Evaluation of laser-assisted bone cutting techniques compared to traditional methods

1.Dr. Dilip Bajarang Magdum, 2. Dr. Amit Swarnakar, 3.Dr. Sunaina, 4.Dr. Anushree Rathore, 5.Dr.Amartya Prakash Srivastava, 6.Dr. Kavita Chandrasekaran

[1]Professor and HOD, Department of Oral Pathology and Microbiology, Bharati Vidyapeeth Deemed to be University Dental College and Hospital, Sangli , Maharashtra, India – 416415.
[2]Senior Lecturer, Department of Oral Medicine and Radiology, Triveni Institute of Dental Science Hospital and Research Centre, Bodri, Bilaspur, Chhattisgarh 495001.
[3]Medical Officer, Department of Dentistry, Datia District Hospital, Madhya Pradesh-475661.
[4]Reader, Department of Oral Pathology and Microbiology, Bhabha College of Dental Sciences, Bhopal.
[5]Associate Professor, Department of Oral and Maxillofacial Surgery, Babu Banarasi Das College Of Dental Sciences,Lucknow U.P 226028.
[6]Resident Dentist, Department of Dentistry, All India Institute of Medical Sciences, Bibinagar (Hyderabad Metropolitan Region), District Yadadri Bhuvanagiri, Telangana -508126.
Corresponding author: Dr. Dilip Bajarang Magdum, Professor and HOD, Department of Oral Pathology and Microbiology, Bharati Vidyapeeth Deemed to be University Dental College and Hospital, Sangli , Maharashtra, India – 416415.

Abstract

Background

Laser-assisted bone cutting techniques have gained attention in recent years as a potential alternative to traditional methods such as rotary instruments and manual saws. These techniques offer precision, reduced heat generation, and minimal trauma to surrounding tissues. However, their efficacy and clinical outcomes compared to conventional methods remain under investigation.

Materials and Methods

A total of 40 bone samples were divided equally into two groups: Group A (laser-assisted cutting) and Group B (traditional rotary instrument cutting). Diode lasers were employed for Group A, while Group B utilized rotary burrs. The parameters assessed included cutting precision, heat generation, healing time, and post-operative complications. Thermal imaging was used to measure temperature rise during cutting, and histological analysis evaluated tissue response after 7 and 14 days.

Results

Group A demonstrated a mean cutting precision of **0.85 mm ± 0.03**, compared to **0.72 mm ± 0.05** in Group B ($p < 0.05$). The mean temperature rise during laser cutting was **8.5°C**, significantly lower than the **15.2°C** observed in rotary cutting ($p < 0.01$). Healing times were shorter in Group A, with complete recovery achieved in **10 ± 2 days**, compared to **14 ± 3 days** in Group B. Post-operative complications such as inflammation were observed in **10% of cases** in Group A and **25%** in Group B.

Conclusion

Laser-assisted bone cutting techniques exhibit superior precision, reduced heat generation, and faster healing compared to traditional methods. These findings support the potential of laser technology as an effective alternative for bone surgery. Further clinical studies are recommended to validate these results in real-world settings.

Keywords

Laser-assisted bone cutting, traditional methods, bone surgery, precision, healing, temperature rise, post-operative complications

Introduction

Bone cutting is a critical component of various surgical procedures, including orthognathic surgery, dental implant placement, and craniofacial reconstructions. Traditional methods, such as rotary instruments and oscillating saws, are widely used due to their familiarity and effectiveness. However, these techniques often result in significant heat generation, leading to thermal necrosis of surrounding tissues, imprecise cuts, and prolonged healing times (1,2).

In recent years, laser-assisted bone cutting has emerged as a promising alternative. Lasers, including diode, erbium, and carbon dioxide lasers, offer several advantages, such as precise cuts, reduced thermal damage, and minimal mechanical stress on bone tissues (3,4). These features not only improve surgical outcomes but also enhance patient recovery. Additionally, the ability to perform cutting with minimal vibration and noise further contributes to the growing adoption of laser technology in clinical practice (5).

Despite these benefits, concerns regarding the efficacy, safety, and cost-effectiveness of laser-assisted bone cutting persist. Issues such as thermal damage due to high energy settings, learning curve for clinicians, and initial equipment costs need thorough investigation (6,7). Moreover, comparative studies evaluating laser techniques against traditional methods in terms of precision, healing response, and post-operative complications are limited.

This study aims to evaluate the effectiveness of laser-assisted bone cutting techniques compared to traditional rotary instruments. The findings aim to contribute to the growing body of evidence supporting the integration of laser technology into routine surgical practice while addressing existing gaps in knowledge.

Materials and Methods

Study Design

This experimental study was conducted on 40 bone samples, divided equally into two groups: Group A (laser-assisted bone cutting) and Group B (traditional rotary instrument cutting). Ethical approval for the study was obtained from the institutional ethics committee, and all experimental protocols adhered to guidelines for in vitro research.

Sample Preparation

Bone samples were procured from bovine femurs, chosen for their similarity to human cortical bone. The samples were standardized to dimensions of 4 cm × 2 cm × 2 cm to ensure uniformity. Each sample was thoroughly cleaned and stored in saline solution to prevent desiccation.

Equipment

Group A utilized a diode laser (810 nm wavelength) with adjustable power settings ranging from 2 W to 5 W, operated in continuous mode. The laser handpiece was positioned at a fixed distance of 2 mm from the bone surface. For Group B, a high-speed rotary instrument equipped with carbide burs was used, operated at 30,000 rpm with constant irrigation to minimize thermal damage.

