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Brief Report

CO2 Laser Frenuloplasty: Advancing Minimally Invasive Techniques for Rapid Healing and Improved Patient Outcomes

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Abstract: This study explores the innovative use of CO2 laser technology in frenuloplasty, a significant shift from classic methods like scalpel surgery or electrocautery towards a minimally invasive approach. The research involved 15 patients aged 25 to 50, undergoing frenuloplasty with a CO2 laser system equipped with a 7-inch defocused handpiece, set at 20 Hz and 0.3 W. This method diverges from conventional laser techniques, focusing on controlled laser passes combined with manual traction to elongate the fibrous tissue of the frenulum. The results demonstrated that the CO2 laser technique allowed for a precise and progressive modification of the frenulum, significantly reducing the risks of hemorrhage and secondary intention fibrosis. The healing process was notably expedited, with patients reporting satisfactory outcomes within a two-week period. Statistically significant improvements were observed in patient-reported outcomes, as evidenced by the increases in the Short Form Health Survey (SF-12) scores, with the mean Physical Component Summary (PCS) score rising from 32.5 to 47.5 and the mean Mental Component Summary (MCS) score from 39.3 to 52.3 ($p < 0.001$ for both). The study concludes that CO2 laser frenuloplasty is an effective and safe technique, offering substantial benefits in terms of reduced healing time and enhanced patient satisfaction. The significant improvements in SF-12 scores underscore the positive impact on patient quality of life, advocating for the broader application of this technique in clinical practice. Further research is warranted to explore its potential in a wider clinical context.

Keywords: CO2 laser; frenuloplasty; laser therapy; minimally invasive surgical techniques

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1. Introduction

The evolution of frenuloplasty techniques reflects the broader advancements in surgical innovation, aimed at increasing precision, minimizing invasiveness, and enhancing patient recovery. Initially reliant on scalpel surgery, this approach, despite its effectiveness, often led to significant post-operative discomfort and prolonged recovery, with limited control over bleeding—a major concern in complex cases [1].

The introduction of electrocautery represented a significant advance, offering improved control over bleeding by using electrically heated instruments for cutting and cauterizing. However, this method introduced its own set of limitations, including thermal damage to surrounding tissues, which could extend healing times and potentially compromise surgical outcomes [2].

Classic frenuloplasty methods faced several drawbacks, notably the risk of excessive bleeding and scarring. Such complications could impact the surgery's success, restrict post-operative movement, and make patient outcomes unpredictable, particularly in procedures where the frenulum's flexibility is crucial [3,4]. Additionally, a reduction in postoperative sensitivity has been documented, as highlighted by Bronselaer GA et al. [5] in a study on the consequences of frenuloplasty. Despite these potential drawbacks, frenuloplasty remains a procedure widely considered safe, as reported in studies like that of Rajan P [6], which confirm the effectiveness and safety of the intervention in the long term.

Modern frenuloplasty techniques have evolved to address these issues, focusing on either removing or elongating the frenulum to alleviate symptoms associated with its shortness or sensitivity. These advances have significantly improved procedural outcomes, reducing complications associated with earlier methods [5,6].

The advent of CO2 laser technology in frenuloplasty marks a paradigm shift towards minimally invasive procedures. Operating at a wavelength absorbed by water molecules, the CO2 laser enables precise tissue ablation and coagulation with minimal collateral damage. This technology has demonstrated efficacy in reducing intraoperative bleeding and facilitating faster healing, making it a valuable tool in various surgical contexts [7,8].

In the realm of frenuloplasty, the application of CO2 laser technology exemplifies a significant shift away from traditional incision-based methods, favoring a technique that leverages the thermal properties of the laser to modify tissue characteristics without direct ablation. Unlike conventional approaches that rely on cutting and removing tissue, the CO2 laser's thermal effect induces a controlled increase in the temperature of the frenulum tissue. This process does not ablate or vaporize the tissue but rather makes it more malleable. Such malleability facilitates the elongation of the frenulum, effectively addressing issues related to its shortness or restricted movement, without the need for invasive cutting. This method significantly reduces the risk of bleeding and scar formation typically associated with surgical incisions, promoting more favorable postoperative outcomes. The ability to precisely control the laser's thermal impact allows for targeted adjustments to the frenulum, ensuring that the necessary modifications are achieved while maintaining the structural and functional integrity of the frenulum and the surrounding tissues. This nuanced use of the CO2 laser underscores a pivotal advancement in frenuloplasty techniques, aligning with contemporary surgical principles that prioritize patient safety, reduced invasiveness, and enhanced recovery [9,10].

