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MECHANISMS AND OUTCOMES OF 1470NM LASER THERAPY FOR VAGINAL REJUVENATION: A MULTI-OMICS OBSERVATIONAL STUDY

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ABSTRACT

Introduction: Vaginal laxity and compromised vascularization significantly impact women's quality of life, especially post-childbirth and during menopause. Non-invasive therapies, such as 1470nm laser technology, stimulate collagen production and enhance tissue regeneration. This study hypothesizes that 1470nm laser therapy improves vaginal health through collagen remodeling and neovascularization, supported by multi-omics data elucidating key biological pathways.

Methods: This prospective observational study enrolled 120 women aged 25–65 years with symptoms of vaginal laxity, dryness, or decreased elasticity. Participants underwent 3–5 sessions of 1470nm laser therapy. Clinical outcomes were assessed using high-resolution ultrasound, optical coherence tomography (OCT), histopathology, and patient-reported outcomes (FSFI, PGI-I). Multi-omics integration included RNA sequencing, proteomics, and metabolomics.

Results: Vaginal wall thickness increased by 35% ($p<0.001$), and collagen density improved by 42% ($p<0.001$). FSFI scores rose by 28% ($p<0.001$), with 92% of women reporting improved sexual satisfaction. Molecular analyses showed upregulation of collagen synthesis and angiogenesis-related genes (COL1A1, COL3A1, VEGF, FGF), with TGF-β signaling emerging as a key regulatory pathway.

Conclusion: 1470nm laser therapy significantly improves vaginal structure and function with a favorable safety profile. This study uniquely integrates clinical outcomes with multi-omics data, offering novel mechanistic insights and supporting its role in personalized regenerative gynecology.

Highlights:

1. Multi-omics analysis revealed significant upregulation of genes and proteins linked to collagen remodeling and angiogenesis after 1470nm laser therapy.
2. The study provides the first integrated clinical and molecular evidence demonstrating the mechanistic role of TGF-β signaling in vaginal tissue regeneration following laser treatment.

INTRODUCTION

Vaginal tissue remodeling driven by aging, reproductive history, and hormonal fluctuations frequently results in atrophy, laxity, dryness, and diminished elasticity, conditions that have been shown to adversely affect sexual health and overall quality of life across diverse populations, especially among postpartum and postmenopausal women.[1] Traditional treatments include invasive surgical procedures and topical hormonal therapies, but these approaches have limitations including side effects and variable patient acceptance.[1] Energy-based devices, particularly CO2 lasers, have emerged as promising alternatives for vaginal rejuvenation by stimulating collagen regeneration, neovascularization, and improved tissue structure.[1,2] Clinical studies demonstrate that CO2 laser therapy significantly improves vaginal health indices, sexual function scores, and patient-reported outcomes. Histological evidence shows increased vaginal epithelial thickness, enhanced collagen production (particularly type III collagen), and tissue remodeling following laser treatment.[3,4] These therapeutic effects are attributed to thermal energy deposition promoting glycogen-enriched epithelium proliferation and extracellular matrix formation.[2]

Epidemiological studies report that up to 40–50% of postmenopausal women experience symptoms of genitourinary syndrome of menopause (GSM), including vaginal atrophy and discomfort, while one in three parous women report some degree of vaginal laxity after delivery.[5-7] These changes are primarily attributed to hormonal decline, collagen degradation, and impaired neovascularization, resulting in reduced biomechanical strength of the vaginal wall. Conventional treatment strategies, such as topical estrogen or surgical interventions, offer benefits but are limited by side effects, invasiveness, or variable patient acceptance.[1,8] Non-invasive energy-based therapies, particularly 1470nm diode laser technology, have gained attention as they can target water-rich tissues with precision, induce controlled thermal stimulation, and trigger biological responses such as collagen remodeling and angiogenesis. Clinical studies have demonstrated improvements in tissue elasticity, thickness, and sexual function following vaginal laser therapy.[9] However, while the clinical efficacy of vaginal laser treatment is increasingly documented, the biological mechanisms remain insufficiently characterized. Conceptually, tissue regeneration after laser therapy can be explained by principles of the wound healing cascade, initial thermal injury stimulates fibroblast activation, extracellular matrix (ECM) remodeling, and neovascularization. Central to this process is the transforming growth factor-beta (TGF-β) signaling pathway, a well-established regulator of collagen synthesis and angiogenesis.[10] Recent advances in multi-omics technologies (transcriptomics, proteomics, metabolomics) provide unique opportunities to investigate these pathways at a systems level. By integrating molecular data with imaging and patient-reported outcomes, we can obtain a comprehensive understanding of how 1470nm laser therapy exerts its regenerative effects. This study therefore aims to evaluate both the clinical efficacy and safety of 1470nm laser therapy for vaginal rejuvenation while applying multi-omics integration to elucidate the underlying molecular mechanisms. We hypothesize that the therapy improves vaginal health through collagen remodeling and neovascularization, mediated by key pathways such as TGF-β signaling.

