BMC Oral Health

RESEARCH Open Access

Enhanced wound closure in rabbit oral vestibule: a comparative analysis of suturing and laser tissue soldering

Mohammad Reza Jamalpour[1], Nima Pouresmaeil[1*] and Salman Khazai[2]

Abstract
This study investigates the comparative effectiveness of laser soldering technique and conventional suturing methods for wound closure in rabbits. Over a 60-day post-operative period, scar formation and healing were monitored, with a particular focus on scar characteristics such as width, height, and overall appearance. Results indicate that the laser group exhibited improved scar characteristics, especially in the early stages (first and third days) of healing. By the seventh day, both groups demonstrated similar scar conditions, though the laser group showed a slightly faster recovery trajectory, with marginally lower scar height observed on the 21st and 60th days. While the laser technique showed some advantages in minimizing short-term complications, the long-term outcomes between the two methods were largely comparable. These findings suggest that the laser soldering method may offer some benefits over traditional suturing, particularly in the early stages of healing, but further research is needed to fully assess its clinical potential.

Keywords Laser, Wound healing, Wound closure, Suturing techniques, Laser tissue soldering

Introduction

Oral surgery, particularly the oral vestibule in the upper jaw, demands cautious attention due to potential aesthetic complications stemming from blood flow disturbances, infections, scarring, and reduced vestibular depth [1, 2]. The complex vascular pathways and vestibular morphology significantly influence surgical outcomes, impacting both intraoperative and postoperative bleeding. As current surgical techniques evolve in complexity, there arises a demanding need for a deeper understanding of various approaches and suture materials to attain optimal repair outcomes [1, 3].

In surgical interventions, the closure of tissue incisions remains a fundamental step, often achieved through methods such as sutures, staples, or adhesives. While suturing stands as a cornerstone, it poses challenges of delicacy, difficulty, and time consumption, reliant on the surgeon's technical expertise [4]. Studies suggest that immediate minimization of wound edge distance, termed "primary wound closure," accelerates the healing process, yet traditional methods like stitches or clips, though reliable and cost-effective, can induce trauma and foreign body reactions, impeding healing and fostering susceptibility to infection [4, 5].

In response to these challenges, innovative techniques such as laser tissue soldering (LTS) have emerged, demonstrating promise in both preclinical and clinical settings [6]. LTS offers a swift and efficient approach to

*Correspondence:
Nima Pouresmaeil
nima.pouresmaeil@gmail.com
[1]Department of Oral & Maxillofacial Surgery, School of Dentistry, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Health Sciences Research Center, Health Sciences & Technology Research Institute, Hamadan University of Medical Sciences, Hamadan, Iran

wound closure, reducing scarring and complications compared to conventional methods. Its mechanism involves the application of laser energy to gently heat wound edges, creating a durable bond without relying on manual dexterity. This technique provides superior macroscopic and microscopic outcomes, offering advantages such as speed, minimal scarring, and reduced fibrosis [7]. However, despite its benefits, concerns persist regarding tissue damage from thermal effects. To mitigate this, biological solders are employed to absorb laser energy selectively, safeguarding adjacent tissues from harm. Various biological materials, including albumin, indocyanine green, hyaluronic acid, and collagen, are explored to enhance laser absorption and tissue bonding while minimizing thermal damage [8, 9].

The choice of an 810 nm diode laser for this study is particularly relevant to oral surgery. The 810 nm wavelength is well-absorbed by both melanin and hemoglobin, making it ideal for oral tissues where vascularity and pigmentation vary significantly. This absorption profile allows the laser to effectively coagulate blood vessels and minimize bleeding, which is crucial in oral surgeries. Moreover, the 810 nm laser has been shown to penetrate tissue at an optimal depth, balancing effective tissue soldering with minimal thermal damage, making it especially suitable for delicate areas like the oral vestibule. Given these properties, the 810 nm laser was selected as a promising tool for improving wound closure outcomes in oral surgical procedures [10, 11].

In this study, we investigate and compare the efficacy of laser tissue soldering method alongside traditional suturing in closing transverse incisions within the maxillary vestibule, akin to those encountered in Lefort I osteotomy surgery. Through this comparative analysis, we aim to contribute to the understanding of optimal approaches for wound closure in oral surgical procedures.

Materials and methods

Materials

The materials used in this study include rabbits (Central Animal House, Hamadan University of Medical Sciences, Hamadan Iran), catgut suture, ketamine and xylazine, injectable analgesic meloxicam, oral antibiotic metronidazole, 47% bovine albumin, indocyanine green (ICG), and hyaluronic acid were purchased from Merck (Darmstadt, Germany).

Sample size

A sample size of 16 rabbits (both male and female) were carefully chosen as subjects for creating transverse incisions within the vestibule of the upper jaw, mimicking the Le Fort I incision. The rabbits were divided into two groups through a simple randomization process. One side of the oral vestibule was designated as the control group, undergoing traditional incision, while the other side received laser treatment. Inclusion criteria encompassed selecting healthy rabbits devoid of any pre-existing ailments or aberrant behavior, ensuring the feasibility of creating incisions of equal size on both sides of the vestibule. Moreover, the exclusion criteria involved specimens that succumbed to mortality post-incision or exhibited abnormal behavior following the procedure. The study was approved by the Research Ethics Committee and Vice-chancellor in Research and Technology (Clinical Trial Number: IR.UMSHA.REC.1402.266) at Hamadan University of Medical Sciences, Iran.