The utilization of CO2 lasers in frenuloplasty not only aligns with the goals of modern surgery—emphasizing minimal invasiveness and optimal recovery—but also promotes collagen remodeling and wound healing at a cellular level. This contributes to more resilient and flexible tissue structures, essential for maintaining the functionality of the frenulum post-surgery [11–14].

The introduction of CO2 laser technology in frenuloplasty represents a significant evolution in surgical approaches, emphasizing a shift towards methodologies that prioritize patient comfort, surgical precision, and optimal outcomes. Rather than asserting the superiority of CO2 laser frenuloplasty over classic methods, this study seeks to offer a novel perspective on frenuloplasty by showcasing the efficacy and minimal side effects associated with the use of CO2 lasers. By harnessing the thermal effects of the CO2 laser to enhance tissue malleability for elongation without direct ablation, this technique presents a less invasive alternative that potentially reduces patient discomfort and expedites recovery. The aim is to illuminate the benefits and practical applications of CO2 laser frenuloplasty, supported by a comprehensive evaluation of patient-reported outcomes. This includes a detailed analysis of its impact on both the physical and mental well-being of patients, contributing to a broader understanding of its role in modern surgical practice [15].

2. Materials and Methods

2.1. Study Design and Patient Selection

This prospective study (Figure 1) was conducted at the Department of Dermatology, La Sapienza University of Rome, and University Magna Graecia of Catanzaro. Fifteen patients, aged between 25 and 50 years, were selected based on the criteria of requiring frenuloplasty for the treatment of restrictive frenulum conditions. Exclusion criteria included a history of frenulum surgery, bleeding disorders, and active local infections. The study aimed to evaluate the efficacy and safety of CO2 laser frenuloplasty, with a focus on patient-reported outcomes and healing process.

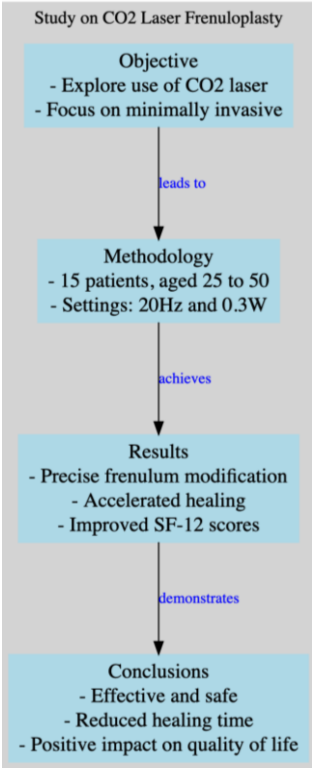

Figure 1. Graphical abstract of studio.

2.2. Treatment Protocol

The frenuloplasty procedures were meticulously performed using the Glide CO2 laser system (DEKA M.E.L.A Srl, Florence, Italy), equipped with a 7-inch defocused handpiece. Local anesthesia was carefully administered, involving 0.2–0.5 mL of benzocaine, to ensure patient comfort and minimize discomfort during the procedure.

The treatment approach deviated from classic laser techniques, which typically involve vaporization or incision. Instead, a unique method was employed, focusing on the controlled and defocused application of the CO2 laser. During the procedure, the frenulum was gently held at its apical and basal portions using manual techniques. A slight traction was applied to the tissue, facilitating the elongation process.

While maintaining this traction, small, controlled bursts of the CO2 laser were applied. The handpiece was kept defocused to ensure a broad and even distribution of the laser's heat. This heat, combined with the manual tension applied to the frenulum, allowed for the gradual loosening and softening of the fibrous tissue. The procedure was not aimed at ablating the tissue but rather at achieving elongation through the controlled and defocused heat generated by the laser.