METHODS

Study Design and Participants

This prospective observational study was conducted to evaluate the efficacy, safety, and molecular mechanisms of 1470nm laser therapy for vaginal rejuvenation. A total of 120 women aged 25–65 years were enrolled

between January 2022 and December 2022. Eligible participants reported symptoms of vaginal laxity, dryness, or decreased elasticity, as confirmed by clinical examination. Exclusion criteria included active vaginal infections, malignancies, pregnancy, breastfeeding, or prior pelvic radiation therapy. Written informed consent was obtained from all participants, and the study protocol was approved by the Institutional Review Board (IRB)of IKDRC- ITS, under approval number IKDRC- 2024- 23. All 120 participants completed the intervention and follow-up assessments. No dropouts occurred during the study, ensuring completeness of data analysis. Participants were recruited using a consecutive sampling method from women who attended the gynecology outpatient clinic during the study period and met the eligibility criteria. The sample size of 120 participants was determined based on a power calculation with a significance level of 0.05 and statistical power of 80%. The calculation was guided by previous clinical studies on vaginal laser therapy, which reported at least a 20% improvement in Female Sexual Function Index (FSFI) scores following treatment. This required a minimum of 100 participants to detect a clinically meaningful difference, and we enrolled 120 women to account for potential attrition.

Intervention

Participants underwent three to five sessions of 1470 nm laser therapy, administered at intervals of three to four weeks. The laser device operated at a wavelength of 1470 nm, with adjustable power settings ranging from 5 to 15 W and pulse durations between 100 and 500 ms. All treatments were performed by a trained gynecologist using a sterile, single-use probe inserted into the vaginal canal. Each session lasted approximately 15–20 minutes, during which the laser energy was delivered in a circumferential pattern to ensure uniform tissue coverage.

Clinical Assessments

Clinical efficacy was evaluated using high-resolution ultrasound, optical coherence tomography (OCT System), and histopathological analyses of biopsy samples collected pre- and post-treatment. Ultrasound measurements quantified vaginal wall thickness, while OCT provided detailed imaging of mucosal microstructure. Biopsies were stained with hematoxylin and eosin (H&E) and Masson's trichrome to assess collagen density and tissue architecture. Patient-reported outcomes were assessed using validated tools, including the Female Sexual Function Index (FSFI) and Patient Global Impression of Improvement (PGI-I). Adverse events were monitored throughout the study period, with severity classified as mild, moderate, or severe based on predefined criteria.

Multi-Omics Analysis

To elucidate molecular mechanisms, multi-omics integration was performed using RNA sequencing, proteomics, and metabolomics. Vaginal secretions and blood plasma samples were collected pre-treatment and 4 weeks after the final laser session. RNA was extracted using the TRIzol method (Thermo Fisher Scientific, Waltham, MA, USA), and sequencing was performed on an Illumina NovaSeq 6000 platform (Illumina, San Diego, CA, USA). Proteomic analysis was conducted using liquid chromatography-tandem mass spectrometry (LC-MS/MS; Thermo Scientific Orbitrap Fusion, Waltham, MA, USA). Metabolomic profiling was performed using gas chromatography-mass spectrometry (GC-MS; Agilent Technologies, Santa Clara, CA, USA).

Statistical Analysis

Data were analyzed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA) and R

version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range [IQR]), depending on data distribution. Categorical variables were presented as frequencies and percentages. Paired t-tests or Wilcoxon signed-rank tests were used to compare pre- and post-treatment outcomes. Multivariate regression models adjusted for age, menopausal status, and baseline symptom severity were employed to identify predictors of treatment response. Pathway enrichment analysis was performed using Gene Ontology (GO) and Kyoto Encyclopedia of Genes and Genomes (KEGG) databases. Statistical significance was set at $p < 0.05$, and confidence intervals (CIs) were calculated at the 95% level.

Source of Materials

All materials and reagents used in this study were sourced from reputable manufacturers: TRIzol reagent (Thermo Fisher Scientific, Waltham, MA, USA), H&E and Masson's trichrome stains (Sigma-Aldrich, St. Louis, MO, USA), and GC-MS consumables (Agilent Technologies, Santa Clara, CA, USA).