Methodology

In this study, sixteen rabbits were selected to undergo transverse incisions in the upper jaw vestibule, resembling the Lefort I incision, to assess wound closure methods. One side of the incisions was closed using absorbable catgut sutures, while the other side underwent closure via laser tissue soldering. Anesthesia was administered prior to surgery using a combination of xylazine and ketamine, ensuring the rabbits were sufficiently anesthetized. Postoperative pain management was facilitated through the administration of Meloxicam, while Metronidazole was used to prevent infection. Soft diets were provided post-surgery to facilitate feeding without interference, and sutures were removed after five days. Evaluations of surgical site quality, including closure efficacy, infection, scarring, step, and desensitization, were conducted on days 1, 3, 7, 21, and 60 post-surgeries by two observers, a maxillofacial surgeon and a final year maxillofacial surgery resident. Scar assessments were performed using both the Visual Analogue Scale (VAS) and the Stony Brook Scar Evaluation Scale (SBSES), categorizing results into three groups based on scar severity: unremarkable, significant but acceptable, and significant and unacceptable [12]. Objective measurements of scar characteristics were conducted at three points along the scar using a caliper ruler, with scores tabulated according to predefined criteria to determine scar quality. Subsequently, the total score is calculated for each scar, allowing for categorization into three distinct groups: weak (0–1 points), average (2–3 points), and good (4–5 points). This classification system facilitates a simplified interpretation of scar quality, aiding clinicians in making informed decisions regarding patient management and treatment outcomes. Below is the Stony Brook scar evaluation scale at Table 1. Moreover, a summary of the whole methodology is shown in Table 2.

Laser system

In this study, we employed a diode laser with a wavelength of 810 nm, optimizing the system parameters based on insights from previous research [13]. These

Table 1 Stony brook's scar evaluation scale, scoring various categories of scar characteristics

Scar category	Points
Width	
> 2 mm	0
2 mm	1
Height	
Depressed or elevated from surrounding skin	0
Flat	1
Discoloration	
Darker than surrounding skin	0
Same color or lighter	1
Notching	
Present	0
Absent	1
Overall Appearance	
Poor	0
Good	1

Table 2 A summary of the methodology

Methodology summary
Sample Selection
– 16 rabbits (male or female) selected for statistical significance.
– Cross-sectional cuts made in the vestibule of the upper jaw, akin to Lefort I incision.
Surgical Procedure
– Anesthesia: 6 mg.kg xylazine and 60 mg.kg ketamine; depth monitored.
– Closure: Cat gut suture (5 – 0) used on one side, laser tissue soldering on the other.
– Mucosal Sutures: Continuous method, 5 mm apart, using absorbable gut sutures (5 – 0).
Postoperative Care
– Pain Relief: Meloxicam (1–2 mg.kg) injected.
– Antibiotics: Metronidazole (20 mg.kg) administered to prevent infection.
– Diet: Soft diet maintained to avoid interference with feeding.
– Suture Removal: Done 5 days post-surgery.
Evaluation Parameters
– Days Evaluated: 1st, 3rd, 7th, 21st, and 60th post-operation.
– Evaluation: Conducted by two observers (maxillofacial surgeon and resident).
– Scarring: Assessed using Visual Analogue Scale (VAS) and Stony Brook Scar Evaluation Scale (SBSES).
– SBSES Criteria: Scored based on scar measurements at three points (anterior, middle, posterior).
– Scoring Groups: Weak (0–1), Average (2–3), Good (4–5).

parameters were determined through comprehensive histological and mechanical analyses. The laser settings utilized were as follows: a wavelength of 810 nm, a power density of 15.9 W/cm², and an exposure time of 5 s per spot.

Throughout the experimentation, the laser maintained a constant power output of 0.5 W over a 5-second duration, resulting in an energy density of 79.61 J/cm², corresponding to a power density of 15.92 W/cm². To ensure precision and consistency, the optical fiber tip was consistently positioned 2 mm above the tissue during laser application. This positioning was critical for maintaining the correct focal distance and ensuring uniform energy distribution. The beam spot size was carefully controlled and measured at 2 mm in diameter. This spot size was chosen to provide optimal coverage of the tissue area being treated while maintaining the desired energy density and power output. In addition to these laser parameters, we utilized albumin as a biological solder during the laser tissue soldering (LTS) process. The albumin acted as a "biological scaffold," reinforcing the welded area and mitigating thermal damage. By standardizing these settings, we aimed to achieve accurate and reproducible results throughout the study. These standardized parameters and techniques were crucial in ensuring that the laser soldering was performed consistently across all samples, allowing for reliable comparison of results between the laser and suturing methods.

Outcome classification and analysis

The healing outcomes of the sutured and laser-treated incisions were evaluated and classified using a binary system, where "0" represented a negative or baseline outcome (e.g., poor healing, significant scarring), and "1" indicated a positive outcome (e.g., good healing, minimal scarring). The specific classifications were as follows:

- **Suture 0**, **Laser 0**: Both the suture and laser treatments resulted in poor or baseline healing outcomes.
- **Suture 1**, **Laser 0**: The suture treatment resulted in a positive healing outcome, while the laser treatment did not.
- **Suture 0**, **Laser 1**: The laser treatment resulted in a positive healing outcome, while the suture treatment did not.
- **Suture 1**, **Laser 1**: Both the suture and laser treatments resulted in positive healing outcomes.

These classifications allowed for a straightforward comparison between the efficacy of the suture and laser methods in promoting wound healing.

Statistical analysis

The comparison between suture and LTS groups regarding infection indices, desensitization, step formation, and hypertrophic tissue was conducted using the CHI SQUARE test. The quality of incision closure was assessed on a quantitative scale ranging from zero to ten and compared between the two groups using the T-test. Data analysis was performed utilizing SPSS26 software, with significance levels set at less than 5%. The concordance between the two observers assessing scar location was evaluated using the kappa coefficient, with values closer to +1 indicating direct and proportional concordance.

