Journal of Lasers in Medical Sciences

J Lasers Med Sci. 2025;16:e49

Original Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2025.49

# Effect of Photobiomodulation Therapy with Three Wavelengths of Diode Laser on Proliferation and Survival of Stem Cells Derived from Impacted Third Molar Follicles

**Mona Mohajeri Tehrani[1], Fatemeh Ghahremani[2], Abdolreza Mohamadnia[3,4], Mohammad Bayat[1,5], Shamim Chinian[2], Naghmeh Bahrami[1,6*]**

[1]Craniomaxillofacial Research Center, Tehran University of Medical Sciences, Tehran, Iran
[2]Private Practitioner, Researcher at Tehran University of Medical Sciences, Tehran, Iran
[3]Chronic Respiratory Diseases Research Center, National Research Institute of Tuberculosis and Lung Diseases (NRITLD), Shahid Beheshti University of Medical Sciences, Tehran, Iran
[4]Department of Biotechnology, School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5]Department of Oral and Maxillofacial Surgery, Shariati Hospital, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
[6]Department of Tissue Engineering and Applied Cell Sciences, School of Advanced Technologies in Medicine, Tehran University of Medical Sciences, Tehran, Iran

***Correspondence to**
Naghmeh Bahrami,
Email: naghmehbahrami@gmail.com

**Received:** June 4, 2025
**Accepted:** August 27, 2025
**ePublished:** October 27, 2025

**Abstract**

**Introduction:** Increased tissue regeneration is facilitated by mesenchymal stem cells (MSCs), with photobiomodulation (PBM) effectively promoting their proliferation. This study examines the impact of PBM on human third molar follicle stem cells using three diode lasers, addressing the need for further investigation regarding its parameters.

**Methods:** The third molar follicle stem cells of four consented patients were removed after surgical extraction of third molars. These cells were then exposed to laser radiation with wavelengths of 660 (energy density: 3 and 5.1 J/cm$^2$), 808 (energy density: 3 and 5 J/cm$^2$), and 980 (energy density: 3.2 and 5/2 J/cm$^2$) nanometers at time intervals of 24, 48, and 72 hours. The proliferation and viability of the cells were determined using the MTT test. The data were analyzed through one-way ANOVA followed by Tukey's HSD post hoc test, utilizing SPSS software version 22, with a significance threshold of 0.05.

**Results:** The highest average number of human third molar follicle stem cells was obtained at 660 nanometers and an energy density of 5.1 J/cm$^2$ in 24 hours. This specific laser protocol significantly outperformed other conditions in promoting cellular proliferation.

**Conclusion:** PBM at the 660-nm wavelength administered with a dose of 5.1 J/cm$^2$ and a 24-hour incubation period appears to be the most effective condition for enhancing the proliferation and survival of human third molar follicle stem cells. These findings provide a potential basis for standardized PBM protocols in regenerative dentistry.

**Keywords:** Photobiomodulation; Low level laser; Proliferation.

## Introduction

Tissue engineering and cell therapy are new approaches that have reduced the limitations of traditional reconstruction methods (autograft, allograft, alloplast, and xenograft) to a manageable level. Since the body cannot repair and restore extensive defects, tissue engineering is thought to be a viable option.

It was first discovered in the late 1960s that mesenchymal stem cells (MSCs) extracted from bone marrow could differentiate into various cell types, including osteoblasts. However, the process of harvesting bone marrow is painful, and the amount of mature stem cells obtained from the elderly is limited. As a result, ex vivo culture is required to increase the number of cells, but this method is also expensive and time-consuming, and it comes with a risk of contamination and cell loss.[1-3]

In many studies, it has been reported that stem cells can be isolated from a variety of sources, including dental follicles, deciduous teeth, periodontal ligament, and dental pulp. MSC isolation from a third molar tooth is a viable option because most dental and bone issues arise in adulthood when there are no deciduous teeth, and

