ORIGINAL ARTICLE

CONTENTS

Ex vivo histological comparison between Er, Cr: YSGG laser and slow-speed hand piece in bone cutting

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ABSTRACT

Aim: This study aimed to compare the efficiency of Er, Cr: YSGG laser, and handpiece bur in bone cutting by histological examination.

Materials and Methods: This was an *ex vivo* study using the bone specimens from the sheep as samples, different ER, CR: YSGG laser parameters will be used (2.5W, 20Hz/4W, 20Hz/6W, 20Hz) versus slow hand piece to make osteotomy. After histopathological processing, the length, width, length-to-width ratio, precision, and carbonization of laser osteotomy will be examined under a light microscope.

Results: ER, CR: YSGG lasers can be considered practical, effective, and easy for bon incisions. The histological results showed high incision quality with the Er, Cr: YSGG laser system, versus slow speed handpiece. The quality of laser incision at 4W, 20HZ is the best among the parameters $p<0.001$.

Conclusions: The Er, CR: YSGG laser if used properly with appropriate parameters is very effective alternative device in oral osteotomy.

KEYWORDS: bon, histology, incision, Er, Cr: YSGG laser, thermal damage

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INTRODUCTION

One of the oldest forms of orthopaedical treatment is osteotomy. It has been around for nearly a thousand years and is still used today. An osteotomy's fundamental idea is to cut or incision bone, usually to alter the shape or alignment of the bone [1]. Tool for osteotomy. Although effective, the bur's direct contact with bone during the cut causes vibrations, making patients uncomfortable. Thus, it has been suggested that lasers be used for osteotomy treatments. Surgical lasers, however, might facilitate the removal of bone tissue without resulting in heat injury, making this feasible [2]. Bone, known as specialized, living, complex connective tissue, supports and shields the body's critical organs [3]. All bones are composed of a dense outer layer of compact bone and a core of cancellous bone. The cancellous bone is the main component of a bone. It surrounds marrow voids that may contain hematological tissue and form a trabecular network [4]. The accurate, contactless laser ablation method can remove the body's hard tissue. Laser osteotomy speeds up the healing of the residual bone compared to traditional bone cutting with piezo osteotomes. Recovery is accelerated because the spongy structure is preserved [5]. Bone defect repair is still a significant clinical orthopedic issue. Bone, a highly vascularized tissue, depends on the intimate spatial and temporal relationship between blood vessels and bone cells to preserve skeletal integrity [6]. Cutting hard/soft tissue is a complex interaction of laser energy with water and tissues (hydrophotonics). When tissues interact with laser energy, the effect is influenced by emission wavelengths, tissue optical properties, time of exposure, laser energy, and absorption of the laser energy into the tissues [7]. Therefore, while cutting bone with a laser, there is less trauma and heat damage. It encourages healing and causes less scar tissue to form, as well as less bleeding and infection [8]. A surgeon can work on tissues more accurately and ablate tissues in hard-to-reach places by using a laser as a surgical tool. The properties of the tissue, including its optical characteristics, color, consistency, and thermal properties heat capacity, temperature conductivity, as well as those associated with the laser system, wavelengths, and emission parameters, such as applied power, focal spot size, and emission mode exposure time, determine how the laser acts on the tissue [9-10]. Because water is the chromophore target, their usage in dentistry goes beyond soft tissues such as mucosa and gingiva, to the hard ones, including enamel, dentine, bone and carious tissue. The thermal effects of erbium lasers on the target tissues can be detected through vaporization. A photomechanical effect is created when water molecules explode, which

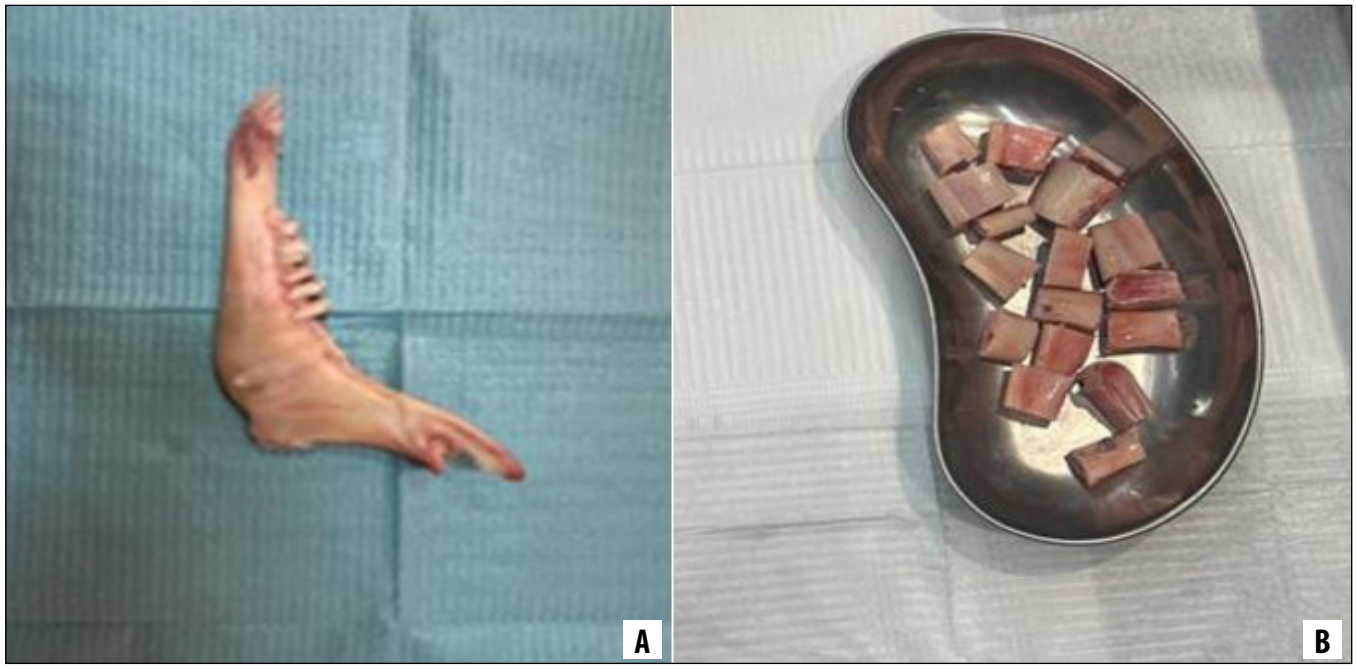


Fig. 1. Sheep mandible and preparation of bone specimens: A. Sheep mandible used for specimen collection; B. Mandibular bone blocks prepared for the osteotomy procedures
Source: Own materials

