination Retainers and Vacuum Formed Retainers (Jin et al., 2018). There is no significant difference in the efficacy of the different fixed retention systems, and the most common protocol is to combine a vacuum-formed retainer or

Hawley retainer in the upper jaw with a mandibular fixed retainer (Andriekute et al., 2017).

2.2.3 Duration of orthodontic retainer wear

The tendency to relapse after orthodontic treatment may always exist, so it is generally required to keep the retainer for at least two years after treatment is completed. Usually, retainers are worn all day in the first year and adjusted as appropriate in the second year, and for some special malocclusions, retainers are required to be worn for life (Stephens, 2015). According to the different needs of different types of orthodontic treatment, the retention program is divided into three categories: (1) limited-term retention; (2) permanent or semi-permanent retention; (3) no retention (Martin et al., 2023b). Of course, it is more beneficial to keep them for as long as possible. The above classification is based on the degree of crowding of the dentition. Although the degree of crowding of the samples in this experiment was not severe and belonged to Category 1 as mentioned above: limited - term retention, to ensure the best treatment effect, the researchers arranged for the experimental volunteers to wear the retainer 24 hours a day during the experiment.

2.3 Methods for accelerating orthodontic tooth movement

Currently, we have three main methods to speed up orthodontic tooth movement: physical methods, pharmaceutical methods, and surgical methods.

There are two main physical methods. One is the pulsed electromagnetic field method, and Zengo et al. (Zengo et al., 1973) studied alveolar bone in dogs and found that negative charges can induce the production of osteoblasts on the tension side, while positive charges can induce the production of osteoclasts on the stress side. Showkatbakhsh (Showkatbakhsh et al., 2010) studied about ten patients to whom a movable denture was made with the addition of an integrated circuit, which produces a magnetic field effect, and after five months, the distance of tooth movement was recorded and the study confirmed that the experimental group moved significantly larger distances than the control group, with statistical differences. Another type of physical method to speed up orthodontic tooth movement is low energy laser treatment.

Pharmacological approaches can use relaxin and 1,25-dihydroxyvitamin D. When orthodontic forces are applied to the teeth and the teeth move, relaxin in the periodontal tissues comes into function and this hormone increases the collagen synthesis on the tension side and decreases the collagen synthesis on the pressure side. In addition, it has been suggested that periodontal ligament remodeling may also reduce the relapse rate after orthodontic treatment. 1,25-dihydroxyvitamin D, as the most active metabolite of vitamin D, can regulate the transport of calcium ions and has a stabilizing effect on the intracellular calcium ion content. It can promote bone deposition and inhibit the release of parathyroid hormone. The low dose of 1,25-dihydroxyvitamin D can lead to more active osteoclasts.

Osteocorticotomy is one of the most common methods of surgically accelerating orthodontic tooth movement. During surgery, the proximal and distal mesial bone cortices of the buccolingual side of the orthodontic teeth were incised vertically to maintain the continuity of the cancellous bone. Sometimes it is also necessary to combine a subapical osteotomy with a horizontally oriented osteocortical incision that intersects with the previous vertically oriented incision, which creates an independent bone block that can be moved. There is also an innovative minimally invasive technique called Piezocision technology, which uses an ultrasonic bone knife to do selective cutting, increasing the safety of the procedure, reducing surgical trauma, decreasing the risk of osteonecrosis, and also allowing the patient to achieve accelerated tooth movement with no obvious root resorption after treatment is completed, thus achieving a good treatment result.

These methods can speed up the movement of orthodontic teeth, but they still have many drawbacks. The adverse effects of oral medication still need to be supported by experimental studies, and patient acceptance of the surgery needs to be improved. The future of low-energy laser irradiation treatment is more promising due to its ease of use and basic lack of side effects. However, the dose and histological changes following the application of low-energy lasers still need to be investigated.

2.4 Application of low-level laser in orthodontics

2.4.1 Analgesic effect of low-level laser in orthodontics

Pain is a feeling and experience that causes distress, and any such unpleasant experience represents the reality that tissue damage has occurred or will occur, and is a hurtful sensation that occurs when an external stimulus is applied. Patients experience pain when undergoing orthodontic treatment, usually appearing within a few days after the application of force, and this negative emotion can have an impact on the patient's cooperation and thus on the effectiveness of orthodontic treatment. Reducing the pain produced by orthodontic treatment on patients is beneficial for their psychological well-being during orthodontic treatment and reduces the impact of treatment on all aspects of their lives.