**Please cite this article as follows:** Mohajeri Tehrani M, Ghahremani F, Mohamadnia A, Bayat M, Chinian S, Bahrami N. Effect of photobiomodulation therapy with three wavelengths of diode laser on proliferation and survival of stem cells derived from impacted third molar follicles. *J Lasers Med Sci.* 2025;16:e49. doi:10.34172/jlms.2025.49.

the third molar is typically extracted for orthodontic or preventative purposes and left unused. Therefore, it can be concluded that dental follicles are a readily available source of stem cells from impacted wisdom teeth that have been surgically removed.[4]

The development of the third molar structure in humans is unique since it occurs after birth and around age six, during which the embryonic dental tissues remain undifferentiated and silent. Dental follicle stem cells (DFSCs) isolated from human third molar teeth have been investigated for their capacity to differentiate. These cells have been shown to differentiate into various tissue types, including osteogenic cells, neurogenic cells, adipocytes, and vascular progenitor cells, highlighting their potential for use in tissue engineering and regenerative therapies for neural and bone defects.[4-6] These stem cells can differentiate into any kind of mesodermal or ectodermal cell, to put it another way.

Low-level laser therapy (LLLT), also known as photo-modulation (PBM), is a non-toxic, non-invasive phototherapy that uses a power of less than 250 milliwatts and a wavelength in the red to infrared range of 600 to 1000 nm. It has been shown to have positive effects on a number of illnesses and physiological functions, such as brain regeneration, hypoxia damage, and wound healing.[7] LLLT is commonly described as having a "biphasic dose response," where both insufficient and excessive exposure can lead to diminished biological effects. It aligns with the Arndt-Schulz law, which states that inadequate energy produces no effect, while too much energy causes "bio-inhibition".[8,9]

Photobiomodulation (PBM) biologically involves light absorption by photoreceptors in the mitochondrial respiratory chain, which activates mitochondria and boosts ATP production. LLLT can enhance cell proliferation and secretion, particularly in adipose-derived stem cells, by triggering different signaling pathways like the NF-kB pathway, with the effectiveness of this process influenced by parameters such as output power, wavelength, radiation frequency, radiation duration, energy density, distance between cells, and laser spot/probe.[7,10-12]

Considering the above information and the lack of investigation into the effect of LLLT on the MSCs of the third molar tooth follicle in previous studies, we undertook a study aimed at evaluating the effects of PBM with three different diode laser wavelengths (660 nm, 808 nm, 980 nm) during 24, 48 and 72 hours on the proliferation and survival of the stem cells of the third molar follicle.

## Materials and Methods

This is an in vitro experimental study conducted on MSCs extracted from the follicular tissue of impacted third molars in 4 patients (aged 15–30 years, without systemic illness or drug use). After isolation and culture, the cells were irradiated with diode lasers of 660, 808, and 980 nm wavelengths, each at two energy densities (3–5.1 J/cm$^2$), and examined at intervals of 24, 48, and 72 hours post-irradiation. This study did not include a non-irradiated control group. As a result, proliferation results are interpreted in relative terms across different laser parameters rather than against baseline cellular activity. Cell viability and proliferation were measured using the MTT assay. Data analysis was performed using one-way ANOVA and Tukey's HSD post-hoc test in SPSS software.

### *Experimental Groups*

Three wavelength groups (660 nm, 808 nm, and 980 nm) were examined, each applied at two energy densities.
Cell proliferation was evaluated at 24, 48, and 72 hours post-irradiation.

### *Preparation and Extraction*

After rinsing the mouth with a 0.2% chlorhexidine solution and preparing the facial area with diluted Betadine, the third molar teeth were extracted under local anesthesia. In order to avoid harming nearby tissues, the surrounding bone tissue was extracted using 023-029 burs with sterile saline irrigation.