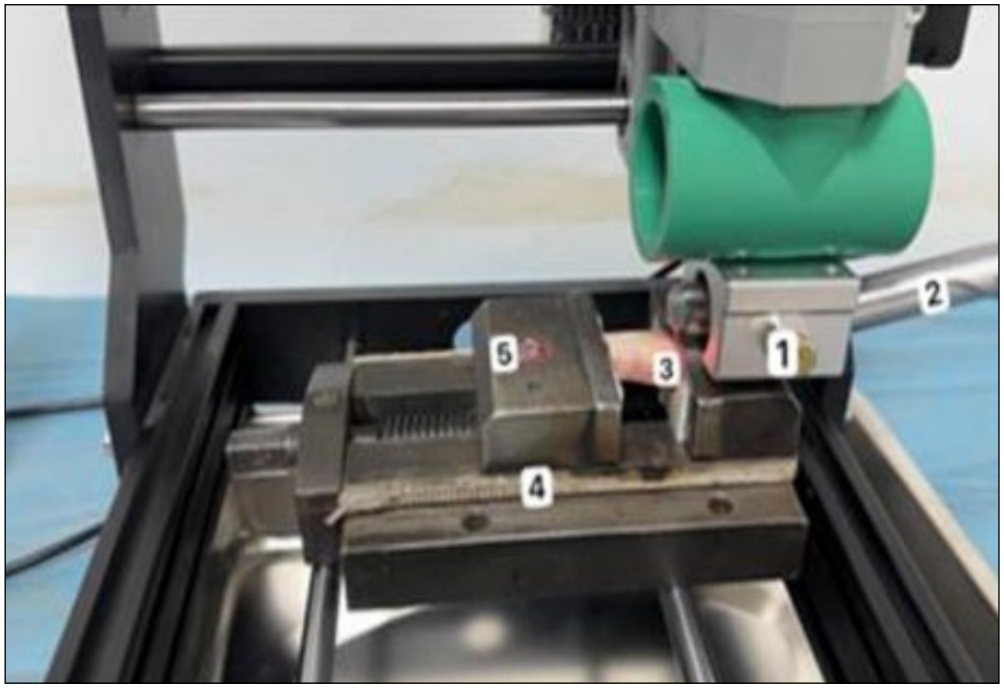


Fig. 2. A CNC devise
1-Handle
2-Laser hand piece
3-Bone specimen
4-Mounted table
5-Arms that hold the specimen
Source: Own materials

aids in the ablative and cleaning processes [11]. A laser can create accurate cutting and reduce mechanical damage to the surrounding tissues when cutting bone [12]. The wavelength of Erbium lasers is highly absorbed by water and hydroxyapatite making it suitable for both hard and soft tissue ablation [13]. Erbium laser offers an attractive alternative drilling modality because it does not require physical contact with the bone in order to drill holes, cut bone with minimal thermal damage & precise control of bone cutting [11]. The Er. Cr: YSGG laser is effective for various dental operations involving both hard and soft tissues because it shows peak absorption by hydroxyapatite (HA) and water at 2780 nm in the infrared spectrum [14]. Since water and hydroxyapatite crystals absorb a large portion of the Erbium, Chromium YSGG laser at 2780 nm wavelength, this free-running pulsed laser has shown promise in treating a variety of hard tissue procedures and soft tissue operations [15]. The considerable heating of the bone and surrounding tissues during irradiation has been controlled by the pulse-mode laser and the water spray,