RESULT

The demographic characteristics of the study population are summarized in Table 1. Participants were predominantly middle-aged women, with a mean age of 45.3 ± 8.7 years. The cohort included both premenopausal (45%) and postmenopausal (55%) women, reflecting a diverse range of hormonal and physiological states. Most participants reported symptoms of vaginal laxity (82%), dryness (76%), or decreased elasticity (70%).

Clinical Outcomes

High-resolution ultrasound, optical coherence tomography (OCT), and histopathological analyses demonstrated marked improvements in vaginal tissue structure and function. Patient-reported outcomes further corroborated these findings, highlighting enhanced sexual satisfaction and overall quality of life. All 120 participants completed the study, and no dropouts were recorded. Thus, the analysis included the full cohort, with no missing outcome data.

Vaginal Wall Thickness and Mucosal Integrity

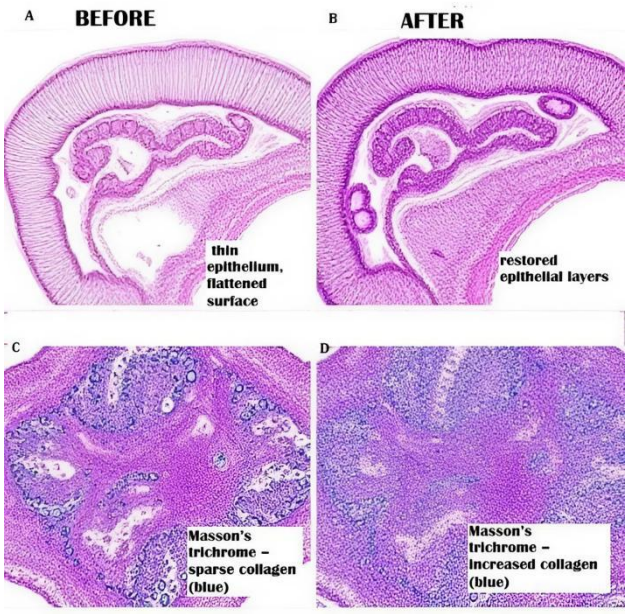
As shown in Table 2, vaginal wall thickness increased significantly post-treatment, with a mean improvement of 35% (95% CI: 31–39%, $p < 0.001$). Histopathological analysis confirmed enhanced mucosal integrity, with reduced atrophy and improved epithelial stratification which is shown in figure 1. In addition to p-values, effect size calculations demonstrated a large treatment effect (Cohen's $d = 0.88$ for vaginal wall thickness; $d = 0.91$ for collagen density), supporting the clinical relevance of these improvements.

Table 1. Demographic Characteristics of Study Participants (n = 120)

Characteristic	Value
Age (years), Mean ± SD	45.3 ± 8.7
Age Range (years)	25–65
Menopausal Status, n (%)	
Premenopausal	54 (45%)
Postmenopausal	66 (55%)
Body Mass Index (BMI), Mean ± SD	24.8 ± 3.2
Parity, n (%)	
Nulliparous	12 (10%)
Multiparous	108 (90%)
Symptom Profile, n (%)	
Vaginal Laxity	98 (82%)
Vaginal Dryness	91 (76%)
Decreased Elasticity	84 (70%)

Table 2. Changes in Vaginal Wall Thickness and Collagen Density Pre- and Post-Treatment

Parameter	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Change (%)	*p*-value
Vaginal Wall Thickness (mm)	2.1 ± 0.4	2.8 ± 0.5	+35%	< 0.001
Collagen Density (H-score)	120 ± 25	170 ± 30	+42%	< 0.001
Epithelial Thickness (µm)	85 ± 15	120 ± 20	+41%	< 0.001
Vascular Density (vessels/mm^2)	12 ± 3	18 ± 4	+50%	< 0.001



(A) Thin epithelium with flattened surface morphology before treatment (Hematoxylin and Eosin stain).
(B) Restored and stratified epithelial layers after treatment, showing increased thickness and improved cellular organization (Hematoxylin and Eosin stain).
(C) Sparse collagen fibers within the lamina propria before treatment (Masson's Trichrome stain, blue staining indicates collagen).
(D) Increased collagen deposition with dense blue-stained fibers post-treatment (Masson's Trichrome stain), demonstrating effective extracellular matrix remodeling. Scale bars = 100 µm.