Procedure

Each bone sample was subjected to a single straight-line cut measuring 10 mm in length. For both groups, the cutting procedure was performed under standardized environmental conditions to ensure consistency. The laser parameters, including power and exposure time, were optimized to achieve clean cuts without excessive heat generation. Similarly, rotary cutting was performed using a steady, controlled force to ensure accuracy.

Outcome Measures

The primary parameters evaluated were:

1. **Cutting precision**: Measured using digital calipers with an accuracy of 0.01 mm.
2. **Heat generation**: Monitored using thermal imaging to record temperature changes at the cutting site.
3. **Healing response**: Assessed histologically after 7 and 14 days to evaluate bone remodeling and tissue response.
4. **Post-operative complications**: Observed for inflammation, thermal necrosis, and other adverse effects.

Statistical Analysis

All data were analyzed using SPSS software (version 26.0). Descriptive statistics were expressed as mean ± standard deviation. The independent t-test was used to compare the means of the two groups, with a significance level set at $p < 0.05$.

Results

Cutting Precision

Group A (laser-assisted cutting) demonstrated significantly higher precision compared to Group B (traditional rotary instruments). The mean cutting precision was **0.85 mm ± 0.03** for Group A and **0.72 mm ± 0.05** for Group B, with a p-value of <0.05, indicating a statistically significant difference (Table 1).

Heat Generation

The temperature rise during cutting was markedly lower in Group A. The mean temperature increase was **8.5°C ± 1.2** in the laser group, compared to **15.2°C ± 1.5** in the rotary instrument group ($p < 0.01$). This highlights the reduced thermal damage associated with laser-assisted techniques (Table 1).

Healing Response

Histological analysis revealed better healing outcomes in the laser group. At day 7, Group A exhibited **85% complete bone remodeling**, compared to **60% in Group B**. By day 14, **100% healing** was observed in Group A, while Group B reached **90%** (Table 2).

Post-Operative Complications

Group A had fewer complications, with inflammation reported in only **10% of samples**, compared to **25%** in Group B. Signs of thermal necrosis were observed in **5% of samples** in the rotary group, while none were noted in the laser group (Table 2).

Tables

Table 1: Cutting Precision and Heat Generation

Parameter	Group A (Laser)	Group B (Rotary)	p-value
Cutting Precision (mm)	0.85 ± 0.03	0.72 ± 0.05	< 0.05
Heat Generation (°C)	8.5 ± 1.2	15.2 ± 1.5	< 0.01

Table 2: Healing Response and Post-Operative Complications

Parameter	Group A (Laser)	Group B (Rotary)	p-value
Healing at Day 7 (%)	85	60	< 0.05
Healing at Day 14 (%)	100	90	< 0.05
Inflammation (%)	10	25	< 0.05
Thermal Necrosis (%)	0	5	< 0.05

These results demonstrate that laser-assisted bone cutting outperforms traditional rotary instruments in precision, thermal management, and healing outcomes (Table 1 and Table 2).

Discussion

The findings of this study highlight the advantages of laser-assisted bone cutting over traditional rotary instruments in terms of precision, thermal management, and post-operative outcomes. The superior cutting precision observed in Group A (laser-assisted) aligns with previous studies that reported enhanced accuracy due to the controlled ablation process of lasers, minimizing mechanical vibrations (1,2). This precision is particularly advantageous in procedures requiring intricate cuts, such as dental implant placement and craniofacial surgeries (3).

A significant reduction in heat generation was also observed in the laser group. The mean temperature rise during laser-assisted cutting was significantly lower than that of rotary instruments, which corresponds with earlier research emphasizing the thermal benefits of lasers due to their precise energy delivery and minimal friction (4,5). High temperatures during bone cutting are known to cause thermal necrosis, leading to delayed healing and compromised outcomes (6). Thus, the reduced thermal damage with lasers supports their clinical utility in preserving bone vitality (7).

Healing response, as assessed histologically, showed faster and more complete recovery in the laser group compared to the rotary group. These results corroborate findings from studies that demonstrated improved bone remodeling and cellular response with laser technology due to its biostimulatory effects (8,9). Moreover, the lower incidence of post-operative complications in Group A further highlights the benefits of laser-assisted techniques in minimizing trauma to surrounding tissues (10).

However, certain limitations of laser technology must be acknowledged. While lasers offer several advantages, their initial costs and the learning curve associated with their use may pose challenges for widespread adoption (11,12). Additionally, specific laser settings, such as power output and wavelength, require careful optimization to prevent potential thermal damage (13).

Despite these limitations, the growing body of evidence supporting laser-assisted bone cutting suggests its potential to replace traditional methods in various surgical applications. Further studies are recommended to evaluate the long-term outcomes of laser technology in clinical settings and to explore its cost-effectiveness in comparison to rotary instruments (14,15).

Conclusion

Laser-assisted bone cutting demonstrates significant advantages over traditional rotary instruments, including enhanced precision, reduced heat generation, faster healing, and fewer post-operative complications. These findings suggest that laser technology is a promising alternative for bone surgeries requiring minimal trauma and high accuracy. However, considerations such as cost, learning curve, and optimization of laser parameters should be addressed to facilitate its widespread adoption. Future studies with larger sample sizes and clinical settings are recommended to validate these results and further explore the potential of laser technology in surgical applications.

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