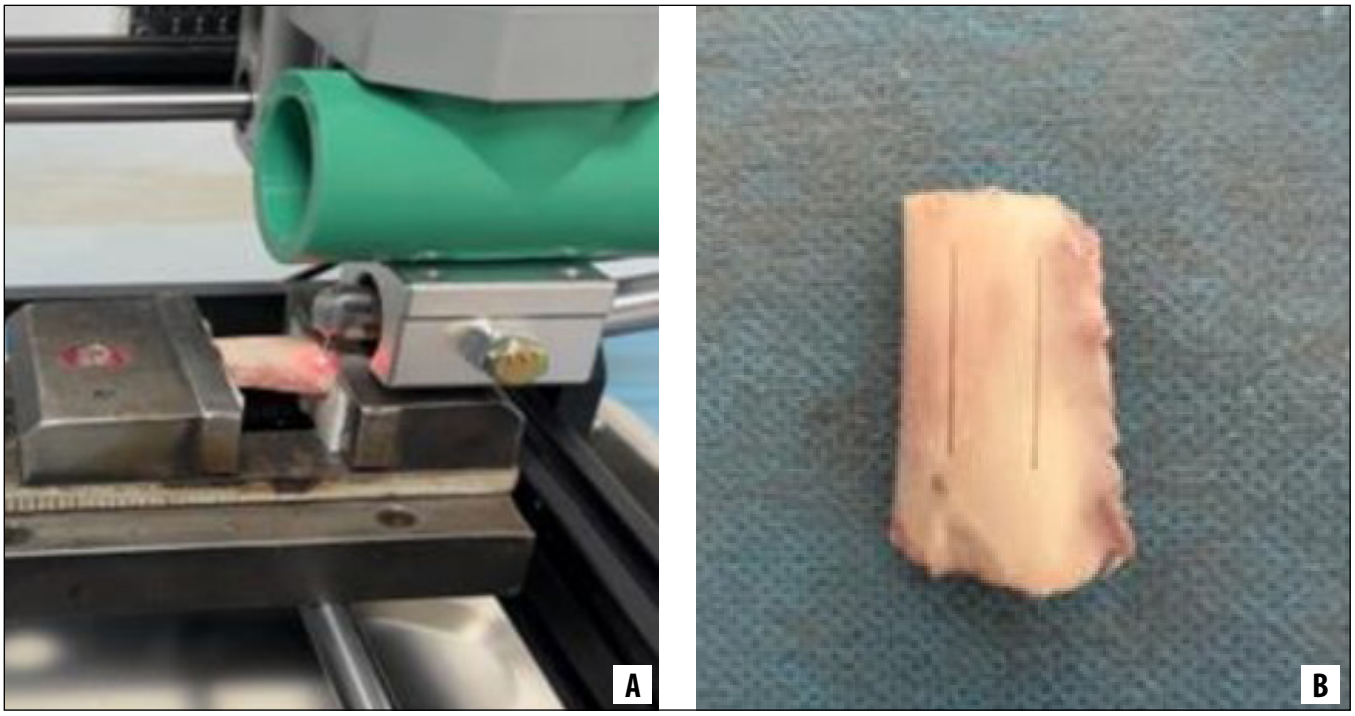


Fig. 3. Laser osteotomy procedure: A. Er, Cr:YSGG laser osteotomy performed on the bone specimen mounted on the CNC device; B. Bone specimen showing the laser incisions after irradiation
Source: Own materials

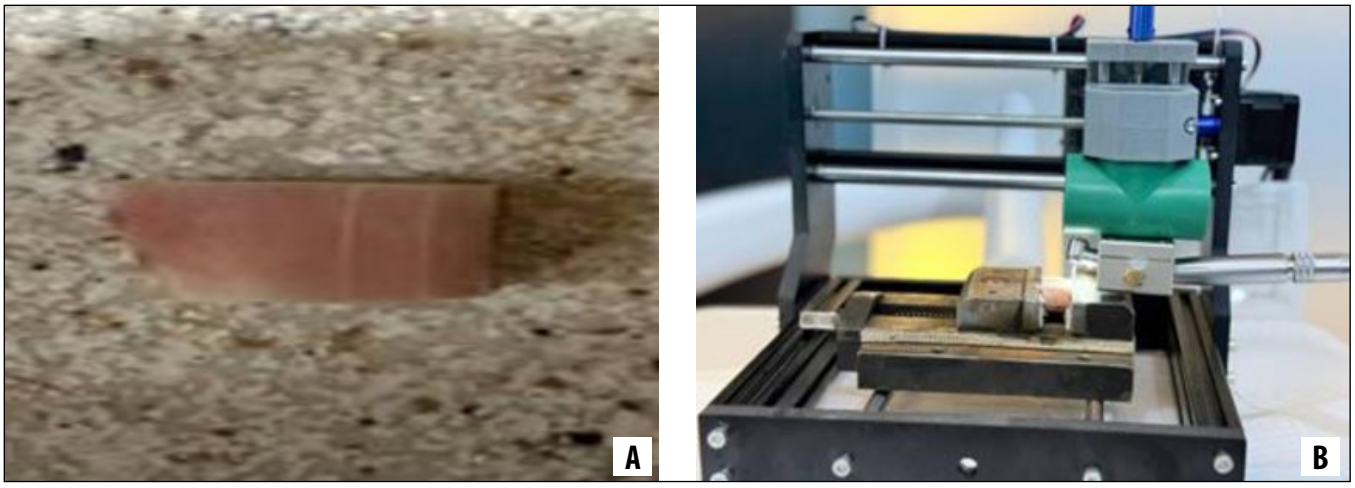


Fig. 4. Conventional osteotomy procedure: A. Conventional osteotomy performed using a low-speed handpiece on the bone specimen mounted on the CNC device; B. Bone specimen showing the conventional incision
Source: Own materials

guaranteeing positive clinical outcomes without compromising wound healing [16]. This *ex vivo* study aimed to compare the efficiency of Er, Cr: YSGG laser, and handpiece bur in bone cutting by histological examination.

MATERIALS AND METHODS

SAMPLES COLLECTION

This study used the following instruments: Er, Cr: YSGG (WATERLASE I plus, BIOLASE) device set at three parameters, and a low-speed handpiece (Guangdong JINME Medical Technology Co., Ltd) using round stainless-steel burs (ISO diameter 018). Ethics approval was taken from the Research & Ethics Committee at the Institute of Laser for Postgraduate Studies/University of Baghdad (464 in 10-10-2023). In this *ex vivo* study, three mandibles of Iraqi sheep (1–1.5 years of age) were used within four to six hours after slaughter. The bone was saved and humidified at the same temperature in an ice box. The sheep's mandible has been cut into blocks (specimens), with measurements of 1 cm in length, 2 cm in width, and

Table 1. Description of length, width and length to width ratio of specimen in different study groups

Characteristic	2.5 W / 20 Hz N = 10[1]	4 W / 20 Hz, N = 10[1]	6 W / 20 Hz, N = 10[1]	Hand Piece, N = 10[1]	P-value[2]
Length (mm)	0.56 ± 0.04	0.91 ± 0.08	0.59 ± 0.05	0.42 ± 0.08	<0.001
Width (mm)	0.79 ± 0.11[c]	0.73 ± 0.05	0.47 ± 0.18	0.94 ± 0.24	<0.001
Length to width ratio	0.72 ± 0.13	1.24 ± 0.16	1.38 ± 0.39	0.46 ± 0.06	<0.001
Grading of L/W ratio					<0.001
1 (<0.7)	6 (60.0%)	0 (0.0%)	3 (30.0%)	10 (100.0%)	
2 (0.7-1.5)	4 (40.0%)	10 (100.0%)	3 (30.0%)	0 (0.0%)	
3 (> 1.5)	0 (0.0%)	0 (0.0%)	4 (40.0%)	0 (0.0%)	