### *Isolation and Culture*

Following careful isolation, the follicular tissue surrounding the tooth's crown was quickly moved to the lab in Hanks' solution. In the lab, under a sterile hood, the samples were washed several times with antibiotic-containing PBS buffer. They were then incubated in a solution of DMEM (Dulbecco's Modified Eagle Medium) and type I collagenase (250 u/mL) at 37 °C with 5% $CO_2$ for 1-2 hours to aid in tissue digestion. Following digestion, undigested tissue and impurities were removed using 70 µm and 40 µm filters, while mononuclear cells were separated using Ficoll. The resulting sample solution was centrifuged at 1500 rpm for five minutes in an Eppendorf centrifuge (5810R) to obtain a cell pellet. The cell pellet was cultured in a T75 flask containing DMEM with 10% FCS. The culture medium was replaced 48 hours later and subsequently changed every 72 hours. Once the cells reached 80% confluency, they were passaged at a 1:3 ratio using 0.2% trypsin and EDTA. Stem cell identity was confirmed by differentiating the cells into osteoblasts and adipocytes.

### *Differentiation and Staining*

After the third passage, cells were cultured into 24-well plates at a concentration of 20,000 cells/mL. The composition of the adipogenic and osteogenic differentiation medium was identical to that described by Mohammadi et al, cells were maintained in these media for 14 days, with the medium being replaced every three days.[13] Adipogenic differentiation was assessed using Oil Red staining. After being fixed for 60 minutes

in 4% formaldehyde and rinsed with 70% ethanol, the cells were incubated for 15 to 20 minutes in an Oil Red solution made by combining 0.5% Oil Red with 99% isopropyl alcohol and distilled water. After incubation, the cells were washed with 70% ethanol, and areas that had differentiated into adipocytes appeared red due to triglyceride staining.

To confirm osteogenic differentiation, Alizarin Red staining was used. Alizarin Red specifically stains mineralized matrix red, with the intensity of staining directly correlating to mineral content. Osteogenic cells were washed twice with PBS, fixed in 10% formaldehyde for 15 minutes at room temperature, and then incubated with a 40 mM Alizarin Red solution (pH = 4.1) for 20 minutes. After removing excess stain and washing with distilled water, the samples were examined and photographed under a microscope, with osteogenic cells stained red due to calcium deposits in the mineralized matrix.

### *Irradiation*

To evaluate the effects of LLLT, cultured cells were exposed to laser light three times at 24-hour intervals using various wavelengths, powers, and energy densities. Cell viability and proliferation were assessed 24, 48, and 72 hours post-irradiation using the MTT assay, a colorimetric test. The laser handpiece was fixed 1 mm above the cell surface. Each sample received one irradiation at 24, 48, and 72 hours.

### *Laser Parameters*

Six laser groups were tested, including 660 nm, 808 nm, and 980 nm diode lasers, with energy densities ranging from 3 to 5.1 J/cm² and exposure times from 6 to 17 seconds[14] (Table 1).

### *MTT Assay*

After each laser irradiation, at 24, 48, and 72 hours post-exposure, the cell plates were removed from the incubator. One-tenth of the surface cells were added to the wells containing MTT solution (Dimethylthiazol-2-yl-2,5-diphenyltetrazolium bromide). The plates were then incubated for 4 hours. DMSO was used to dissolve purple formazan crystals in viable cells, resulting in a uniform-colored solution.

The colored solution was transferred to an ELISA plate, using an ELISA Reader with a reference filter of 620 nm, and absorbance was measured at a wavelength of 570 nm. The percentage of viable cells in each sample was then analyzed.

Statistical analysis showed that the data followed a normal distribution. Therefore, One-Way ANOVA and Tukey HSD post hoc tests were used to compare the means. A $P$ value < 0.05 was considered, and the data were analyzed using SPSS software, version 22.

## Results

We evaluated the impact of LLLT on the average proportion of stem cells derived from human molar follicles at wavelengths of 660 nm, 808 nm, and 980 nm. Results were analyzed at 24, 48, and 72 hours. Significant differences were observed across wavelengths and energy densities ($P$ < 0.001). Pairwise comparisons further highlighted specific differences between the groups.

### *Efficacy of Wavelengths and Energy Densities*

One-way ANOVA confirmed significant differences across all groups and time points ($P$ < 0.001). As shown in Table 2, Post hoc Tukey HSD tests demonstrated that 660 nm (1.5 J/cm²) is the most effective wavelength and energy density combination for promoting stem cell activity across all time intervals (24, 48, and 72 hours). On the other hand, 980 nm (2.3 J/cm²) consistently demonstrated the least efficacy. Pairwise comparisons highlighted statistically significant differences between most groups, underscoring the superior performance of 660 nm over 808 nm and 980 nm.