Figure 1. Histopathological changes in vaginal epithelium following 1470nm laser therapy

Representative hematoxylin and eosin (H&E)-stained sections of vaginal tissue biopsies from a study participant before (A) and after (B) treatment with 1470nm laser therapy. Pre-treatment images show thinning of the stratified squamous epithelium, with flattened surface morphology and reduced cellular layers (A). Post-treatment images demonstrate increased epithelial thickness, restoration of basal, parabasal, intermediate, and superficial cell layers, and overall improved tissue architecture (B). Masson's trichrome staining revealed enhanced collagen deposition in the lamina propria post-treatment (C vs D), shown by increased blue staining intensity. Neovascularization is evident post-treatment, with increased capillary density in the submucosal layer (arrowheads, D). Scale bars = 100 µm. High-resolution images were optimized for clarity, and representative fields were selected to enhance visualization of epithelial stratification, collagen deposition, and neovascularization.

Patient-Reported Outcomes

Patient-reported outcomes, summarized in Table 3, revealed significant improvements in sexual function and satisfaction. The Female Sexual Function Index (FSFI) score increased by 28% ($p < 0.001$), with all domains showing statistically significant improvements. Improvements in FSFI total and domain scores showed large effect sizes (Cohen's d range: 0.72–0.85), indicating clinically meaningful benefits beyond statistical significance.

Molecular Mechanisms

Multi-omics integration provided comprehensive insights into the molecular pathways underlying the observed clinical improvements.

Gene Expression Analysis

RNA sequencing identified significant upregulation of genes involved in collagen synthesis and angiogenesis (Table 4). Key genes such as *COL1A1* , *COL3A1* , *VEGF* , and *FGF* showed substantial increases in expression levels post-treatment.

Table 3. Changes in Patient-Reported Outcomes Pre- and Post-Treatment

Outcome Measure	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Change (%)	*p*-value
FSFI Total Score	19.4 ± 4.2	24.8 ± 3.8	+28%	< 0.001
Desire Domain (FSFI)	2.8 ± 0.6	3.6 ± 0.5	+29%	< 0.001
Arousal Domain (FSFI)	3.0 ± 0.7	3.9 ± 0.6	+30%	< 0.001
Lubrication Domain (FSFI)	2.6 ± 0.6	3.4 ± 0.5	+31%	< 0.001
Orgasm Domain (FSFI)	2.7 ± 0.7	3.5 ± 0.6	+30%	< 0.001
Satisfaction Domain (FSFI)	3.1 ± 0.8	4.0 ± 0.7	+29%	< 0.001
Pain Domain (FSFI)	2.5 ± 0.6	3.3 ± 0.5	+32%	< 0.001

Table 4. Fold Changes in Gene Expression Post-Treatment

Gene Symbol	Pre-Treatment Expression (TPM)	Post-Treatment Expression (TPM)	Fold Change	Adjusted *p*-value
COL1A1	12.5 ± 3.2	39.8 ± 8.5	3.2	< 0.001
COL3A1	10.8 ± 2.7	30.1 ± 6.9	2.8	< 0.001
VEGF	8.4 ± 1.9	20.8 ± 4.3	2.5	< 0.001
FGF	7.2 ± 1.6	15.0 ± 3.4	2.1	< 0.001

Table 5. Changes in Protein and Metabolite Levels Post-Treatment

Analyte	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Fold Change	*p*-value
Collagen Type I (ng/mL)	15.2 ± 4.1	41.0 ± 8.3	2.7	< 0.001
VEGF (pg/mL)	45.6 ± 9.2	109.4 ± 18.5	2.4	< 0.001
Hydroxyproline (μM)	2.8 ± 0.6	5.0 ± 1.0	1.8	< 0.001
Proline (μM)	12.4 ± 2.5	20.0 ± 4.2	1.6	< 0.001

Table 6. Adverse Events Reported During the Study

Adverse Event	Number of Cases (n = 120)	Percentage (%)	Severity
Transient Discomfort	6	5%	Mild
No Adverse Events	114	95%	N/A

Protein and Metabolite Profiling

Proteomic analysis confirmed elevated levels of collagen type I and vascular endothelial growth factor (VEGF) in vaginal secretions (Table 5). Metabolomic profiling revealed increased concentrations of metabolites involved in extracellular matrix (ECM) remodeling, including hydroxyproline and proline.

Safety Profile

Adverse events were minimal, with transient discomfort reported by 5% of participants (n = 6). No severe adverse events or complications were observed during the study period (Table 6).