Note: [1]Mean ± SD; n (%) [2]One-way ANOVA; Fisher's exact test

Table 2. Description of the precision of cut and carbonization of bone specimens using different laser settings

Characteristic	2.5 W/20 Hz, N = 10[1]	4 W/20 Hz, N = 10[1]	6 W/20 Hz, N = 10[1]	Hand Piece, N = 10[1]	P-value[2]
Precision	2.9 ± 0.3	2.8 ± 0.4	2.0 ± 0.7	1.0 ± 0.0	<0.001
1 (bad)	0(0.0%)	0(0.0%)	2(20.0%)	10(100.0%)	
2 (moderate)	1(10.0%)	2(20.0%)	6(60.0%)	0(0.0%)	
3 (good)	9(90.0%)	8(80.0%)	2(20.0%)	0(0.0%)	
Carbonization	1.0 ± 0.0	1.3 ± 0.7	1.3 ± 0.5	1.0 ± 0.0	0.079
1 (mild)	10(100.0%)	8(80.0%)	7(70.0%)	10(100.0%)	
2 (moderate)	0(0.0%)	1(10.0%)	3(30.0%)	0(0.0%)	
3 (severe)	0(0.0%)	1(10.0%)	0(0.0%)	10(100.0%)	

Note: [1]n (%) [2]Fisher's exact test

Table 3. Description of the total score utilized in this study and the statistical differences between study groups

Characteristic	2.5 W / 20 Hz, N = 10[1]	4 W / 20 Hz, N = 10[1]	6 W / 20 Hz, N = 10[1]	Hand Piece, N = 10[1]	P-value[2]
Total score	7.3 ± 0.7	7.8 ± 0.8	6.8 ± 1.4	5.0 ± 0.0	<0.001

Note: [1]Mean ± SD [2]One-way ANOVA

original compact thickness, by electrical saw Figure 1, the total number used for this study was four blocks.

For the comparative purpose of study between conventional and laser osteotomy, the bone blocks are categorized as follows:

G1: In this bone specimen, the osteotomy was performed by an ER CR: Y S GG laser with the following parameters: 6 watts, 20 Hz, 50% air, 50% water.

G2: In this bone specimen, the osteotomy was performed by an ER CR: Y S GG laser with the following parameters: 4 watts, 20 Hz, 50% air, 50% water.

G3: In this bone specimen, the osteotomy was performed by an ER CR: YS GG laser with the following parameters: 2.5 watts, 20 Hz, 50% air, 50% water.

G4: The osteotomy was performed using a low-speed handpiece (20000- 40000 rpm) and around bur (stainless ISO size 18).

A CNC (computed numerical control) device will be used for conventional and laser osteotomy. This device provides a more precise cutting procedure and verified experimental conditions (Fig. 2). Bone samples were mounted on an X–Y table and traversed across the X plane at a speed of 0.8mm/s during laser and conventional osteotomy.

IRRADIATION FOR LASER OSTEOTOMY

Each specimen was irradiating with Er, CR: YCGG laser 2790nm for 25s for each parameter. Irradiation was performed in contact mode to make a 2 cm incision using an MGG6-6 laser tip. Different laser parameters were used in each irradiation episode (Fig. 3).

HAND PIECE OSTEOTOMY (CONVENTIONAL)

In the control group, a 2 cm incision was made in the bone specimen using a low-speed handpiece and around bur (stainless ISO size 18) for 25 s (Fig. 4).

HISTOLOGICAL EVALUATION

After the laser and conventional osteotomy, 10% buffered formalin solution was used to fix the specimens.

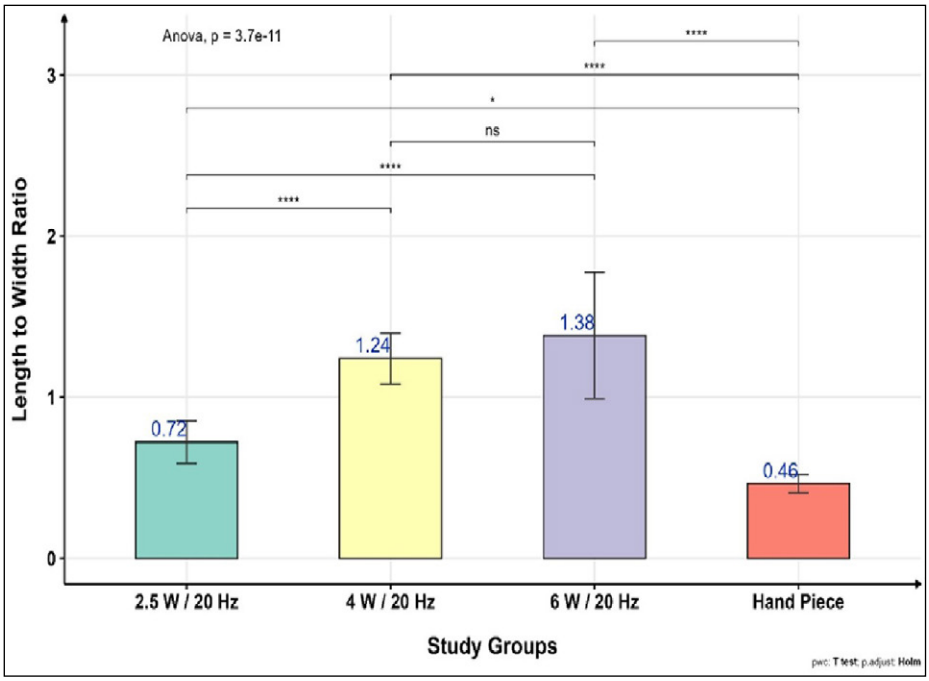


Fig. 5. Tukey's post-hoc test for the differences in length-to-width ratio between study groups
Source: Own materials