In patients during orthodontic treatment, tooth movement compresses the periodontium, causing local ischemia and a subsequent inflammatory response in which mast cells produce and release inflammatory substances such as histamine, bradykinin, and prostaglandins, causing patients to experience pain (Polat, 2007). Clinical observations have shown that these sensations usually appear a few hours after the application of orthopedic forces (Ngan et al., 1989) or on the first day or days after treatment, with pain levels decreasing to normal levels after seven days (Jones & Chan, 1992).

Many solutions have been proposed by doctors to relieve patients' pain, such as oral NSAIDs, masticatory decompression, psychological interventions, local anesthesia, etc. However, these methods often bring some adverse reactions to the patient's body or affect bone metabolism and hinder the movement of teeth. Nowadays, it is proposed that low-level laser can be applied to reduce orthodontic pain.

Low-level-laser therapy, also known as cold laser, is a type of radiation that does not raise tissue temperature (Chung et al., 2012). Subcellular photoreceptors can respond to visible red and near-infrared wavelengths, which is the mechanism of action. Stimulation of these receptors can affect the electron transport chain, respiratory chain and oxidation as a process that increases cellular metabolism (Johar, 2011). The neurological effects of laser treatment include stabilization of the membrane potential and inhibition of the activation of pain signals (Sonesson et al., 2016). The inhibition of the pulpal response to painful stimuli is manifested in class C fibers after laser irradiation (Wakabayashi et al., 1993). In addition, laser irradiation reduces inflammatory mediators such as prostaglandin E2 (which can cause the sensation of pain) (Bjordal et al., 2006).

Abi-Ramia (Abi-Ramia et al., 2010)LB et al used orthodontic forces to move the teeth of rats and examined the changes in their dental pulp, and the results demonstrated that low-level laser treatment accelerated the regeneration of blood vessels and promoted the recovery of dental tissues. Similarly, a study by Xie H et al (Xie et al., 2004) has demonstrated that He-Ne laser irradiation has a vasodilatory effect. By studying the molecular mechanisms of low-level laser irradiation in reducing orthodontic pain, some scholars have shown that the mechanisms may be a combination of multiple effects, including inhibiting the release of local inflammatory cytokines, promoting revascularization, improving blood circulation, reducing the release of pain-causing neurotransmitters, increasing the release of analgesic effect transmitters, and affecting ion channels.

In orthodontic clinical practice, many scholars have conducted experiments with low-level lasers, and the results have shown that low-level lasers can reduce pain perception during orthodontic force application. In the randomized clinical experiment, Gauri (Doshi-Mehta & Bhad-Patil, 2012) used semiconductor laser to irradiate the canine to make the canine move distally. The data showed that the pain pass value of the experimental group was significantly smaller than that of the control group on the third and thirtieth days after applying force to the canine, and there was a statistical difference. There was a significant difference in the pain value on the third and first days in the experimental group, and the results showed that low-level laser irradiation was helpful to reduce pain. Similar results were observed by Koji (Fujiyama et al., 2008) et al. who found that low-level laser irradiation significantly reduced pain after tooth splitting. Tortamano A (Tortamano et al., 2009) et al. used low-level laser irradiation of the teeth right after the archwire was placed at the beginning of the treatment phase and demonstrated that the laser treatment group had the lowest mean pain values and the fastest disappearance of pain perception, but low-level laser treatment did not affect However, the low-level laser treatment did not affect the perception of pain at the beginning, nor did it change the most painful period, and there was no significant difference in the value of the pain pass between the maxillary and mandibular.

2.4.2 The role of low-level-laser to accelerate tooth movement

During long-term orthodontic treatment, periodontal diseases, cooperation problems, mainly resorption of the roots, cause a lot of concern among orthodontists (Mohammed et al., 1989). Although some authors (King & Thiems, 1979) stated that the movement of orthodontic teeth is not easy unless going to damage the roots and alveolar bone, there are also experiments that demonstrate the possibility of rapid tooth movement without any tissue damage. These studies used prostaglandins (Kanzaki et al., 2002), osteocalcin (Hashimoto et al., 2001), neuropeptides, leukotrienes (Tyrovola & Spyropoulos, 2001), and nitric oxide (Akın et al., 2004) to convert mechanical forces into cellular responses and reduce tissue resistance during tooth movement. In addition, some experimental studies (Lavine et al., 1974) used direct current and pulsed electromagnetic fields to accelerate tooth movement. Furthermore, it has been demonstrated that systemic factors such as parathyroid hormone (Goldie & King, 1984), 1,25-dihydroxycholecalciferol (the activated form of vitamin D) (Kale et al., 2004) and cortisone (Ong et al., 2000), as well as local factors such as osteocorticotomy and laser treatment can accelerate tooth movement (Krishnan et al., 2021a).