### *Time-Point Comparisons*

Out of the observed time points, the one at 24 hours post-sampling had the highest overall mean stem cell percentage (57.68%) as well as the highest individual value of 66.67%. The lowest recorded value was observed at 72 hours with a mean of 42.46% (Supplementary file, Figure S1-S3).

## Discussion

During the last ten years, several studies have been

**Table 1.** Laser Parameters

| Laser Type | Wavelength (nm) | Peak Power (mW) | Irradiation Time (s) | Spot Diameter at the Focus (cm²) | Energy Density (J/cm²) | Sessions | Emission Mode | Delivery System | Energy Distribution |
|---|---|---|---|---|---|---|---|---|---|
| Diode Laser | 660 | 150 | 10 | 0.5 | 3.0 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |
| Diode Laser | 660 | 150 | 17 | 0.5 | 5.1 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |
| Diode Laser | 808 | 250 | 6 | 0.5 | 3.0 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |
| Diode Laser | 808 | 250 | 10 | 0.5 | 5.0 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |
| Diode Laser | 980 | 200 | 8 | 0.5 | 3.2 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |
| Diode Laser | 980 | 200 | 13 | 0.5 | 5.0 | 3 (24-hour intervals) | Continuous Wave | Konftec | Uniformed |

**Table 2.** Comparison of the Effect of 660, 808 and 980 nm Wavelengths of Low-Level Laser in 24, 48, and 72 Hours on the Average Percentage of Follicle Stem Cells of Human Third Molar Teeth

| Time (h) | Group I | Group J | Mean ± SD (I) | Mean ± SD (J) | Difference (I-J) | Statistical Significance (*P*) |
|---|---|---|---|---|---|---|
| 24 | 660 (3 J/cm²) | 660 (1.5 J/cm²) | 63.91 ± 0.38 | 66.67 ± 1.15 | -2.75 | < 0.001 |
| 24 | 660 (3 J/cm²) | 808 (3 J/cm²) | 63.91 ± 0.38 | 59.87 ± 0.58 | 4.04 | < 0.001 |
| 24 | 660 (3 J/cm²) | 808 (5 J/cm²) | 63.91 ± 0.38 | 60.45 ± 0.39 | 3.46 | < 0.001 |
| 24 | 660 (3 J/cm²) | 980 (2.3 J/cm²) | 63.91 ± 0.38 | 45.19 ± 1.05 | 18.72 | < 0.001 |
| 24 | 660 (3 J/cm²) | 980 (2.5 J/cm²) | 63.91 ± 0.38 | 50.00 ± 0.19 | 13.91 | < 0.001 |
| 48 | 660 (1.5 J/cm²) | 808 (5 J/cm²) | 64.41 ± 0.82 | 59.54 ± 0.68 | 4.86 | < 0.001 |
| 48 | 808 (5 J/cm²) | 980 (2.5 J/cm²) | 59.54 ± 0.68 | 48.95 ± 0.88 | 10.59 | < 0.001 |
| 72 | 660 (1.5 J/cm²) | 980 (2.3 J/cm²) | 63.16 ± 0.88 | 42.46 ± 0.77 | 20.70 | < 0.001 |
| 72 | 808 (3 J/cm²) | 980 (2.5 J/cm²) | 56.90 ± 0.86 | 46.44 ± 0.62 | 10.46 | < 0.001 |

carried out to explore the potential for isolating stem cells from different dental tissues, including the periodontal ligament, dental follicles, and root apical papilla.[15,16] A highly accessible source of stem cells among them is the follicle of the third molar tooth, which can be surgically extracted from impacted wisdom teeth at a reasonable cost. In humans, the organogenesis of the third molar starts after birth and is complete by age six[17]; therefore, the capacity of DFSCs to differentiate into various types of tissues, including neural and osseous tissues, has potential applications in cell-based therapies for maxillofacial bone defects and nerve damage repair.[4,18]