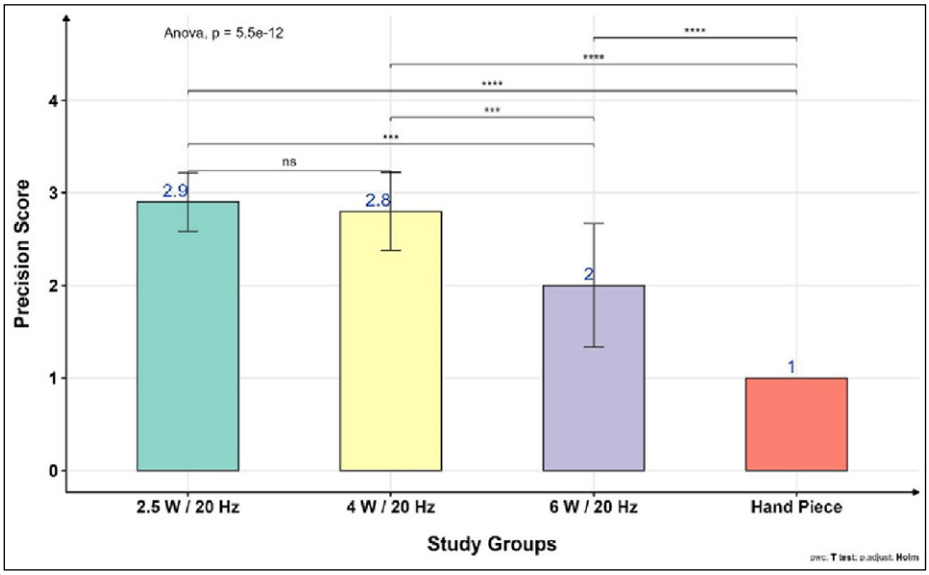


Fig. 6 Tukey's post-hoc test for the differences in precision score between study groups
Source: Own materials

They were then delivered to the histology lab for a histological analysis the same day.

SLIDES NUMBER

Ten stained slides were obtained from each bone block, and 40 slides were taken. 10 slides for the control group and 30 slides for the laser group.

HISTOLOGICAL CRITERIA

For histological assessment, each slide was examined under a light microscope by a histopathologist to evaluate the following for laser and conventional osteotomy incision:

1 - Length of incision
2 - Width of incision
3 - Length to width ratio: scored from 1-3 according to the following:
<0.7 - 1
0.7-1.5 - 2
1>1.5 - 3
4 - Carbonization: scored from 1-3 according to the f1ollowing:
1Sever - 1
Moderate - 2
Mild - 3
5-Precision: scored from 1-3 according to the following:
Bad - 1
Fair - 2
1Good - 3