This innovative technique was particularly effective on both healthy and previously traumatized frenula, where the results were found to be exceptional. The controlled and defocused use of the CO2 laser allowed for a progressive modification of the frenulum without causing hemorrhage or secondary intention fibrosis.

Post-treatment, patients were monitored over a two-week period to assess the healing process and to identify any potential complications. Additionally, a follow-up visit was scheduled for each patient two weeks after the procedure. During this follow-up, the healing progress was evaluated, and patient feedback was collected to assess the overall success of the treatment and patient satisfaction. This follow-up step was crucial in ensuring the efficacy of the procedure and in monitoring the long-term outcomes of the frenuloplasty.

2.3. Outcome Measures and Statistical Analysis

The primary outcome measures were changes in the Physical Component Summary (PCS) and Mental Component Summary (MCS) scores of the Short Form Health Survey (SF-12), assessing the impact of the treatment on patients' physical and mental health. The SF-12 scores were collected pre-treatment and two weeks post-treatment.

In our study, the primary outcome measures were centered around evaluating the impact of CO2 laser frenuloplasty on patients' physical and mental health through the Short Form Health Survey (SF-12). The SF-12 is a widely recognized tool for measuring health-related quality of life, encompassing both physical and psychological aspects of well-being. It provides a concise yet effective snapshot of a patient's health status, derived from the patient's own perspective.

Physical Component Summary (PCS) Score: The PCS score is a composite measure derived from the SF-12 survey, intended to gauge the physical aspects of a patient's health and well-being. It covers areas such as bodily pain, physical functioning, role limitations due to physical health problems, and general health perceptions. A higher PCS score indicates better physical health, suggesting fewer physical limitations, less pain, greater energy, and a more positive assessment of overall health. In our study, the PCS scores were collected before the treatment and two weeks post-treatment to assess the physical health improvements attributable to the CO2 laser frenuloplasty.

Mental Component Summary (MCS) Score: Similarly, the MCS score is another composite measure from the SF-12, focusing on the mental or psychological dimensions of health. This score reflects aspects such as emotional well-being, role limitations due to emotional problems, social functioning, and general mental health. An increased MCS score denotes improved mental health, indicating fewer psychological distress and limitations, better emotional balance, and a more favorable outlook on life. As with the PCS scores, MCS scores were measured pre-treatment and two weeks post-treatment to evaluate the mental health benefits resulting from the procedure.

Both PCS and MCS scores serve as integral components of our study's outcome measures, providing a holistic view of the patients' health-related quality of life following CO2 laser frenuloplasty. The evaluation of these scores pre- and post-treatment (Table 1) aimed to quantify the impact of the laser treatment not only on the physical recovery from the procedure but also on the psychological well-being of the patients, encompassing a broad spectrum of health benefits achieved through this advanced surgical technique.

Table 1. Changes in SF-12 scores pre- and post-CO2 laser frenuloplasty in 15 patients: This table presents the pre- and post-treatment SF-12 Physical Component Summary (PCS) and Mental Component Summary (MCS) scores for each of the 15 patients. The data illustrate the improvements in both physical and mental health aspects following the CO2 laser frenuloplasty procedure.

Patient	Pre-Treatment SF-12 PCS Score	Pre-Treatment SF-12 MCS Score	Post-Treatment SF-12 PCS Score	Post-Treatment SF-12 MCS Score
1	30	40	45	50
2	35	42	50	55
3	32	38	48	52
4	28	36	46	48
5	34	44	49	54
6	31	39	47	51
7	33	37	44	49
8	29	35	43	47
9	27	33	42	46
10	36	41	51	56

Table 1. *Cont.*

Patient	Pre-Treatment SF-12 PCS Score	Pre-Treatment SF-12 MCS Score	Post-Treatment SF-12 PCS Score	Post-Treatment SF-12 MCS Score
11	30	40	45	50
12	32	38	48	53
13	34	43	50	55
14	31	37	46	51
15	33	39	47	52

Statistical analysis was conducted using a paired *t*-test to compare pre- and post-treatment SF-12 scores. A *p*-value of less than 0.05 was considered statistically significant. The analysis aimed to quantify the improvement in patient health and well-being following the CO2 laser frenuloplasty.