This study focused on evaluating the effects of 660 nm, 808 nm, and 980 nm PBM at varying energy densities on the proliferation of stem cells derived from third molar follicles. PBM has been proven to stimulate growth and cell proliferation.[19-21] Therefore, it could be applied to stimulate stem cell proliferation or to induce differentiation into various cell types.[22] However, its performance is heavily dependent on various factors, including laser power, wavelength, exposure time, energy density (fluence), and power density (irradiance).[23]

Our findings demonstrate that PBM at 660 nm, 808 nm, and 980 nm wavelengths affects the differentiation and proliferation of human molar follicle stem cells with significant variations across different time points. Specifically, the 660 nm at 5.1 J/cm² showed superior performance compared with others. Additionally, the highest overall mean stem cell percentage (57.68%) and the maximum individual value (66.67%) were observed at 24 hours. Differences across groups were statistically significant ($P < 0.001$) (For further understanding, review Supplementary file, Figures S4-S6).

Our protocols align with the established protocols of LLLT in cellular and tissue modulation. The effectiveness of the selected wavelengths and energy densities of low-level lasers applied in this study is supported by previous studies. The 660 nm wavelength has been extensively studied for its impact on tissue repair and inflammation control. Previous studies indicate that the energy densities of 3 J/cm² and 5 J/cm² lead to significant alteration of fibroblast cell viability, inhibition of pro-inflammatory cytokines, and improvement of healing in collagenase-induced tendinitis models.[24,25] The 808 nm wavelength at energy densities of 3 J/cm² and 5 J/cm² has improved skeletal muscle performance and delayed fatigue.[26] Additionally, research on animals has demonstrated that the 980 nm wavelength can decrease neuropathic pain, with the 5 J/cm² dose providing more pronounced relief.[27]

Naderi et al. in their study on human hair follicles found that a wavelength of 685 nm and an energy density of 5 J/cm² (among various densities ranging from 0 to 20 J/cm²) exhibited the maximum rate of proliferation and enhanced hair follicle survival.[28] These results are consistent with the findings of our study.

Comparing 24 hours to 48 and 72 hours, our results show that cell viability and proliferation are better at the 24-hour time point. The least effectiveness was observed at the 72-hour time point. Ferro et al.'s findings are in line with our results; we also observed significant increases in cell viability at 24 hours compared to later time points, suggesting that early responses to PBM are more pronounced.

These biological responses may be linked to the intracellular signaling and mitochondrial mechanisms triggered by PBM at specific wavelengths and energy density.

PBM at wavelengths of 660 nm, 808 nm, and 980 nm, applied at energy densities similar to those in our study (≈ 1–5 J/cm²), has been shown to influence mitochondrial function, ATP production, reactive oxygen species (ROS) signaling, and NF-κB activation, thereby modulating stem cell proliferation and survival. Etemadi et al and Hamblin[30] investigated the underlying mechanisms using 810 nm at ~3 J/cm², which demonstrated increased mitochondrial membrane potential (MMP) and ATP, along with a controlled rise in ROS, which activated NF-kB via protein kinase D, resulting in greater cell proliferation. This effect was blocked when ROS were neutralized, although ATP production remained elevated.[29,30] In an

in vitro comparison of 635, 660, 808, and 980 nm PBM on human periodontal ligament mesenchymal stem cells (PDLMSCs), 980 nm at 4 J/cm² produced the most pronounced increase in viability by day 3, with sustained proliferation on day 5 across all densities. Similarly, Etemadi et al investigated 660 nm and 980 nm PBM in PDLMSCs over several irradiation cycles, reporting improved viability, reduced apoptosis, and enhanced osteogenic differentiation markers (e.g., RUNX2, OPN, OCN), especially under 660 nm conditions versus controls.[31] Additionally, Etemadi et al tested 980 nm at 4 J/cm² on buccal fat pad stem cells in a different study, finding a significant proliferation boost at 48–72 hours, highlighting wavelength-dependent effects on signaling and survival.[32]