Results

The results in Table 3 highlight a comparison between the suture and laser groups regarding indicators such as wound width, height, color change, notch, and overall appearance, as evaluated by the surgeon. On the first day, the laser group exhibited significant improvements in width, height, and overall appearance of scars compared to the suture group ($p<0.001$). However, neither group showed satisfactory color change outcomes. Notch conditions were deemed good in both groups. By the third day, except for the notch indicator, where no significant difference was observed between groups ($p=0.32$), the laser group showed superior outcomes in other indicators ($p<0.05$). Nevertheless, inadequate color change persisted in 75% of cases across both groups on this day. On the seventh day, both groups exhibited good conditions in terms of width, notch, and overall scar appearance. However, the laser group showed better results for notch and color change ($p<0.05$). On the 21st and 60th days, apart from scar height, which favored the laser group significantly ($p<0.05$), no significant differences were observed between the groups across other indicators.

In Table 4, the comparison between two groups, one using suturing and the other laser, is conducted based on indicators such as width, height, color change, notch, and overall appearance of the wound, as assessed by the resident. On the initial day, the laser group exhibited significantly better width, height, and overall scar appearance ($p<0.001$). However, neither group showed satisfactory color change. Notch conditions were good in both groups. By the third day, the laser group showed superior results in most indicators compared to the suture group ($p<0.05$), except for notch and color change. On the seventh day, both groups demonstrated good notch conditions and overall scar appearance. Height was appropriate in 100% of laser group cases, and no significant differences were observed in scar width and color change between the groups ($P>0.05$). On the 21st and 60th days, except for scar height, which was significantly better in the laser group ($p<0.05$), no significant differences were found between the groups in the remaining indicators.

In Table 5, the concordance between the two suturing and laser methods that was checked by the surgeon was determined on the days under review, and as it can

Table 3 Comparison of indicators related to scar in two suture and laser groups examined by the surgeon

Day	Index	Suture 0, Laser 0	Suture 1, Laser 0	Suture 0, Laser 1	Suture 1, Laser 1	*P*.Value
Day 1	Width	5	0	11	0	< 0.001
	Height	2	0	14	0	< 0.001
	Color Change	16	0	0	0	–
	Notch	0	0	0	16	–
	Overall Appearance	0	0	15	1	< 0.001
Day 3	Width	0	0	15	1	< 0.001
	Height	0	0	16	0	< 0.001
	Color Change	12	0	4	0	0.045
	Notch	0	0	1	15	0.32
	Overall Appearance	0	0	6	10	0.01
Day 7	Width	0	0	0	16	–
	Height	0	0	15	1	< 0.001
	Color Change	8	0	4	4	0.04
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–
Day 21	Width	0	0	0	16	–
	Height	1	0	12	3	< 0.001
	Color Change	0	0	1	15	0.32
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–
Day 60	Width	0	0	0	16	–
	Height	0	0	7	9	0.008
	Color Change	0	0	0	16	–
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–

Table 4 Comparison of indicators related to scar in two suturing and laser groups examined by the resident

Day	Index	Suture 0, Laser 0	Suture 1, Laser 0	Suture 0, Laser 1	Suture 1, Laser 1	*P*.Value
Day 1	Width	5	0	11	0	< 0.001
	Height	1	0	15	0	< 0.001
	Color Change	16	0	0	0	–
	Notch	0	0	0	16	–
	Overall Appearance	0	0	14	2	< 0.001
Day 3	Width	0	0	14	2	< 0.001
	Height	1	0	15	0	< 0.001
	Color Change	14	0	2	0	0.16
	Notch	0	1	0	15	0.32
	Overall Appearance	0	0	3	13	0.08
Day 7	Width	0	0	1	15	0.32
	Height	0	0	16	0	–
	Color Change	9	1	3	3	0.32
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–
Day 21	Width	0	0	0	16	–
	Height	0	0	13	3	< 0.001
	Color Change	0	0	0	16	–
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–
Day 60	Width	0	0	0	16	–
	Height	0	0	7	9	0.008
	Color Change	0	0	0	16	–
	Notch	0	0	0	16	–
	Overall Appearance	0	0	0	16	–

Table 5 The level of concordance between the two techniques of suturing and laser methods checked by surgeon. The numbers in each cell represent how many times a particular combination of suture and laser results occurred

Suture	Day	Laser				Percentage of concordance
			Weak	Average	Good	
	Day 1	Weak	0	(5.37) 6	9 (56.25)	25.6
		Average	0	1 (6.25)	0	
		Good	0	0	0	
	Day 3	Weak	0	0	6 (37.5)	6.25
		Average	0	0	14 (87.5)	
		Good	0	0	0	
	Day 7	Weak	0	0	0	25
		Average	0	0	12 (75)	
		Good	0	0	4 (25)	
	Day 21	Weak	0	0	0	100
		Average	0	0	0	
		Good	0	0	16 (100)	
	Day 60	Weak	0	0	0	100
		Average	0	0	0	
		Good	0	0	16 (100)	

be seen, during the days under review, it was 6.25% on the first and third day. It reached 25% on the 7th day and 100% on the 21st and 60th days.

Moreover, in Table 6, the assessment of concordance levels between the suturing and laser methods, conducted by the resident, was observed across the evaluated days. There was an increase in concordance from 12.5% on the initial day to 25.6% on the third day, 18.75% on the seventh day, and ultimately reached 100% on both the 21st and 60th days.