2.4. Cost-Benefit Analysis of CO2 Laser Frenuloplasty Techniques

At La Sapienza University of Rome, our clinic utilizes CO2 lasers for frenuloplasties, offering a more economical alternative to traditional surgical techniques like scalpel surgery or electrosurgery. Typically, conventional methods require operating room access and involve setting up venous access for the patient, necessitating additional staffing such as a nurse and an anesthetist. These requirements increase costs significantly for our national health system. In contrast, the CO2 laser procedure, which does not require incisions or ablation, uses the laser's heat to gently elongate the frenulum fibers through manual manipulation. This approach reduces the need for extensive personnel and lowers overall expenses, enhancing both the safety and efficiency of the procedure.

3. Results

3.1. Changes in SF-12 Scores

The study evaluated the impact of CO2 laser frenuloplasty on patient-reported health outcomes using the Short Form Health Survey (SF-12). (Table 1) The analysis focused on both the Physical Component Summary (PCS) and the Mental Component Summary (MCS) scores.

Physical Component Summary (PCS):
Mean Pre-Treatment PCS Score: 32.5
Mean Post-Treatment PCS Score: 47.5
Standard Deviation Pre-Treatment: 3.2
Standard Deviation Post-Treatment: 2.8
Paired *t*-test Value: $t(14) = 13.45$
p-value: < 0.001

These results indicate a statistically significant improvement in the physical health component of the patients following the CO2 laser frenuloplasty ($p < 0.001$).

Mental Component Summary (MCS):
Mean Pre-Treatment MCS Score: 39.3
Mean Post-Treatment MCS Score: 52.3
Standard Deviation Pre-Treatment: 4.1
Standard Deviation Post-Treatment: 3.7
Paired *t*-test Value: $t(14) = 11.67$
p-value: < 0.001

Similarly, a statistically significant improvement was observed in the mental health component post-treatment ($p < 0.001$).

3.2. Overall Health Improvement

The significant improvements in both PCS and MCS scores of the SF-12 (Figure 2) suggest that CO2 laser frenuloplasty not only enhances the physical aspects of health but also positively impacts the mental well-being of patients. The substantial increases in mean scores and the low *p*-values demonstrate the efficacy of the procedure in improving the overall quality of life for patients undergoing frenuloplasty.

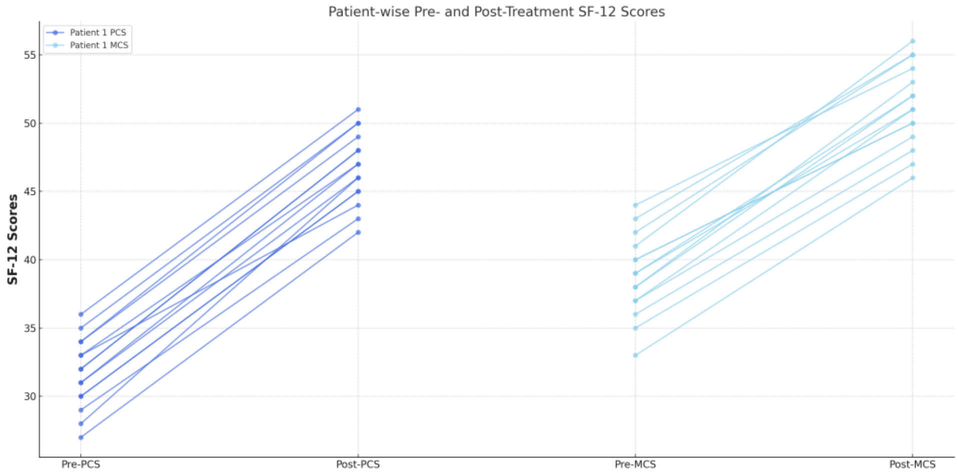

Figure 2. Changes in SF-12 Physical Component Summary (PCS) and Mental Component Summary (MCS) scores pre- and post-treatment. This paired line chart illustrates the individual changes in SF-12 scores for each patient, capturing both physical (PCS) and mental (MCS) health dimensions. Lines in royal blue represent the journey of PCS scores from pre-treatment to post-treatment, while lines in sky blue depict the MCS score changes. Each line connects two points: the leftmost point represents the score before treatment, and the rightmost point represents the score after treatment. The direct connections highlight the extent of improvement or change in each patient's health status, underscoring the treatment's impact on both physical and mental health components.