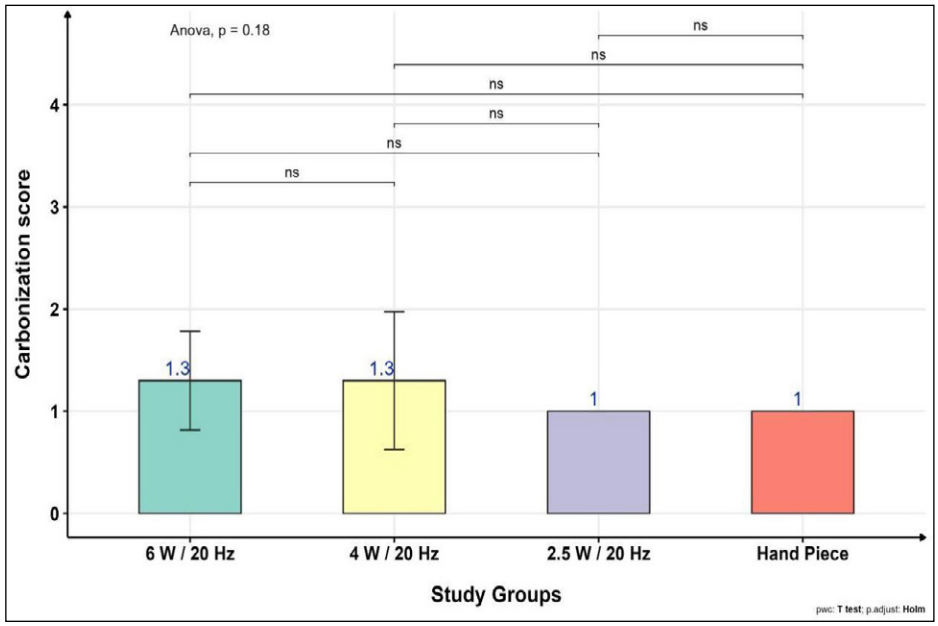


Fig. 7. Tukey's post-hoc test for the differences in carbonization score between study groups
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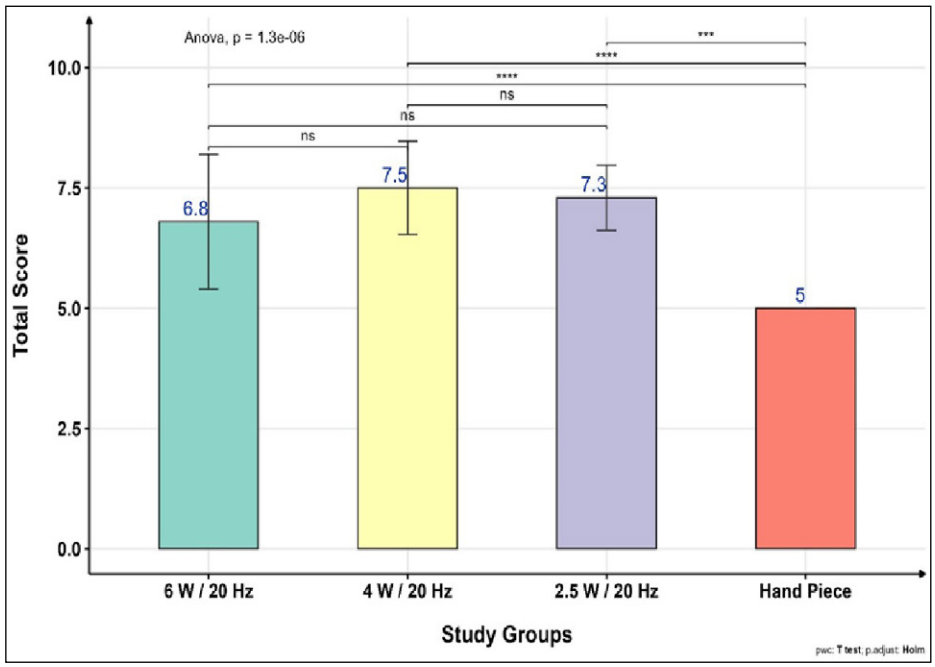


Fig. 8. Tukey's post-hoc test for the differences in total score between study groups
Source: Own materials

STATISTICAL ANALYSIS

Continuous variables were expressed as means and standard deviations. Categorical variables were expressed as frequency and percentages. The one-way ANOVA and Tukey's post-hoc test with holm adjustment was performed to find the differences in means between the study groups. The difference between categorical variables was investigated using Fisher's exact test. A P-value less than 0.05 was considered statistically significant. R software packages (dplyr, gt_summery and ggplot) were used for data processing, visualization, and statistical analysis ("R version 4.2.2, R Foundation for Statistical Computing, Vienna, and Austria").

ETHICS APPROVAL

Ethics approval was taken from the Research & Ethics Committee at the Institute of Laser for Postgraduate Studies/University of Baghdad (464 in 10-10-2023).

RESULTS

THE LENGTH, WIDTH, AND LENGTH-TO-WIDTH RATIO (L/W RATIO)

The comparative analysis of bone cutting dimensions among the four study groups - 2.5 W/20 Hz, 4 W/20 Hz, 6 W/20 Hz Er, Cr: YSGG laser settings, and the conventional

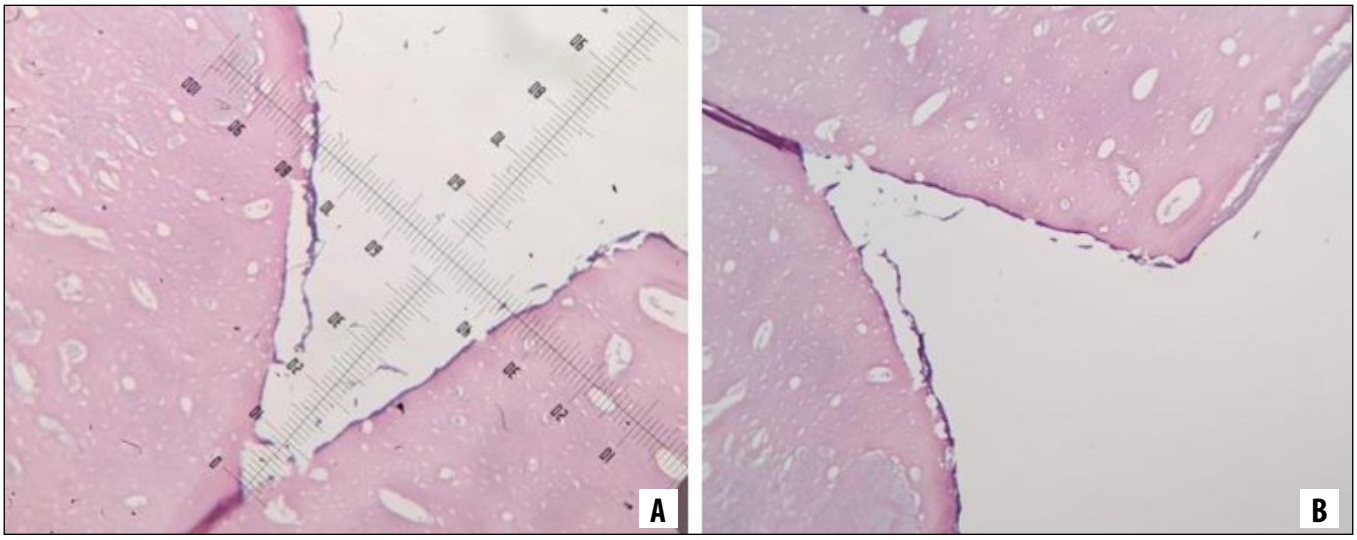


Fig. 9. Histological sections of Er, Cr:YSGG laser osteotomy at 4 W/20 Hz: A. Histomorphometric measurement showing a deep, narrow, and precise laser incision; B. Well-defined incision margins with minimal carbonization
Source: Own materials