The biological basis of orthodontic tooth movement is periodontal remodeling (Krishnan et al., 2021a). When orthodontic forces are applied to the teeth, the oral periodontal tissue is in a state of stress, inducing the synthesis and release of bioactive factors (Luppanapornlarp et al., 2010). After orthodontic force is applied to the teeth, new bone starts to form on the tension side of the teeth, and osteoclasts start to be produced on the stress side at the same time, causing bone resorption, and the two interact to cause directed tooth movement and reconstruction of periodontal tissues such as alveolar bone.

There are several recent studies on the effects of laser on dental soft and hard tissues. There are in vivo and in vitro studies on the biostimulatory effects of laser in bone remodeling and tooth movement in orthodontic treatment. yoshida et al. found that low level laser treatment was effective in increasing tooth movement velocity in rats, while micro-CT analysis showed that bone density was significantly lower in rats after low level laser irradiation than in normal controls (T. Yoshida et al., 2009). In in vitro experiments, using rats as an experimental model, it was found that using low-level laser irradiation during the expansion of the rat's maxillary hard palate, the experimental group had significantly more bone in the midpalatal suture than the control group, and also increased the distance of tooth movement (Saito et al., 1997).Saito and Shimizu (Saito et al., 1997) found that their laser irradiated group moved teeth 20-40% faster than the control group.Kawasaki and Shimizu (Kawasaki & Shimizu, 2000) found that the teeth of rats irradiated with low levels of laser accelerated tooth movement by 30%. limpanichkul et al (Limpanichkul et al., 2006) did not find an increase in tooth movement in the laser irradiated group. This result may be due to factors such as the dose of laser irradiation and the duration of irradiation. Additionally, the lack of clarity regarding the parameters of various early laser experiments might have also contributed to the observed differences, as it is difficult to compare and draw definitive conclusions without accurate knowledge of the experimental conditions.

2.5 Basis for the Selection of Parameters in Low-Level Laser Therapy

In orthodontic treatment, the selection of appropriate radiation time and dose for low - level laser therapy (LLLT) is of utmost importance. These parameters directly impact the effectiveness and safety of LLLT in promoting tooth movement and maintaining stability during the retention phase.

Previous studies have delved into a wide range of radiation times and doses to evaluate their influence on orthodontic outcomes. For instance, certain investigations (Gonçalves et al., 2024) have demonstrated that a radiation dose of 75 J/cm², when applied with a radiation time of 6 seconds per point, can effectively stimulate the biological processes associated with tooth movement. However, it should be noted that different studies have reported varying optimal values, which are contingent upon multiple factors such as the type of laser employed, the specific treatment objective, and the characteristics of the patient population.

In this study, the determination of radiation time and dose was based on a meticulous review of previous literature and experimental data (El-Angbawi et al., 2023). After comprehensive consideration, a radiation dose of 75 J/cm² used in some previous successful studies was chosen, and the radiation time was set at 6 seconds per point. This combination was aimed at maximizing the beneficial effects of LLLT on tooth movement and stability while minimizing potential adverse effects. By selecting these parameters, we intended to enhance the biostimulatory impact of LLLT on the periodontal ligament and alveolar bone, thereby promoting the remodeling and strengthening of these tissues. This, in turn, is expected to contribute to more efficient and controlled tooth movement and better long - term stability following orthodontic treatment.

Justifying the research method in terms of radiation time and dose not only provides a solid scientific foundation for the study but also ensures the reliability and applicability of the obtained results in clinical practice. It enables a more accurate assessment of the potential advantages of LLLT in orthodontics and paves the way for establishing a more standardized approach in future research in this domain.

2.6 Other applications of lasers in the oral cavity

It has been demonstrated that low-level lasers can improve osseointegration of implants in the oral cavity. In animal experiments, researchers placed implants in the tibia of rats while using a low-level laser to administer irradiation treatment in the surgical area, ensuring that the implants were not overloaded, and executed the rats on the thirtieth and forty-fifth days, with better results in the irradiated group than in the blank control group, suggesting that the low-level laser can increase the intensity between the implant and bone interface and facilitate osseointegration of the implants (Boldrini et al., 2013). Low-level laser increases fibroblast production and facilitates fibroblast attachment, therefore improving the biological closure of the implant and reducing peri-implant bone resorption. In addition, low-level laser promotes fracture healing as well as the healing of extraction wounds. This may be due to the fact that low-level laser modulates the inflammatory process and accelerates bone regeneration. In endodontics, laser irradiation therapy is used in the treatment of dentin hypersensitivity, reducing the sensitivity of dentin to mechanical or hot and cold stimuli. In oral mucosal medicine, laser irradiation can reduce the size of the lesion of lichen planus and relieve the patient's pain. Laser irradiation can similarly reduce the pain of burning mouth syndrome. In ulcers, laser irradiation accelerates ulcer healing, shortens treatment time, and is painless for the patient, making the clinical procedure very comfortable for the patient. The therapeutic effect of low-level laser for temporomandibular disorder syndrome has also been confirmed by scholars in clinical practice.