Collectively, these findings reinforce the concept that PBM effects are wavelength-specific. In particular, 980 nm at ~4 J/cm² appears especially effective for long-term cell viability, while 660 nm at lower fluences enhances mitochondrial ATP and differentiation signaling. In line with these data, the enhanced proliferative response at 660 nm and 5.1 J/cm² in our study likely reflects a balance of mitochondrial activation and redox-sensitive pathway engagement, potentially including NF-κB and PI3K/Akt signaling. Confirmatory studies probing gene expression and mitochondrial metrics in follicular stem cells are needed to precisely map these pathways.

## Conclusion

On the basis of the results of the current study, we concluded that the highest mean percentage of human third molar follicle stem cells was achieved by a 24-hour energy density of 5.1 J/cm² at a wavelength of 660 nm. To achieve optimal results, various factors such as irradiation conditions, output power, equipment calibration, and other parameters must also be investigated. However, despite the limitation of this study, the 660-nm wavelength at a fluence of 5.1 J/cm² at 24 hours could be potentially suggested as the protocol for achieving the best results in the proliferation of third molar follicle stem cells. To confirm the observed effects and develop standardized PBM protocols for clinical application, further studies with larger sample sizes are recommended.

### Authors' Contribution

**Conceptualization:** Mona Mohajeri Tehrani, Naghmeh Bahrami.
**Data curation:** Fatemeh Ghahremani, Abdolreza Mohamadnia.
**Formal analysis:** Mohammad Bayat, Shamim Chinian.
**Investigation:** Fatemeh Ghahremani, Abdolreza Mohamadnia.
**Methodology:** Mona Mohajeri Tehrani, Naghmeh Bahrami.
**Project administration:** Mona Mohajeri Tehrani, Naghmeh Bahrami.
**Resources:** Abdolreza Mohamadnia, Naghmeh Bahrami.
**Software:** Abdolreza Mohamadnia, Mohammad Bayat.
**Supervision:** Naghmeh Bahrami.
**Validation:** Mona Mohajeri Tehrani, Mohammad Bayat, Shamim Chinian.
**Visualization:** Naghmeh Bahrami, Fatemeh Ghahremani, Shamim Chinian.
**Writing–original draft:** Mona Mohajeri Tehrani, Fatemeh Ghahremani, Shamim Chinian.
**Writing–review & editing:** Mona Mohajeri Tehrani, Naghmeh Bahrami.

### Competing Interests

None.

### Ethical Approval

This study was conducted with the approval of the ethics committee, with the designated reference code of IR.TUMS.DENTISTRY.REC.1401.119.

### Funding

This is a self-funded study.

### Supplementary Files

Supplementary file 1 contains Figures S1-S6.

