Influence of semiconductor laser irradiation on the rate of orthodontic tooth movement

Guanjun Zhou, Lihua Shan, Rong Tan

Department of Orthodontics, The Second Hospital of Hebei Medical University, Shijiazhuang, China

Received May 15, 2017; Accepted May 24, 2018; Epub September 15, 2019; Published September 30, 2019

Abstract: Objective: To explore the influence of semiconductor laser on tooth movement and the mechanism. Methods: A total of 10 g of orthodontic force was applied to rat molars to cause experimental tooth movement. A semiconductor laser was used to irradiate the area around the moved tooth, and after 3, 7 and 14 days, the amount of tooth movement and root length were measured. Alveolar bone structure parameters were also measured. The parameters included alveolar bone density (BMD), bone volume fraction (BV/TV) and TbSp. Results: On 14 days after laser irradiation, the distance of tooth movement and root length in irradiation group were much higher than the control group. BMD and BV/TV in the compression side in the irradiation group was significantly lower than the control group, while TbSp was obviously higher. The number of osteoblasts and osteoclasts in irradiation group were observably higher than the control. Conclusion: Semiconductor laser irradiation can accelerate the speed of tooth movement, reduce root resorption during tooth movement and accelerate the reconstruction of alveolar bone.

Keywords: Laser, tooth movement, root resorption, alveolar bone

Introduction

Orthodontic treatment has its importance based on esthetic and functional rehabilitation of the masticatory system. Because it is the result of orthodontic forces promoting the remodeling of alveolar bone tissue, the movement should be as slight as possible, in order to prevent collateral effects such as bone necrosis or root resorption [1]. Moreover, Discomfort pain is a burdensome side effect accompanying orthodontic treatment due to force application for tooth movement. It has been emphasized that pain reduction without analgesic drugs is necessary in orthodontic treatment [2].

Many studies have tried to find methods that can increase the rate of tooth movement without damage to the tooth and periodontium at the same time. Recently, several papers showed that the acceleration of tooth movement can be produced by the local injection of prostaglandins and osteocalcin around the alveolar socket, electric stimulation and ultrasound application [3]. These methods depend on injections, that could be associated to discomfort and pain, or a sophisticated apparatus that demands applications for a long term to achieve its therapeutic effects.

More recently, different researchers have studied the results of low-level laser therapy (LLLT) and found that its stimulatory effects can stimulate bone regeneration at bone fracture and extraction sites, increase the rate of orthodontic tooth movement in rats, accelerate bone regeneration in a midpalatal suture during rapid palatal expansion and so on [4, 5]. Sousa et al reported diode laser evidently increased the rate of tooth movement and reduced the cost time of orthodontic treatment compared with the control [6].

Root resorption is a common idiopathic problem associated with orthodontic treatment and has recently received considerable attention because of medicolegal exposure [7]. There are many factors that influence root resorption, such as genetic factors, age, gender and endocrine hormone. Currently, two-dimensional X-ray or three-dimensional CBCT was often used to evaluate root resorption.
Influence of semiconductor laser irradiation on tooth movement

In this study, we used Micro-CT method to observe the effect of semiconductor laser irradiation on changing situation of orthodontic tooth movement, root resorption and alveolar bone microstructure.

Material and methods

Animals

A total of 80 male Sprague-Dawley rats at 5 weeks old (200 ± 10 g) were used for the experiments. They were kept in the animal center of the Second Hospital of Hebei Medical University, in a 12-hour light/dark environment at a constant temperature of 23°C and provided with food and water ad libitum. The health status of each rat was evaluated by daily body weight monitoring for 1 week before the start of the experiments.

The rats were divided into 4 groups according to the time of orthodontic treatment: 0, 3, 7 and 14 days after treatment. Each group has 20 rats. Each group was also divided into 2 groups: laser irradiation group and the control.

Laser irradiation

The equipment used in this study was a Gallium Aluminum Arsenide (GaAlAs) semiconductor diode laser (Twin Laser, MM Optics Ltd., São Carlos, SP, Brazil), emitting infrared radiation at 780 nm, operating in continuous wave mode with a cylindrical quartz tip of 4 mm² surface. All irradiations were done by the same operator with an output power of 20 mW, dose of 5 J/cm², and exposure time of 10 seconds. The tip was held perpendicular and in contact to the mucosa during the laser procedure. A total of ten irradiations each time, five by the buccal side and five by the palatal side, were carried out, distributed, and ordered as follows, to cover the periodontal fibers and alveolar process around the canine teeth: (a) Two irradiation doses on the cervical third (one medial and one distal); (b) Two on the apical third (one medial and one distal); (c) One on the medium third (on the center of the root).