Table 7 displays the total scar scores for both the laser and suture groups, as assessed individually by the examiner across the observed days. It is notable that throughout all the evaluated days, whether evaluated by the

Table 6 The degree of concordance between the two suturing and laser methods checked by resident. The numbers in each cell represent how many times a particular combination of suture and laser results occurred

Suture	Day	Laser				Percentage of concordance
			Weak	Average	Good	
	Day 1	Weak	0	3 (18.75)	11 (68.75)	5.12
		Average	0	2 (12.5)	0	
		Good	0	0	0	
	Day 3	Weak	0	0	2 (12.5)	6.25
		Average	0	1 (6.25)	13 (81.25)	
		Good	0	0	0	
	Day 7	Weak	0	0	0	18.75
		Average	0	0	13 (81.25)	
		Good	0	0	3 (18.75)	
	Day 21	Weak	0	0	0	100
		Average	0	0	0	
		Good	0	0	16 (100)	
	Day 60	Weak	0	0	0	100
		Average	0	0	0	
		Good	0	0	16 (100)	

Table 7 The comparison of overall scar scores between the laser and suture groups, as evaluated by the examiner across the observed days

P. Value	Average score (Laser)	Average score (Suture)	Day	Checked by	Overall score
< 0.001	3.56 ± 0.51	1.12 ± 0.50	Day 1	Surgeon	
< 0.001	4.19 ± 0.56	1.69 ± 0.60	Day 3		
< 0.001	4.5 ± 0.52	3.25 ± 0.45	Day 7		
< 0.001	5	4.13 ± 0.34	Day 21		
0.002	5	4.56 ± 0.51	Day 60		
0.005	5	4.56 ± 0.51	Day 1	Resident	
< 0.001	4.06 ± 0.44	1.93 ± 0.44	Day 3		
< 0.001	4.44 ± 0.51	3.19 ± 0.40	Day 7		
< 0.001	5	4.19 ± 0.40	Day 21		
0.002	5	4.56 ± 0.51	Day 60		

surgeon or the resident, the overall score in the laser group was significantly higher than in the Suture group ($p < 0.05$). Additionally, Fig. 1A and B depict the comparison of overall scar scores between the laser and suture groups, assessed separately by the surgeon and resident on the examined days, respectively.

In Table 8, the level of concordance between the suturing and laser methods, qualitatively assessed by the surgeon and the resident, was determined across the reviewed days. The concordance rate during the days assessed by the surgeon was 56.25%, reaching 81.25% on the first day, 6.25% on the seventh day, 12.5% on the 21st day, and 75% on the 60th day. Similarly, the concordance rate during the days assessed by the resident increased from 50% on the first day to 68.75% on the third day, 6.25% on the seventh day, 18.75% on the 21st day, and 62.5% on the 60th day.

The Fig. 2. presents a visual timeline illustrating the healing process of the maxillary vestibule following surgical intervention. It begins with a pre-operative view, followed by the Lefort incision made in the maxillary vestibule. On the day of surgery, one side of the incision is sutured while the other is treated using laser tissue soldering. Subsequent images depict the progression of healing at various intervals post-surgery, including the first, third, seventh, 21st, and 60th days. A comparison between the sutured and laser-treated sides provides insights into the efficacy of each method in promoting wound closure and tissue regeneration over time (Fig. 2. A, B, C, D, E, F, E,H).

Discussion

The oral mucosa plays a crucial role in various functions including swallowing and speaking, given its constant exposure to liquids and high sensitivity [14]. Injuries or cuts in the upper jaw mucosa can lead to potential infections and difficulties in swallowing and speaking. Therefore, prompt healing is essential, necessitating the careful closure of wound edges to minimize risks of bleeding and infection [15]. Traditionally, suturing has been employed for wound closure, but it often involves numerous complications such as infection, tissue damage, scarring, and