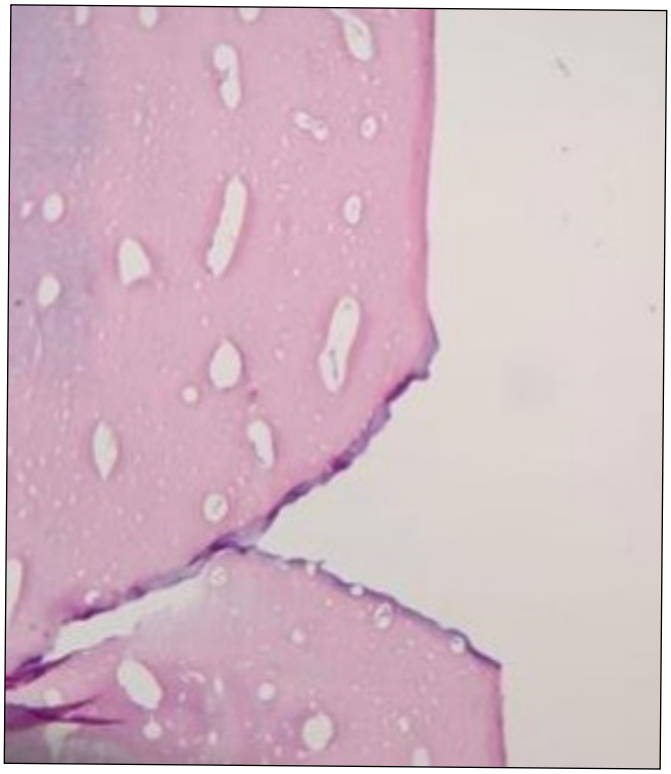


Fig. 10. Histological sections of laser osteotomy of 2.5 WATT, 20 HZ
Source: Own materials

handpiece - revealed statistically significant differences p<0.001 in all measured parameters. The 4 W/20 Hz laser group exhibited the greatest mean cut length 0.91±0.08 mm, significantly higher than all other groups, whereas the handpiece group had the shortest 0.42±0.08 mm. In terms of width, the handpiece produced the widest cuts 0.94±0.24 mm, while the 6 W/20 Hz laser group produced the narrowest 0.47±0.18 mm. The highest length-to-width ratios were observed in the 6 W/20 Hz (1.38±0.39) and 4 W/20 Hz (1.24±0.16) groups, indicating more elongated cuts, whereas the handpiece group had the lowest ratio 0.46±0.06, indicating broader, less elongated cuts. Grading of the length-to-width ratio further supported these findings: all handpiece specimens fell into Grade 1 (<0.7), indicating low elongation, while the majority of 4 W/20 Hz specimens were Grade 2 (0.7–1.5), and the 6 W/20 Hz group displayed the widest distribution across all three grades, including 40% in Grade 3 (>1.5) as show in table 1 and Figure 5.

PRECISION AND CARBONIZATION

The assessment of cut precision and carbonization levels among the study groups revealed statistically significant differences p<0.001, underscoring the impact of varying Er, Cr: YSGG laser settings and conventional handpiece use on bone cutting quality. Precision scores were highest in the 2.5 W/20 Hz group 2.9±0.3, followed closely by the 4 W/20 Hz group 2.8±0.4, indicating superior cutting accuracy compared to both the 6 W/20 Hz laser 2.0±0.7 and the handpiece 1.0±0.0. Notably, 90% and 80% of specimens in the 2.5 W and 4 W groups, respectively, were graded as having good precision, whereas all handpiece specimens were graded as poor. Regarding carbonization, the lowest levels were observed in the 2.5 W group and the hand-piece group 1.0±0.0, with all specimens demonstrating only mild carbonization. Moderate to severe carbonization was increasingly observed with higher power settings: 10% of the 4 W group and 30% of the 6 W group showed moderate to severe changes as shown in figures 6-7 and Table 2.

The comparative analysis of the total score, which integrates multiple parameters assessed in this study,

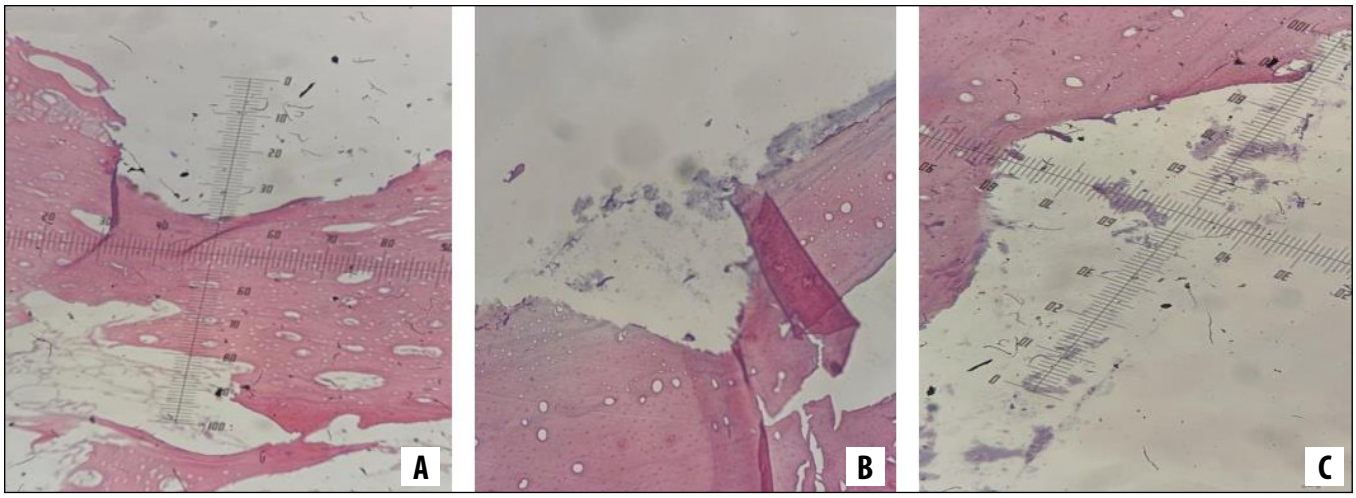


Fig. 11. Histological sections of conventional osteotomy: A. Histomorphometric measurement showing a short and wide incision; B. Irregular incision margins with disruption and fragmentation of the bone; C. Wide and irregular osteotomy surface with minimal carbonization
Source: Own materials

demonstrated statistically significant differences among the four groups $p<0.001$. The highest mean total score was observed in the 4 W/20 Hz laser group 7.8±0.8, followed closely by the 2.5 W/20 Hz group 7.3±0.7, indicating superior overall performance in terms of bone cutting efficiency, precision, and minimal thermal damage. The 6 W/20 Hz group exhibited a moderately lower total score 6.8±1.4, reflecting a decline in overall performance likely due to decreased precision and increased carbonization. In contrast, the handpiece group had a markedly lower and uniform total score 5.0±0.0, significantly inferior to all laser-treated groups, highlighting the limitations of the conventional method in achieving optimal surgical outcomes, as shown in table 3, figures 8-11.