Experimental tooth movement

All operations were carried out under general anesthesia by using an intraperitoneal injection of sodium pentobarbital (50 mg/kg body weight). For mesial movement of the upper left 1st molar, the wire end of a 7.0-mm length of stainless steel, closed-coil spring (wire size: 0.005-inch, diameter: 1/12-inch, Accurate Sales Co. Chiba, Japan) was ligated with the maxillary 1st molar cleat by a 0.008-inch stainless steel ligation wire (Tomy International Inc, Tokyo, Japan). The other side of the coil spring was also ligated, with the holes in the maxillary incisors drilled laterally just above the gingival papilla with a #1/4 round bar, by using the same ligation wire. The orthodontic force exerted by the appliance was 10 g in the beginning of the experiment. The force was determined based on a preliminary study that showed that the rat’s upper 1st molar could be moved by orthodontic force without a decrease of body weight or hyalinized degenerative tissues. Tooth movement was performed for 14 days (day 0~14).

Measurement of tooth movement

Micro-CT (SkyScan1076, Belgium) was taken under general anesthesia at day 0 (before and immediately after the appliance was set), 3, 7 and 14 in the same animal. Micro-CT settings were 73 kV and 142 μA, depth of stratum was 18 μm. Pixel size were 1024×1024, field-of-view diameter was 14.4 mm, and height was 14.4 mm. Magnification was set at 6.7.

CTAn software (J. Morita MFG Corp, Kyoto, Japan) was used to determine the distance between the first and second tooth. The measuring method was shown as follows: Make the teeth tooth plane parallel to the ground plane, the shortest distance between the first odontoprisis and the second odontoprisis was tooth movement distance.

Measurement of root length

Make the teeth tooth plane parallel to the ground plane, during the process from dental crown to root length, the image that firstly appeared mesial root was 1, while the image that lastly appeared mesial root was 2, the distance between two images was 18 μm, the root length = 18×N.

Measurement of alveolar bone structure parameters

We selected alveolar bone cancellous located in the mesiocclusion of the first odontoprisis
Influence of semiconductor laser irradiation on tooth movement

and used CTVol software to three-dimensional rebuild the selected area. We also used CTVol software to determine the three-dimensional microstructure parameters of bone trabecula. The parameters included alveolar BMD, bone volume fraction (BV/TV) and TbSp.

Histochemical examination

For histologic examination, 24 rats were divided into six groups of four rats each as follows: the irradiation groups (day 0-3, day 0-7, day 0-14) and the control groups (day 0-3, day 0-7, day 0-14). All rats were fixed by transcardial perfusion of 4% (w/v) paraformaldehyde in 0.1 mol/l phosphate buffered saline (PBS) solution. The maxillae, including the molars, were removed, immersed overnight in the same fixative at 4°C, and then rinsed with PBS solution.

The tissue blocks were demineralized in 10% (w/v) ethylenediaminetetra-acetic acid for 14 days at 4°C and then embedded in paraffin. The embedded specimens were cut into 4.0-mm-thick sections, in a parallel plane 3.0 mm below the upper occlusal plane, the same area as for the ground sections.

Statistical analysis

The values in each figure are represented as the mean ± SD for each group. Intergroup comparisons of the average values were conducted with Tukey’s t-test for analysis of body weight change and Student’s t-test for equal variance of the other comparisons. A value of P < 0.05 was considered to indicate a significant difference.

Results

Distance of tooth movement

The results of tooth movement distance in each group are shown in Figure 1. As shown, both irradiation group and the control group had no obvious tooth movement on 3 days, while the distance between irradiation group and control group had significant difference on 7 and 14 days, and the value in irradiation group was evidently higher than the control group (P < 0.05).

Distance of tooth movement in irradiation group and control group

The rate of tooth movement in both irradiation group and the control group on 3-7 days was slowed down compared with that on 0-3 days. On 7-14 days, the rate of tooth movement in both irradiation group and the control group were increased compared with that on 3-7 days.

Changes of root length

The results of tooth movement distance in each group are shown in Figure 2. As shown, the root length in both irradiation group and the control group on 3-7 days was slowed down compared with that on 0-3 days. On 7-14 days, the root length in both irradiation group and the control group were increased compared with that on 3-7 days.

**Figure 1.** Distance of tooth movement in irradiation group and control group on 0, 3 d, 7 d and 14 d. *P < 0.05 and **P < 0.01 were considered as significant and very significant difference respectively.

**Figure 2.** Root length in irradiation group and control group on 0, 3 d, 7 d and 14 d. *P < 0.05 was accepted when there was a significant difference between irradiation group and control group.
Influence of semiconductor laser irradiation on tooth movement

Root length in irradiation group and control group

However, the root length between irradiation group and the control group had no remarkable difference on 3 and 7 days.