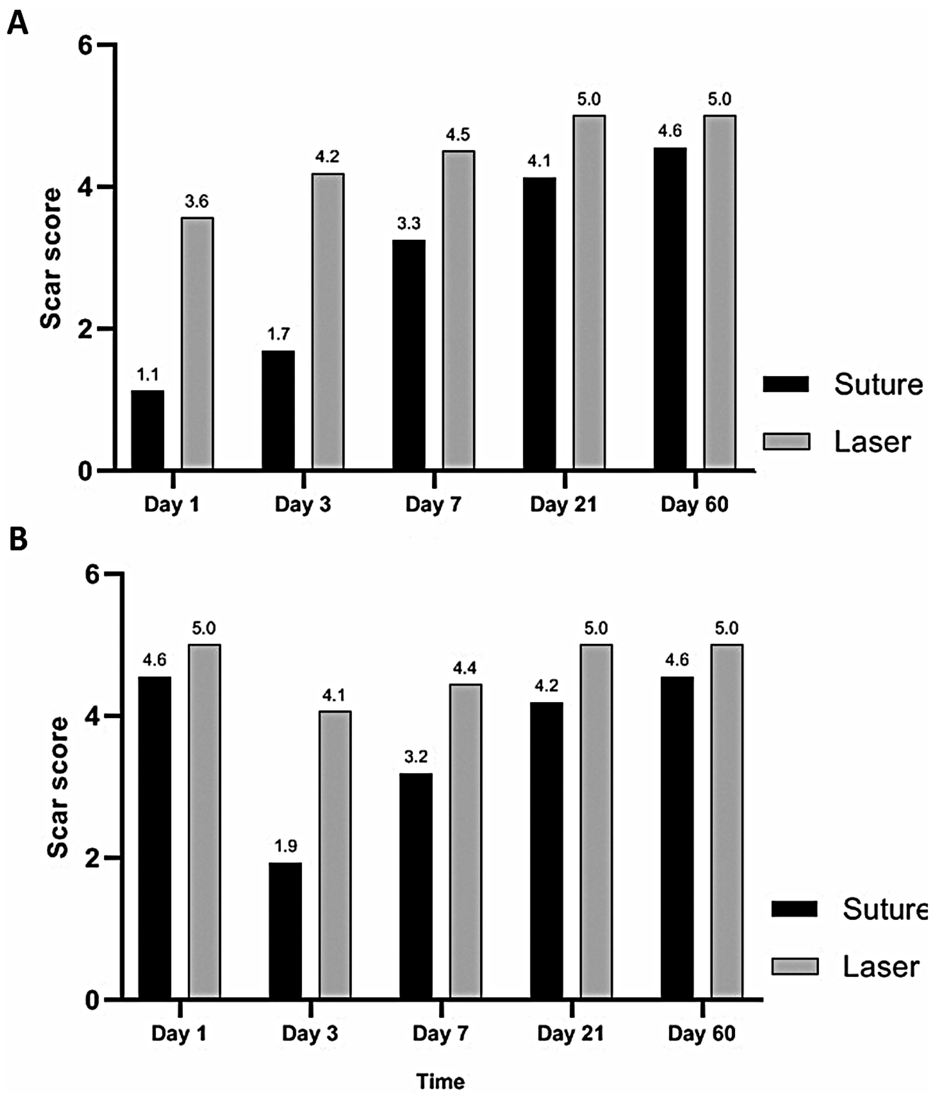

Fig. 1 The comparison of overall scar scores between the laser and suture groups, individually assessed by the (**A**) surgeon and (**B**) resident on the examined days, respectively

prolonged healing times, demanding high surgical expertise [16]. Hence, there is a pressing need for research to explore alternative methods that are cost-effective, less complex, and associated with fewer complications, which was the aim of this study.

The findings of our study indicate that, on the first and third days, scars from the laser-treated group exhibited significant improvement compared to those from the sutured group. However, by the seventh day, scars from both groups showed favorable and comparable outcomes, suggesting that the laser method facilitates quicker recovery and scar reduction. Notably, on the 21st and 60th days, while scars appeared similar, those treated with the laser method demonstrated lower scar height. This suggests that, besides accelerated healing, the laser approach yields smaller overall scar sizes compared to traditional suturing methods.

In accordance with our results, the findings from Gulsoy et al. study, evaluating scars on the backs of mice treated with two methods—suturing and laser at a wavelength of 980 nm—demonstrated that by the 21st day, scars were deemed acceptable in both groups. However, on the seventh day, scars in the laser-treated group were significantly smaller, indicating faster recovery with the laser method [17]. Furthermore, findings from Suh et al. study, conducted on rat skin, revealed that starting from the seventh day, scars at the wound site were relatively consistent in both LTS methods with a wavelength of 810 nm and standard suturing. However, by the third day, laser-treated scars were less prominent than those treated with sutures. This study also underscores a faster recovery rate in the laser group, consistent with the findings observed in our study [18].

Table 8 The concordance level between the suturing and laser methods evaluated by both the resident and the surgeon

Day	Surgeon				Resident			
	Quality of concordance	**Suture**	**Laser**	**Percentage of concordance**	**Quality of concordance**	**Suture**	**Laser**	**Percentage of concordance**
Day 1	Significant but unacceptable	7 (43.75)	0	56.25	Significant but unacceptable	8 (50)	0	50
	Significant but acceptable	9 (56.25)	16 (100)		Significant but acceptable	8 (50)	16 (100)	
	Negligible	0	0		Negligible	0	0	
Day 3	Significant but unacceptable	0	0	81.25	Significant but unacceptable	0	0	68.75
	Significant but acceptable	16 (100)	13 (81.25)		Significant but acceptable	16 (100)	11 (68.75)	
	Negligible	0	3 (18.75)		Negligible	0	5 (31.25)	
Day 7	Significant but unacceptable	0	0	6.25	Significant but unacceptable	0	0	6.25
	Significant but acceptable	16 (100)	1 (6.25)		Significant but acceptable	16 (100)	1 (6.25)	
	Negligible	0	15 (93.75)		Negligible	0	15 (93.75)	
Day 21	Significant but unacceptable	0	0	12.5	Significant but unacceptable	14 (87.5)	0	18.75
	Significant but acceptable	15 (93.75)	1 (6.25)		Significant but acceptable	2 (12.5)	1 (6.25)	
	Negligible	1 (6.25)	15 (93.75)		Negligible	0	15 (93.75)	
Day 60	Significant but unacceptable	0	0	75	Significant but unacceptable	0	0	62.5
	Significant but acceptable	3 (18.75)	1 (6.25)		Significant but acceptable	2 (12.5)	4 (25)	
	Negligible	13 (81.25)	15 (93.75)		Negligible	14 (87.75)	12 (75)	

The study conducted by Khosroshahi et al., which focused on incisions on the backs of rats, demonstrated that by the 10th day, scars in the LTS group with a wavelength of 810 nm were less pronounced compared to those in the suture group. This finding suggests a quicker healing process with laser treatment, aligning with our study's outcomes. However, it's plausible that with extended follow-up, up to the 21st day or beyond, the scars in both groups might exhibit more similarity [19]. Findings from Alexander et al. study, also conducted on rabbit skin, similarly revealed reduced scarring in the LTS group with an 810 nm wavelength compared to the suture group after ten days of observation. This parallels the findings of Khosroshahi's et al. study, and further investigation over an extended duration might indicate converging outcomes between the two groups [20].