### References

1. Farré-Guasch E, Martí-Pagè C, Hernádez-Alfaro F, Klein-Nulend J, Casals N. Buccal fat pad, an oral access source of human adipose stem cells with potential for osteochondral tissue engineering: an in vitro study. Tissue Eng Part C Methods. 2010;16(5):1083-94. doi: 10.1089/ten.TEC.2009.0487.
2. Friedenstein AJ, Piatetzky-Shapiro II, Petrakova KV. Osteogenesis in transplants of bone marrow cells. J Embryol Exp Morphol. 1966;16(3):381-90.
3. Yamada Y, Boo JS, Ozawa R, Nagasaka T, Okazaki Y, Hata K, et al. Bone regeneration following injection of mesenchymal stem cells and fibrin glue with a biodegradable scaffold. J Craniomaxillofac Surg. 2003;31(1):27-33. doi: 10.1016/s1010-5182(02)00143-9.
4. Bayat M, Bahrami N, Bayat H, Manafi Z, Daustany M, Mohamadnia A. Comparison the differentiate ability of wisdom tooth follicle stem cells into nerve and bone tissue. J Appl Tissue Eng. 2017;4(1):11-22. doi: 10.22034/jate.2017.17.
5. Mori G, Ballini A, Carbone C, Oranger A, Brunetti G, Di Benedetto A, et al. Osteogenic differentiation of dental follicle stem cells. Int J Med Sci. 2012;9(6):480-7. doi: 10.7150/ijms.4583.
6. Yalvac ME, Ramazanoglu M, Rizvanov AA, Sahin F, Bayrak OF, Salli U, et al. Isolation and characterization of stem cells derived from human third molar tooth germs of young adults: implications in neo-vascularization, osteo-, adipo- and neurogenesis. Pharmacogenomics J. 2010;10(2):105-13. doi: 10.1038/tpj.2009.40.
7. Ahrabi B, Rezaei Tavirani M, Khoramgah MS, Noroozian M, Darabi S, Khoshsirat S, et al. The effect of photobiomodulation therapy on the differentiation, proliferation, and migration of the mesenchymal stem cell: a review. J Lasers Med Sci. 2019;10(Suppl 1):S96-103. doi: 10.15171/jlms.2019.S17.
8. Duggett N. Photobiomodulation in Animal Models of Ageing and Alzheimer's Disease [dissertation]. Durham University; 2013.
9. Medhat A, El-Zainy MA, Fathy I. Photo biomodulation of dental derived stem cells to ameliorate regenerative capacity: in vitro study. Saudi Dent J. 2024;36(2):347-52. doi: 10.1016/j.sdentj.2023.11.018.
10. Borzabadi-Farahani A. Effect of low-level laser irradiation on proliferation of human dental mesenchymal stem cells; a systemic review. J Photochem Photobiol B. 2016;162:577-82. doi: 10.1016/j.jphotobiol.2016.07.022.
11. El Gammal ZH, Zaher AM, El-Badri N. Effect of low-level laser-treated mesenchymal stem cells on myocardial infarction.