Changes of alveolar bone structure

Alveolar bone density (BMD): The changes of alveolar BMD in compression side and tension side were shown in Figure 3A and 3B, respectively. As Figure 3A showed, BMD in irradiation group on 7 and 14 days was much lower than the control group \(P < 0.05\). BMD in both irradiation group and the control group showed a decreasing trend. On 3 d, BMD between irradiation group and the control group had no statistical differences. However, BMD in tension side in irradiation group was significantly lower than the control group \(P < 0.05\). On 7 and 14 days, BMD in irradiation group was significantly higher than the control group \(P < 0.05\). BMD in tension side in both groups decreased firstly, and then increased with the increase of time.

Bone volume fraction (BV/TV): The changes of alveolar BV/TV in compression side and tension side were shown in Figure 3C and 3D, respectively. As Figure 3C showed, BV/TV ratio in irradiation group was significantly lower than the control group on 7 and 14 days \(P < 0.05\). BV/TV ratio in both groups showed a decreasing trend. On 3 days, BV/TV in irradiation group and the control group had no statistical differences. As Figure 3D showed, BV/TV ratio in tension side of irradiation group was significantly higher than the control group at 14 days \(P < 0.05\). On 3 and 7 days, BV/TV ratio in irradiation group and the control group had no statistical differences. BV/TV ratio in tension side of both groups decreased firstly, and then increased with the increase of time.

Bone trabecular space: The changes of bone trabecular space in compression side and tension side were shown in Figure 3E and 3F, respectively. As Figure 3E showed, bone trabecular space in irradiation group was significantly lower than that of the control group \(P < 0.05\). Bone trabecular space in both groups showed a decreasing trend. At 3 days, bone trabecular space in irradiation group had no statistical differences when compared to the control group. As Figure 3F showed, bone trabecular space in tension side of irradiation group was significantly higher than that of the control group at 14 days \(P < 0.05\). On 3 and 7 days, bone trabecular space in irradiation group.
Influence of semiconductor laser irradiation on tooth movement

Figure 4. (A) Periodontal tissue of control group: The blue arrow points to the compression side of the narrowed periodontal membrane. The black arrows point to the tension side of the widened periodontal membrane (×200, HE). (B) Irradiation group-Tension: The black arrow points to the expansion of blood vessels. The blue arrow points to new alveolar bone (×200, HE). (C) Irradiation group-Tension: The black arrow points to many new alveolar bone and osteoblasts (×200, HE). Morphological view of periodontal tissue tension. (A) was tension control group which was observed at 200 times; (B) was Irradiation group-tension which was observed at 200 times; (C) was Irradiation group-tension which was observed at 200 times.

Figure 5. (A) Control group-compression: The black arrow points to hyaline degeneration (×200, HE). (B) Irradiation group-compression: The black arrow points to many osteoclasts and absorption of alveolar bone (×200, HE). (C) Control group-compression: The green arrow points to the root resorption to dentin. The blue arrow points to osteoclasts (×200, HE). Morphological view of periodontal tissue compression. (A) was compression control group which was observed at 200 times; (B) was Irradiation group-compression which was observed at 200 times; (C) was Irradiation group-compression which was observed at 200 times.

group and the control group had no statistical differences. Bone trabecular space in tension side of both groups decreased firstly, and then increased in a time-dependent way.

Histochemical examination

The histochemical examination at tension side were shown in Figure 4. As shown, in both irradiation group and the control group, the periodontal ligament clearance was widened, alveolar bone appeared osseous crater, a small number of osteoclasts around was visible and dent periosteal fibers arranged along the direction of traction. In irradiation group, there showed more vasodilation congestion and a small amount of new alveolar bone. The number of vessels and fibroblasts increased in both irradiation group and the control group. In irradiation group, osteoblast number on the surface of alveolar bone was distinctly higher than that of the control group, osteogenesis was very active, small lacuna along the edge of alveolar bone became smooth and the bone matrix on the surface deposited and new bone formed. New bone formation was obvious found in both groups, and the number of formed new bone in irradiation group was largely much than the control.

The histochemical examination at tension side were shown in Figure 5. The periodontal ligament clearance became narrow and osteoclasts were found in shallow sunken place of alveolar bone. The number of osteoclasts in irradiation group was significantly lower than the control. The periodontium became transparent and vascular compartment became nar-
row in irradiation group, while hyaline change was not seen and vessels had no obvious change in the control. The width of periodontium had some recovery and many absorbing pouches were found on the surface of alveolar bone in both groups. The number of osteoclasts in irradiation group was significantly larger, osteoclasts were more active and sunken was much deeper than the control. In irradiation group, root resorption was found occasionally and only involved cementum, while root resorption reached dentin in the control. The number of osteoclasts reduced significantly in irradiation group, while in the control group, hyaline change has been basically cleared and some root resorption reached to dentin.