Rasca et al. study, which compared the efficacy of LTS with an 810 nm wavelength to oral suturing, revealed a trend towards reduced scarring in the laser group, albeit without statistical significance. While our study indicates a significant difference in scar outcomes between the laser and suturing methods, it's important to note the discrepancies in findings. Several factors could contribute to these inconsistencies, including variations in sample size, methodology, or even the specific characteristics of the surgical procedures performed. Further exploration into these differences could offer valuable insights into the nuances of wound healing dynamics and the relative effectiveness of different treatment modalities [21].

Our study findings provide valuable insights into the dynamics of wound healing following LTS and suturing procedures, as assessed by both the surgeon and the resident. Initially, discoloration, indicative of inflammatory responses to treatment, was notably present in both groups on the first day, reflecting typical postoperative effects. However, by the third day, discoloration began to resolve more rapidly in the laser group compared to the suture group, with significant improvement observed by the seventh day. Notably, throughout the study period, discoloration remained consistently better in the laser group compared to the suture group, as assessed by the surgeon. Conversely, the resident's observations did not reveal a significant difference in color change between the two groups, suggesting a degree of subjectivity or variability in the assessment. Overall, while color change and inflammatory complications appeared largely comparable between the two groups based on the resident's observations, the surgeon's assessments highlighted the favorable outcomes associated with LTS, particularly in the early stages of wound healing. In similarity with our results, D'Arcangelo et al. investigation on rat skin have shown interesting findings regarding the comparison between suturing and LTS with an 810 nm wavelength. Notably, a significant discrepancy in inflammation

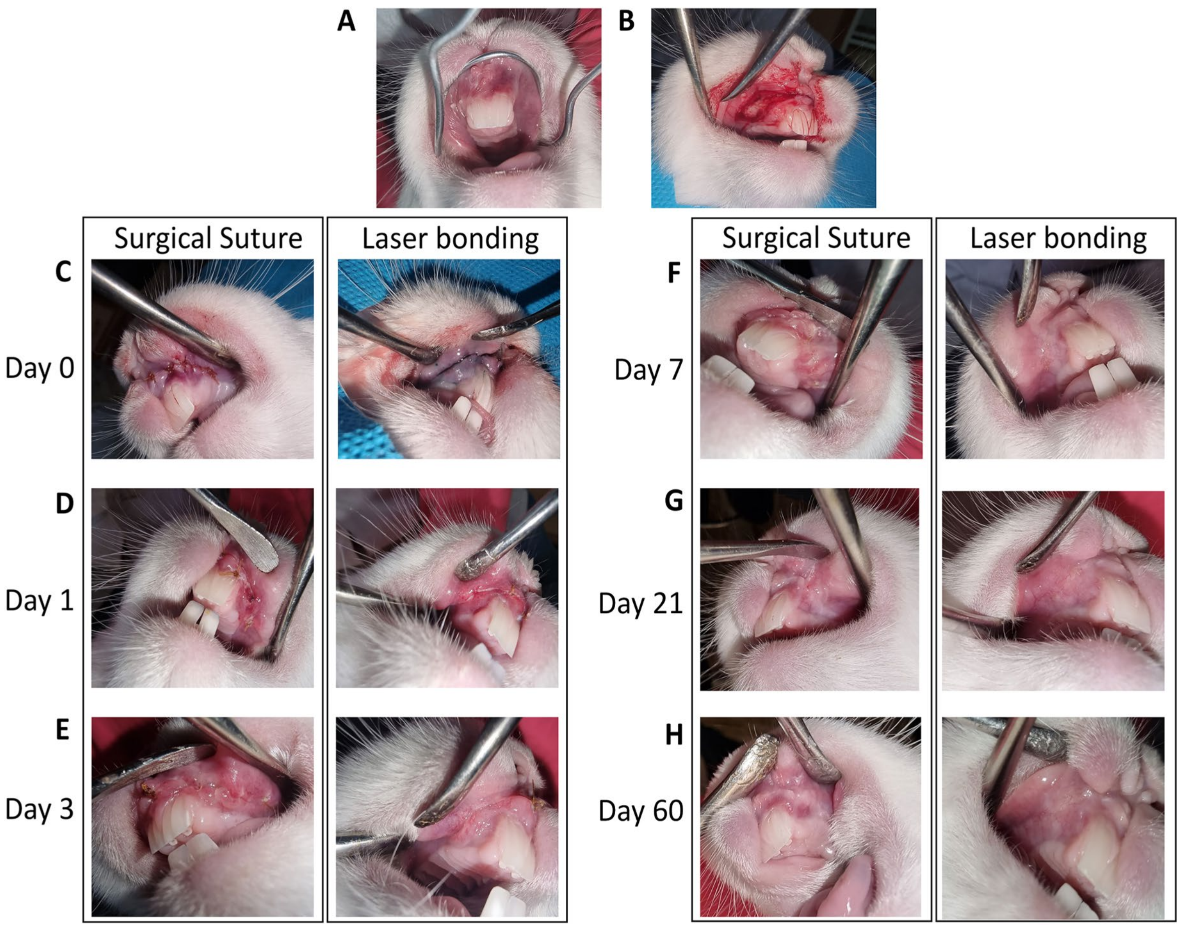

Fig. 2 Sequential images depicting the progression of wound healing in the maxillary vestibule from pre-surgery to 60 days post-surgery. The images illustrate the surgical incision, with one side sutured and the other side treated with laser tissue soldering, at various time points post-operation, including the first, third, seventh, 21st, and 60th days

induction was detected solely on the seventh day, with no notable difference observed by the fourteenth day, mirroring our own study's outcomes [22].