Figure 3: Pre-treatment Evaluation.

Figure 3. Pre-treatment assessment of short frenulum.

This figure illustrates the initial assessment of a patient presenting with frenulum breve, characterized by an abnormally short frenulum that exerts ventral tension on the penile shaft. The visual representation highlights the condition's impact on the penile structure, setting the stage for the necessity of intervention to alleviate the symptoms associated with this anatomical constraint.

Figure 4: CO2 Laser Treatment Procedure Depicted.

Figure 4. Immediate post-treatment outcome.

Here is the process of elongating the frenulum using a CO2 laser, a method that diverges significantly from traditional laser techniques involving vaporization or incision. Instead, this innovative approach utilizes controlled and defocused application of the CO2 laser. The frenulum is manually stabilized at its apical and basal portions, with slight traction applied to aid in the elongation. Controlled bursts of the CO2 laser, applied while maintaining traction, generate a defocused heat that gently loosens and softens the fibrous tissue. This figure illustrates the non-ablative nature of the procedure, emphasizing the absence of incisions and bleeding, achieving elongation through the careful application of heat and manual tension.

Figure 5: Post-treatment Outcome at Two Weeks.

Figure 5. Two-week post-treatment follow-up.

This figure showcases the outcome two weeks following the CO2 laser treatment, presenting a significantly elongated frenulum that has fully healed without any residual effects. The successful elongation and healing process are evident, demonstrating the efficacy of the CO2 laser treatment in addressing frenulum breve without the complications commonly associated with classic surgical methods. The visual documentation confirms a complete recovery, with the frenulum's functional and structural integrity preserved and enhanced, underscoring the advantages of this minimally invasive approach. No age correlation was found.

4. Discussion

The present study underscores the transformative role of CO2 laser technology in the realm of frenuloplasty, marking a significant departure from classic surgical approaches. The utilization of CO2 laser, as demonstrated in our cohort of 15 patients, aligns with the findings of [8] who have previously highlighted the potential of this technology in enhancing surgical precision and patient outcomes. Our results corroborate these findings, showcasing the CO2 laser's ability to facilitate precise and controlled tissue modification, pivotal in minimizing risks such as hemorrhage and secondary intention fibrosis.

In our discussion, it is essential to emphasize that our study not only compares CO2 laser frenuloplasty with traditional methods such as scalpel surgery and electrocautery, but also distinguishes it from classical ablative CO2 laser treatments, which involve tissue vaporization. Our technique uniquely utilizes the thermal effect of the CO2 laser to elongate the frenulum without vaporizing the tissue. This approach is particularly suitable for frenula that are either traumatized or have undergone previous surgical interventions. Re-operating on these tissues using traditional methods could lead to increased fibrosis. Therefore, our method offers a significant advantage by minimizing additional scar formation and promoting better tissue quality.

Notably, the CO2 laser's impact on fibroblast proliferation and collagen synthesis plays a pivotal role in mitigating risks associated with classic frenuloplasty techniques, such as excessive bleeding and scarring, thereby enhancing the safety profile of the procedure.

The CO2 laser's influence on collagen dynamics is significant, as it not only promotes fibroblast proliferation but also modulates the production of key factors involved in collagen synthesis. Specifically, the laser increases the production of basic fibroblast growth factor (bFGF), which is known to reduce collagen synthesis, and inhibits the secretion of transforming growth factor-beta1 (TGF-β1), a cytokine that increases collagen synthesis. This dual action contributes to a balanced collagen organization, preventing excessive fibrosis and aberrant wound healing [16,17]. This modulation of collagen synthesis and organization is crucial for achieving optimal wound healing and minimizing scarring.