DISCUSSION

In various fields of dentistry, laser technology and minimally invasive therapy are attracting interest. The newest laser type, the Er, Cr: YSGG laser, is ideal for surgical procedures, including osteotomy, because it can precisely coagulate arteries and ablate both soft and hard tissue while minimizing heat damage [17]. Because of its high stiffness, high mineral and water content, and quick heat dispersion from the initial absorption layer, hard bone tissue presents difficulties for laser osteotomy [18]. The Er, Cr: YSGG pulsed laser's water and air sprays may allow for precise, clean, and straight ablation of hard bone tissue with little thermal damage to surrounding tissue [19]. Turbines, hand pieces, and burs are examples of conventional surgical instruments that restrict access, interfere with depth control, release aerosolized particles, and induce heat necrosis. The development of laser bone surgery methods offers a substitute for conventional instruments and processes [20]. In the present study, the cutting efficiency of the bone is compared between Er, Cr: YSGG pulsed laser and the hand piece (conventional method). The comparative analysis of bone cutting length among the four study groups - 2.5 W/20 Hz, 4 W/20 Hz, 6 W/20 Hz Er, Cr: YSGG laser settings, the 4 W/20 Hz laser group exhibited the greatest incision length significantly higher than all other groups, whereas the handpiece group had the shortest incision length. In contrast to earlier studies that presented differences in cutting depth, the histological depth of the cut is comparable between the laser and the hand piece [21]. The width of bone incision is widest in handpiece sample, while the 6 W/20 Hz laser group produced the narrowest incision. The highest length-to-width ratios were observed in the 6 W/20 Hz, and 4 W/20 Hz groups, indicating more elongated cuts, whereas the handpiece group had the lowest ratio indicating broader, less elongated cuts. The length-to-width ratio of a surgical incision refers to the relationship between the length of the incision and its width. This ratio can indeed affect the quality of the surgical incision in terms of healing, scar formation, and overall patient outcomes. Decreased width of the incision and increased length have good impacts on the quality of laser incisions. The result of the present study match with recent studies showing that, in comparison to conventional handpiece burs, laser bone cutting provides smaller, more accurate incisions with less mechanical and thermal damage. These benefits could lead to better healing results and higher-quality osteotomies [22]. The current study's histology and statistical findings demonstrate that, especially when

compared to traditional bur procedures, the Er, Cr: YSGG laser provides the most precise bone cut at various depths [23]. Clinically, thermo-mechanical tissue ablation using infrared lasers, particularly erbium lasers, is still regarded as the most dependable and progressive method because these laser systems are only appropriate for high precision osteotomy of very small and thin bone structures [24]. When accurate tissue removal or drilling is needed without destabilizing pieces, the use of lasers in bone cutting is advantageous. Bone fracture risk can be reduced, if not completely eliminated, by laser drilling thin bones [25]. In the current study, the Er, CR: YSGG laser showed the highest level of bone cut accuracy at all depths; there were no bone fragments at any laser incision, these findings confirm those of other authors [26]. It is more challenging to construct an ideal osteotomy line or an anatomically correct drilling technique when using conventional osteotomy samples because of the large torque moment or because the bur's serration is coarser. Obtained results align with the previous study observations [27]. In the present study hard tissue laser have shown better results due to greater precision as they preserved the bone morphology, compared with low-speed handpiece. The obtained results agreed with previous studies [28]. Similar to earlier studies, specimens with a high frequency and low radiation power output showed better incision quality, particularly at 20 Hz [29-30]. The incision length was highest in the 4 W/20 Hz group and, lowest in the hand piece group. Deeper ablation can be achieved simply by raising the average power, increasing the energy, and lowering the repetition rate [31]. Carbonization, which is undesirable in medical laser applications because it increases thermal unfavorable effects on adjacent tissues and slows recovery, is reached as the temperature rises with continued laser exposure. The size, exposure time, and location of the heat deposited inside the tissue are the primary determinants of the ablation's geographic extent [32]. Heat damage and carbonizations are a major concern in our study, but all examine samples of the laser group show no thermal damage. Because erbium lasers use water as their primary chromophore, they are a great option for surgical hard tissue procedures. The thermal relaxation time is facilitated by the erbium laser's pulse emission mode and sufficient cooling with an aerosol, ideally composed of air and water [15, 33]. The results of present study match with evidence from prior *ex vivo* experiments that demonstrated that the Erbium laser did not cause any heat damage to bone tissue when osteotomy was carried out with cooling air/ water irrigation [34]. All specimens demonstrate only mild carbonization. The lowest levels of carbonation were observed in the hand piece group [2]. Finally, the histological results showed high incision quality with the Er, Cr: YSGG laser system, versus slow speed handpiece. The interpretation related to laser-tissue interaction, which depends on multiple laser intrinsic and extrinsic parameters (wavelength, power, mode of emission, beam profile, pulse duration, frequency, and spot size), and on the chemical and optical properties of the targeted tissue (soft tissue chromophores; water and pigments) [35-36]

CONCLUSIONS

In *ex vivo* studies, the Er, Cr: YSGG laser allows for accurate surgical ablation with little thermal damage to nearby tissues. The optimal result is obtained with a 4watt, 20Hz setting.

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