Furthermore, concerning the symmetry of both sides of the repair (Notch), as per the surgeon's assessments, the condition of both groups was deemed satisfactory on the first, third, 21st, and 60th days, with no significant disparities noted. However, on the seventh day, the laser group exhibited notably superior outcomes compared to the suture group. Conversely, according to the resident's evaluations, no significant discrepancy in the notch between the two groups was identified on any of the assessment days.

The findings of this study hold clinical significance, particularly in the context of oral surgery, where rapid wound healing and minimal scarring are crucial for functional and aesthetic outcomes. The LTS technique, using an 810 nm wavelength, demonstrated a clear advantage in the early stages of wound healing compared to traditional suturing methods. This was evidenced by the reduced scar height and improved overall appearance observed in the laser-treated group on the first- and third-days post-operation. These outcomes suggest that LTS can facilitate faster recovery and potentially reduce the risk of complications such as infections or excessive scarring, which are common concerns in oral surgery [23].

However, while the study indicates that the LTS method shows promise, particularly in the short term, the potential for human application must be approached with caution. The study was conducted on an animal model, and although the results are encouraging, they may not fully translate to human clinical scenarios due to differences in tissue composition, healing processes, and potential long-term effects. Moreover, while the laser method exhibited advantages in early recovery, the outcomes between the laser and suturing methods converged by the 21st and 60th days, indicating that the long-term benefits of LTS over suturing might be limited. Given these considerations, while the 810 nm laser soldering technique shows potential as a viable alternative to traditional suturing, further research is necessary. Clinical trials involving human subjects are essential to validate these findings, assess the long-term safety and efficacy of LTS in various types of oral surgical procedures, and determine the optimal parameters for its application.

Previous research has not uncovered a comparable investigation exploring the efficacy of LTS for closing oral vestibular incisions. In essence, upon reviewing similar studies and meticulously scrutinizing our current findings, it becomes apparent that the primary strength of our study, in comparison to preceding research of a similar nature, lies in the duration of the assessment period, enabling a more comprehensive depiction of the disparities in the effectiveness of laser and suture techniques. Notably, our study reveals that while the laser method yields fewer short-term complications, such as reduced inflammation, better scar characteristics, and improved notching, these advantages tend to converge with those of the suture method over the long term, with both methods showing similar outcomes by the 21st and 60th days.

A key limitation of our study is the reliance on visual and qualitative assessments, which, although standardized, are inherently subjective. This reliance may impact the reproducibility and generalizability of the results. To address this limitation in future research, it would be beneficial to incorporate more objective measurement techniques, such as digital imaging analysis, quantitative histological evaluations, or other advanced imaging technologies. These methods could provide a more precise and unbiased assessment of scar characteristics, thereby complementing and validating the visual observations used in this study.

Conclusion

In conclusion, our study demonstrates that the 810 nm laser soldering method offers distinct short-term benefits in wound healing, particularly in terms of reducing scar height and improving early-stage recovery when compared to traditional suturing techniques. However, by the later stages of healing (21st and 60th days), the outcomes between the two methods appeared to converge. While these findings suggest that laser soldering may be a viable alternative for specific surgical applications, it is important to recognize that the study was conducted on an animal model, and the results should not be generalized to broader clinical use without further evidence. Additional in vitro and in vivo studies are necessary to thoroughly assess the long-term safety, efficacy, and potential complications of the laser method compared to traditional suturing, ensuring that any clinical adoption is based on robust and comprehensive data.

Abbreviations

LTS	Laser tissue soldering
ICG	Indocyanine green
VAS	Visual Analogue Scale
SBSES	Stony Brook Scar Evaluation Scale

Acknowledgements
Not applicable.

Author contributions
MR J, N P designed the research, performed the data analysis and visualized the figures. S KH, and N P performed animal studies, analyzed the data, wrote the main draft and evaluated the final data. MR J conceptualized the project, revised the manuscript, and providing final suggestions. All authors read and approved the final manuscript.

Funding
This work is supported by a grant from Hamadan University of Medical Sciences, Hamadan, Iran (No. 140204062669).

Data availability
All the data employed in this study are comprehensively presented within the article, and availability upon reasonable request from the corresponding author is ensured.

Declarations

Ethics approval and consent to participate
All procedures were performed in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee and Vice-chancellor in Research and Technology (Clinical Trial Number: IR.UMSHA.REC.1402.266) at Hamadan University of Medical Sciences, Iran.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 26 May 2024 / Accepted: 1 October 2024
Published online: 14 October 2024