Discussion

In the present study, we clearly demonstrated the effects of laser irradiation on experimental tooth movement. Gonzales C et al reported mouse odontoids was 20 times less than human odontoids, and 10 g force value can make mouse teeth produces more obvious movement compared with 25 g, 50 g and 100 g force value [8]. Takako et al reported different force value can cause different degrees of root absorption and tooth movement [9]. So, we selected the optimal value 10 g for tooth movement. Study showed the loading cycle on rats was 14 days, cementum will showed obvious absorption with tooth movement for 7 days and cementum began to renovate on 14 days [10]. Therefore, we selected 14 days as loading cycle. Laser has been used in dermatology, ophthalmology and stomatology, and semiconductor laser has been applied in orthodontics. Shirazi et al used diode laser for orthodontics, results showed the distance of tooth movement in irradiation group was 2.3 times of the control group [11]. Garcia et al considered semiconductor laser could enhance blood circulation, increase angiogenesis and induce cell proliferation [12]. The study by Brognard et al showed effect of tooth movement with weak laser energy density (5-8 J/cm\(^2\)) was better than energy density of 20-25 J/cm\(^2\) [13]. Cruz et al explored the influence of low level laser on the speed of human orthodontic tooth movement, and results found low level laser could accelerate the speed of tooth movement and shorten the time of treatment [14]. Our study showed semiconductor laser accelerate the speed of tooth movement, and on 7 and 14 days, distance of tooth movement in irradiation group was much larger than the control group. This was the result of semiconductor laser accelerating alveolar bone reconstruction. Semiconductor laser increased the number of osteoclasts in the compression side and promoted bone absorption and the formation of new bone. Yamaguchi used Ga-Al-As diode laser to irradiate the region around movement teeth and measured the distance of tooth movement. Results showed the movement distance in irradiation group was markedly higher than control group [15]. This was consistent with our results. Kalkwarf et al reported about 90% of patients after orthodontic treatment will occur root resorption [16]. Root absorption is part of the transparent sample clearance. Serious root absorption will result in agomphasia and even fall off. Many researchers are exploring methods to reduce root absorption. In our study, we used Micro-CT to measure the length of mesial root in the first molar of mouse. Results showed on 14 days, root length in control group was less than irradiation group. On 7 days, root length in irradiation group and control group had no statistical difference. The histological slices showed the region of hyaline change was obvious in the compression side of root in control group, while hyaline change was few in irradiation group. The results were consistent with the study by Brudvik et al [17]. This indicated laser irradiation could reduce the occurrence of hyaline change during tooth movement, decrease the damage of periodontal ligament and weaken the degree of root resorption.

BMD in the compression side in irradiation group and control group first decreased, and then increased with then increase of time. Alveolar bone reconstruction was slowly conducted with tooth movement. On 3 days, tooth movement at mesiocclusion and new bone had not formed, so BMD decreased at first. BMD in irradiation group was lower than control group, since laser accelerated the process of bone rebuilding. On 7 and 14 days, the amount of new bone formation increased more and more, and BMD increased. BMD in irradiation group was higher than control group, since laser irradiation increased the number of osteoblasts which resulted in BMD in irradiation group was higher than control group. Study by Yoshida
Influence of semiconductor laser irradiation on tooth movement

showed BMD in the tension side of tension side first decreased, and then increased during tooth movement, which was consistent with our study [18]. Laser could promote bone calcification process, and then accelerates the process of bone formation. On 14 days, BV/TV in irradiation group was higher than control group, while the change of Tb.Sp was adverse to control group. Moreover, BMD and BV/TV in the compression side of first molar mesiocclusion gradually decreased during tooth movement. On 7 and 14 days, BMD and BVTV in irradiation group were much lower than control group. From tissue slices, we observed blood circulation in the compression side in the irradiation group was well and there had few occluded vessels. Good blood circulation can provide more nutrients and oxygen for reconstruction related cells of alveolar bone absorption, speed up the adaptive change of alveolar bone, quicken the decrease of BMD and BVTV in the compression side and absorption of alveolar bone, which was more beneficial to rapid tooth movement. Altan et al evaluated the influence of diode laser (820 nm) on the proliferation of osteoclast and osteoblasts during tooth movement, results showed the number of osteoclast and osteoblasts increased obviously, which accelerated the process of bone rebuilding [19].

All those indicated semiconductor laser irradiation can accelerate the speed of tooth movement, reduce root resorption during tooth movement, and accelerate the reconstruction of alveolar bone.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Guanjun Zhou, Department of Orthodontics, The Second Hospital of Hebei Medical University, Shijiazhuang, China. E-mail: guanjunzhou123@sina.com

References


[14] Cruz DR, Kohara EK, Ribeiro MS and Wetter NU. Effects of low-intensity laser therapy on the orthodontic movement velocity of human