2.7 Key points in the retention phase

2.7.1 Retention is a vital component of the post-orthodontic treatment process

Orthodontists have long recognised that the use of orthodontic appliances to move teeth within the jaw or to adjust the upper and lower jaw relationship to normal has the potential to return to the original position. After moving the teeth within the jaw or adjusting the upper and lower jaw relationship to normal, there is a tendency to return to the original position (Krishnan et al., 2021a). This is known as a relapse. Retention is needed to prevent relapse and to stop this tendency from occurring. However, in order to prevent relapses, one must first know the causes of relapses. There are several reasons for this.

2.7.1(a) Normal structure and function of the periodontal tissue has not been restored

After the teeth have been moved by orthodontic treatment, the tension of the stretched or compressed gingival and periodontal fibers has not yet established a new balance, and the position of the teeth is unstable and prone to relapse. In particular, the alteration of the fibers on the alveolar ridge and the transverse septal fibers is very slow, and the tension generated tends to make the moved tooth revert to its original misaligned state (Krishnan et al., 2021b) In addition, it takes some time for the alveolar bone to change from transitional bone to normal alveolar bone.

2.7.1(b) Occlusal balance not fully established

In the orthodontic process, the relationship between the teeth, dental arch, and jawbone position is changed, thus destroying the original habitual abnormal occlusion. The newly constructed occlusion relationship has not yet reached the contact relationship between the jaws and the beveled surfaces of the cusps of the teeth and must undergo constant occlusion adjustment, during which the occlusion deformity has a tendency to recur (McNamara, 1976).

2.7.1(c) Unfinished modification of the neuromuscular dynamic balance of the maxillofacial system

The neuromuscular dynamic (Nanda & Nanda, 1992)balance of the dento-mandibular system plays an important role in the stability of the orthodontic outcome. In addition to the malocclusion deformity formation process, in addition to the morphological abnormalities exhibited by the malocclusion surface, there is also the generation of a neuromuscular dynamic balance that is compatible with the deformity, and the abnormal neuromuscular dynamics of the maxillofacial system play an important role in the occurrence and development of malocclusion . Orthodontic treatment changes the position of the teeth, dental arch, or jawbone, but until the modification of this abnormal neuromuscular dynamic balance is completed, it will adversely affect the treated teeth, dental arch, or jawbone and cause relapse.

2.7.2 Prevention of relapses and treatment after relapse

2.7.2(a) Prevention of relapses

After orthodontic treatment is completed, to prevent the relapse of orthodontic effect, it is very necessary to carry out correct retention design. However, retention and treatment are not two separate phases but should be a closely related and indispensable process. A comprehensive and complete treatment design should include a reasonable and effective orthodontic plan and a retention plan, and the retention factor should be taken into full consideration before, during and after orthodontic treatment, so as to guide the process of orthodontic treatment and choose a reasonable and stable retention method through the analysis of the possible causes of relapse (Johnston & Littlewood, 2015). The final result after retention is the most reliable criterion for evaluating the success of orthodontic treatment. The following are some of the main methods to prevent relapse after orthodontic treatment:

2.7.1(a)(i) Over-correction of malocclusion:

For misaligned teeth and jaw malocclusion which is serious and prone to relapse, over-correction in the course of orthodontic treatment is an effective means to prevent relapse. For example, in the case of deep overbite or open bite of anterior teeth, over-correction should be done to a degree more than normal overbite; the relapse of rotated teeth after the orthodontic treatment is one of the most common types of relapse, and over-correction of the teeth can reduce the chances and degree of the relapse after the orthodontic treatment; for lateral relationship disorders, it is also necessary to over-correct the patients obviously (Bock et al., 2016).

2.7.1(a)(ii) Early orthodontic treatment, conducive to stability:

Early diagnosis and early treatment are conducive to the maintenance of long-term stability of orthodontic effect. Early treatment can prevent irreversible changes of soft and hard tissues, and maximize the potential of growth and development of patients, reduce excessive dental compensation, and stop the development of malocclusion, for example, correcting skeletal relationship disorders when the bone joints and joints are not fully developed, and establishing a new balance of muscle function through the change of tooth position and jaw position, and the balance of muscle can in turn promote bone growth. Early treatment is also recommended in the case of teeth rotated (Littlewood et al., 2017).