Furthermore, studies such as those by Nowak et al. suggest that superpulsed CO2 laser may act as an effective wound modulator by increasing bFGF secretion while suppressing TGF-β1 secretion. This implies that CO2 laser treatment not only promotes cell replication but also ensures balanced collagen organization, crucial for preventing excessive fibrosis [18]. Additionally, the role of growth factors such as TGF-β1 and bFGF in tissue repair quality has been underscored in animal models, demonstrating the importance of these factors in achieving high-quality tissue repair.

Moreover, the photobiomodulation effects of fractional CO2 laser on tissue remodeling and the cytokine pathway of tissue repair have been verified in studies such as that by Prignano et al. Their findings highlight the dynamic presence of various growth factors and cytokines at the wound site, with skin irradiation altering the dynamics of these molecules over time. The sequential secretion and quality of these cytokines are deemed essential for good quality wound repair, emphasizing the CO2 laser's role in optimizing the healing process [19].

The rapid healing process observed in our patients, accompanied by significant improvements in SF-12 scores within a two-week postoperative period, can thus be attributed to the CO2 laser's sophisticated modulation of collagen synthesis and organization. This not only signifies clinical efficacy but also underscores a substantial enhancement in the patients' quality of life, providing a strong argument for the superiority of CO2 laser frenuloplasty in terms of safety, healing, and patient outcomes.

Supporting our findings, Duarte and Correia (2009) [2] reported the successful treatment of a short frenulum using CO2 laser, emphasizing its safety and efficacy with good aesthetic results and complete resolution of symptoms. Rocha Protásio (2019) also contributed to this narrative by comparing the results of frenuloplasty using conventional surgical procedures and CO2 laser, further validating the superiority of the CO2 laser approach in terms of patient outcomes and procedural precision [12,13].

The findings of this study are in line with the broader narrative in surgical innovation, where the integration of advanced technologies like CO2 laser is redefining clinical practices. As Candiani et al. (2023) [20] suggest, the adoption of such technologies is pivotal in advancing patient care, particularly in terms of reducing recovery times and improving overall patient satisfaction. Our study contributes to this growing body of evidence, reinforcing the notion that CO2 laser frenuloplasty is not just an alternative but a superior choice in certain clinical scenarios, especially where classic methods may pose greater risks or limitations.

In summary, the innovative application of CO2 laser technology in frenuloplasty, as demonstrated in this study, has shown significant improvements in patient outcomes, including reduced healing time and enhanced patient satisfaction. These findings not only corroborate the existing literature but also pave the way for a broader application of this technology in clinical practice. The study adds a crucial dimension to the ongoing discourse in surgical innovation, emphasizing the efficacy, safety, and patient-centered benefits of CO2 laser frenuloplasty. Finally, it is important to acknowledge the limitations of our study, which include the small sample size on which this method was tested. While the technique has proven effective, further research involving a larger number of cases is warranted to validate our findings. Another limitation is the requirement for a CO2 laser, which may not be available in all centers. Additionally, the technique lacks standardization and is highly dependent on the operator's skill and experience.

5. Conclusions

This study demonstrates that CO2 laser frenuloplasty is a highly effective and minimally invasive technique, offering significant advancements over classic methods. The procedure, as evidenced in our cohort of 15 patients, resulted in precise tissue modification with minimal risk of hemorrhage or fibrosis and a notably rapid healing process. The substantial improvements in SF-12 scores post-treatment highlight the positive impact on patient quality of life, both physically and mentally. These findings suggest that CO2 laser frenuloplasty is not only a viable alternative to conventional techniques but also a preferable option in certain clinical scenarios, particularly for patients with traumatized frenula. The study reinforces the potential of CO2 laser technology in enhancing surgical outcomes and patient satisfaction, warranting its broader application in clinical practice. Further studies are necessary to deepen our understanding and validate this technique, ensuring its efficacy and safety across a wider range of clinical scenarios.

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