References

1. Shahbazi A, Feigl G, Sculean A, Grimm A, Palkovics D, Molnár B, Windisch P. Vascular survey of the maxillary vestibule and gingiva—clinical impact on incision and flap design in periodontal and implant surgeries. Clin Oral Investig. 2021;25:539–46.
2. Taherkhani A, Moradifar G, Bayat Z, Samadi P, Jamshidi S. A systems biology approach to uncover key genes and pathways mediating progression of leukoplakia to primary oral squamous cell carcinoma. J Oral Maxillofacial Surg Med Pathol. 2024;36(1):120–32.
3. Shahbazi A, Pilsl U, Molnár B, Feigl G. Detection of Vascular Pathways of Oral Mucosa Influencing Soft- and Hard Tissue Surgeries by Latex Milk Injection. J Vis Exp. 2020 May 7;(159).
4. Birkelbach MA, Smeets R, Fiedler I, Kluwe L, Wehner M, Trebst T, Hartjen P. In vitro feasibility analysis of a new sutureless wound-closure system based on a temperature-regulated laser and a transparent collagen membrane for laser tissue soldering (LTS). Int J Mol Sci. 2020;21(19):7104.
5. Zuhr O, Akakpo DL, Hürzeler M. Wound closure and wound healing. Suture techniques in contemporary periodontal and implant surgery: interactions, requirements, and practical considerations. Quintessence Int. 2017;48(8).
6. Ashbell I, Agam N, Katzir A, Basov S, Platkov M, Avital I, Nisky I, Netz U. Laser tissue soldering of the gastrointestinal tract: A systematic review LTS of the gastrointestinal tract. Heliyon. 2023.
7. Md Fadilah NI, Mohd Abdul Kader Jailani MS, Badrul Hisham MAI, Sunthar Raj N, Shamsuddin SA, Ng MH, Fauzi MB, Maarof M. Cell secretomes for wound healing and tissue regeneration: next generation acellular based tissue engineered products. J Tissue Eng. 2022;13:20417314221114273.
8. Hiebl B, Ascher L, Luetzow K, Kratz K, Gruber C, Mrowietz C, Nehring M, Lendlein A, Franke R-P, Jung F. Albumin solder covalently bound to a polymer membrane: New approach to improve binding strength in laser tissue soldering in-vitro. Clin Hemorheol Microcirc. 2018;69(1–2):317–26.
9. Rossi F, Magni G, Colasanti R, Banchelli M, Iacoangeli M, Carrassi E, Aiudi D, Di Rienzo A, Giannoni L, Pieri L. Characterization and Ex vivo application of

Indocyanine Green Chitosan Patches in Dura Mater Laser Bonding. Polymers. 2021;13(13):2130.

10. Dalvi S, Lingala S, Khetal N, Benedicenti S, Hanna R. Utilisation of an 810 nm diode laser for surgical management of oral soft tissues related to orthodontic treatment: a case series. J Orthod. 2022;49(2):221–7.
11. Liu G-q, Chen X-X, Gong K. Impact of 810nm diode laser, intraoral and extraoral applications, on postoperative pain, swelling, wound healing, and patient satisfaction following mandibular third molar extraction: a comparative study. Lasers Dent Sci. 2023;8(1):1.
12. Simhon D, Gabay I, Shpolyansky G, Vasilyev T, Nur I, Meidler R, Hatoum OA, Katzir A, Hashmonai M, Kopelman D. Temperature-controlled laser-soldering system and its clinical application for bonding skin incisions. J Biomed Opt. 2015;20(12):128002–128002.
13. Alam Z, Mohan M, Pal K, Poddar R. Albumin-PEG-based biomaterial for laser-tissue soldering and its real-time monitoring with swept-source optical coherence tomography. Lasers Surg Med. 2021;53(6):815–29.
14. Hurjui LL, Gradinaru I, Dorus C, Tanase DM, Armencia A, Hurjui I, Tarniceriu CC, Mitrea M, Lozneanu L, Balcos C. Oral mucosa-pathophysiological and pharmacotherapeutic aspects. Romanian J Oral Rehabilitation. 2021;13(4):108–14.
15. Minhas S, Sajjad A, Kashif M, Taj F, Al Waddani H, Khurshid Z. Oral ulcers presentation in systemic diseases: an update. Open Access Macedonian J Med Sci. 2019;7(19):3341.
16. Xu L, Liu Y, Zhou W, Yu D. Electrospun medical sutures for wound healing: a review. Polymers. 2022;14(9):1637.
17. Gulsoy M, Dereli Z, Tabakoglu HO, Bozkulak O. Closure of skin incisions by 980-nm diode laser welding. Lasers Med Sci. 2006;21:5–10.
18. Suh DD, Schwartz IP, Canning DA, Snyder HM, Zderic SA, Kirsch AJ. Comparison of dermal and epithelial approaches to laser tissue soldering for skin flap closure. Lasers Surg Medicine: Official J Am Soc Laser Med Surg. 1998;22(5):268–74.
19. Gerasimenko AY, Morozova EA, Ryabkin DI, Fayzullin A, Tarasenko SV, Molodykh VV, Pyankov ES, Savelyev MS, Sorokina EA, Rogalsky AY. Reconstruction of soft biological tissues using laser soldering technology with temperature control and biopolymer nanocomposites. Bioengineering. 2022;9(6):238.
20. Khosroshahi M, Nourbakhsh M, Saremi S, Hooshyar A, Rabbani S, Tabatabai F, Anvari MS. Application of albumin protein and indocyanine green chromophore for tissue soldering by using an IR diode laser: ex vivo and in vivo studies. Photomed Laser Surg. 2010;28(6):723–33.
21. Rasca E, Nyssen-Behets C, Tielemans M, Peremans A, Hendaoui N, Heysselaer D, Romeo U, Nammour S. Gingiva laser welding: preliminary study on an ex vivo porcine model. Photomed Laser Surg. 2014;32(8):437–43.
22. D'Arcangelo C, Di Maio FDN, Prosperi GD, Conte E, Baldi M, Caputi S. A preliminary study of healing of diode laser versus scalpel incisions in rat oral tissue: a comparison of clinical, histological, and immunohistochemical results. Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology. 2007;103(6):764–73.
23. Wiens B. Effects of Er: YAG Photobiomodulation Therapy on Wound Healing of Human Palatal Mucosa After Connective Tissue Graft Harvesting: A Pilot Study. 2020.

Publisher's note