Lasers Med Sci. 2017;32(7):1637-46. doi: 10.1007/s10103-017-2271-1.
12. Han B, Fan J, Liu L, Tian J, Gan C, Yang Z, et al. Adipose-derived mesenchymal stem cells treatments for fibroblasts of fibrotic scar via downregulating TGF-β1 and Notch-1 expression enhanced by photobiomodulation therapy. Lasers Med Sci. 2019;34(1):1-10. doi: 10.1007/s10103-018-2567-9.
13. Mohammadi F, Bahrami N, Nazariyan M, Mohamadnia A, Hakimiha N, Nazariyan A. Effect of photobiomodulation therapy on differentiation of mesenchymal stem cells derived from impacted third molar tooth into neuron-like cells. Photochem Photobiol. 2022;98(6):1434-40. doi: 10.1111/php.13627.
14. Etemadi A, Sadatmansouri S, Sodeif F, Jalalishirazi F, Chiniforush N. Photobiomodulation effect of different diode wavelengths on the proliferation of human gingival fibroblast cells. Photochem Photobiol. 2021;97(5):1123-8. doi: 10.1111/php.13463.
15. Namvaran Abbasabad A, Tavakkoli Ghazani F. The effect of *Salvia officinalis* hydroalcoholic extract on PTZ-induced seizure threshold in vincristine injected mice. J Shahrekord Univ Med Sci. 2012;13(6):47-55. [Persian].
16. Bayat M, Karimi Aval S, Amirzade MH, Mohamadnia A, Bahrami N. Reconstruction of alveolar defects with regenerative properties of adipose-derived stem cells. J Craniomaxillofacial Res. 2023;10(2):46-51. doi: 10.18502/jcr.v10i2.14050.
17. Takeda T, Tezuka Y, Horiuchi M, Hosono K, Iida K, Hatakeyama D, et al. Characterization of dental pulp stem cells of human tooth germs. J Dent Res. 2008;87(7):676-81. doi: 10.1177/154405910808700716.
18. Mohammadi Golrang E, Dibaji F, Bahrami N, Mohammadi Golrang A. Human dental pulp stem cells differentiation: a review. J Craniomaxillofacial Res. 2018;5(1):461-7.
19. Orăsan MS, Bolfa P, Coneac A, Mitrea DR, Moldovan R, Mihu C, et al. Stimulation of hair regrowth using low-level laser treatment in a rat model of alopecia. Digest J Nanomater Biostruct. 2013;8(4):1571-80.
20. van Gemert MC, Welch AJ. Clinical use of laser-tissue interactions. IEEE Eng Med Biol Mag. 1989;8(4):10-3. doi: 10.1109/51.45950.
21. Gardin C, Ricci S, Ferroni L. Dental stem cells (DSCs): classification and properties. In: Zavan B, Bressan E, eds. Dental Stem Cells: Regenerative Potential. Cham: Springer International Publishing; 2016. p. 1-25. doi: 10.1007/978-3-319-33299-4_1.
22. Malthiery E, Chouaib B, Hernandez-Lopez AM, Martin M, Gergely C, Torres JH, et al. Effects of green light photobiomodulation on dental pulp stem cells: enhanced proliferation and improved wound healing by cytoskeleton reorganization and cell softening. Lasers Med Sci. 2021;36(2):437-45. doi: 10.1007/s10103-020-03092-1.
23. de Freitas LF, Hamblin MR. Proposed mechanisms of photobiomodulation or low-level light therapy. IEEE J Sel Top Quantum Electron. 2016;22(3):7000417. doi: 10.1109/jstqe.2016.2561201.
24. Szezerbaty SK, de Oliveira RF, Pires-Oliveira DA, Soares CP, Sartori D, Poli-Frederico RC. The effect of low-level laser therapy (660 nm) on the gene expression involved in tissue repair. Lasers Med Sci. 2018;33(2):315-21. doi: 10.1007/s10103-017-2375-7.
25. Torres-Silva R, Lopes-Martins RA, Bjordal JM, Frigo L, Rahouadj R, Arnold G, et al. The low-level laser therapy (LLLT) operating in 660 nm reduce gene expression of inflammatory mediators in the experimental model of collagenase-induced rat tendinitis. Lasers Med Sci. 2015;30(7):1985-90. doi: 10.1007/s10103-014-1676-3.
26. de Almeida P, Lopes-Martins RA, De Marchi T, Tomazoni SS, Albertini R, Corrêa JC, et al. Red (660 nm) and infrared (830 nm) low-level laser therapy in skeletal muscle fatigue in humans: what is better? Lasers Med Sci. 2012;27(2):453-8. doi: 10.1007/s10103-011-0957-3.
27. Masoumipoor M, Jameie SB, Janzadeh A, Nasirinezhad F, Soleimani M, Kerdary M. Effects of 660- and 980-nm low-level laser therapy on neuropathic pain relief following chronic constriction injury in rat sciatic nerve. Lasers Med Sci. 2014;29(5):1593-8. doi: 10.1007/s10103-014-1552-1.
28. Naderi MS, Tabaie SM, Soheilifar MH, Pornour M. Evaluation of the effect of low-level laser irradiation on viability and ROS production in human hair follicle stem cells. Tehran Univ Med J. 2021;79(1):26-32. [Persian].
29. Etemadi A, Faghih A, Chiniforush N. Effects of photobiomodulation therapy with various laser wavelengths on proliferation of human periodontal ligament mesenchymal stem cells. Photochem Photobiol. 2022;98(5):1182-9. doi: 10.1111/php.13588.
30. Hamblin MR. Mechanisms and mitochondrial redox signaling in photobiomodulation. Photochem Photobiol. 2018;94(2):199-212. doi: 10.1111/php.12864.
31. Etemadi A, Aghaie M, Sayar F, Chiniforush N. Effect of photobiomodulation therapy with 660 and 980 nm diode lasers on differentiation of periodontal ligament mesenchymal stem cells. Sci Rep. 2024;14(1):20587. doi: 10.1038/s41598-024-71386-3.
32. Etemadi A, Khajehmougahi K, Solimei L, Benedicenti S, Chiniforush N. Photobiomodulation effect of different diode wavelengths on the proliferation of human buccal fat pad mesenchymal cells. Appl Sci. 2024;14(2):847. doi: 10.3390/app14020847.