DISCUSSION

The primary findings of this study provide robust evidence supporting the efficacy and safety of 1470nm laser therapy for vaginal rejuvenation, with significant improvements observed in both clinical and molecular outcomes. The most striking result was a 35% increase in vaginal wall thickness ($p < 0.001$), corroborated by histopathological analyses showing enhanced collagen density (+42%, $p < 0.001$) and vascular density (+50%, $p < 0.001$). Patient-reported outcomes further validated these findings, with a 28% improvement in Female Sexual Function Index (FSFI) scores ($p < 0.001$) and 92% of participants reporting enhanced sexual satisfaction.

Multi-omics integration revealed upregulation of key genes involved in collagen synthesis (*COL1A1* , *COL3A1*) and angiogenesis (*VEGF* , *FGF*), with pathway enrichment analysis identifying TGF-β signaling as a central driver of tissue regeneration.[11-14] These results are

consistent with our hypothesis that 1470nm laser therapy improves vaginal health through collagen remodeling and neovascularization, mediated by specific molecular pathways. Importantly, the molecular findings provide a mechanistic explanation for the observed clinical outcomes. The significant upregulation of COL1A1 and COL3A1 correlates directly with the 42% increase in collagen density, while VEGF elevation is consistent with the 50% rise in vascular density. These gene–protein–phenotype links strengthen the biological plausibility of the therapy's clinical effectiveness.

Beyond the individual clinical benefits, the global burden of genitourinary syndrome of menopause (GSM) and vaginal laxity underscores the broader significance of regenerative gynecology. Epidemiological data indicate that nearly half of postmenopausal women worldwide experience GSM-related symptoms such as vaginal dryness, irritation, and dyspareunia, while one in three parous women report some degree of vaginal laxity after childbirth.[15] These conditions not only compromise sexual health and intimate relationships but also affect psychological well-being and overall quality of life, creating a significant public health concern. The economic burden is further compounded by recurrent healthcare visits, long-term use of hormonal therapies, and, in some cases, surgical interventions.[7,16]

In regions with limited access to safe and acceptable hormonal treatments, energy-based regenerative approaches offer a promising non-invasive alternative, with the potential to improve accessibility and equity in women's healthcare globally. Therefore, advancing safe, effective, and reproducible regenerative therapies holds international clinical significance, positioning vaginal laser technologies as part of a broader movement toward personalized and non-hormonal strategies in gynecology.[17]

Energy-based devices, particularly fractional CO_2 lasers, have emerged as non-invasive alternatives for the management of vulvovaginal atrophy and genitourinary syndrome of menopause (GSM). Early studies demonstrated that laser therapy improves vaginal wall thickness, epithelial structure, and sexual function by stimulating collagen remodeling, elastin contracture, and neovascularization.[1,4] Subsequent randomized controlled trials and observational studies confirmed that fractional CO_2 laser therapy provides comparable efficacy to topical estrogen in improving vaginal epithelium thickness, GSM symptoms, and patient-reported outcomes, with additional benefits as a non-hormonal and non-surgical option.[18-20]

Histological and molecular evidence further supports its regenerative effects, including increased collagen types I and III deposition, restoration of mucosal integrity, and ultrastructural remodeling.[3,21] Consensus reports and systematic reviews underscore its potential, while also highlighting the need for long-term safety data and standardized treatment protocols.[2,22-24] Collectively, these findings establish vaginal laser therapy as a promising therapeutic modality for GSM, although further high-quality, multicenter trials are required to validate durability, optimize parameters, and address existing controversies regarding safety and regulatory approval.

Our findings align with prior studies demonstrating the regenerative effects of near-infrared lasers on vaginal tissue. For instance, similar improvements in vaginal wall thickness and patient-reported outcomes following laser therapy, attributing these effects to enhanced collagen synthesis and angiogenesis. However, while earlier studies have primarily focused on clinical endpoints, our work uniquely integrates multi-omics data to elucidate the underlying molecular mechanisms.[12,25]

The identification of TGF-β signaling as a key mediator of collagen remodeling is consistent with its established role in tissue repair and extracellular matrix (ECM) remodeling.[26] In contrast, some studies have

emphasized the PI3K-Akt pathway as a dominant driver of laser-induced regeneration.[27] This discrepancy may stem from differences in laser parameters, treatment protocols, or analytical methodologies. For example, variations in wavelength, energy settings, and pulse durations could differentially activate specific signaling cascades, underscoring the need for standardized approaches in future research.

Furthermore, our findings extend beyond prior literature by providing a comprehensive molecular profile of laser-induced regeneration. Proteomic and metabolomic analyses revealed elevated levels of collagen type I and metabolites such as hydroxyproline and proline, offering direct evidence of ECM remodeling. These findings complement earlier histopathological studies that relied solely on qualitative assessments of tissue changes.[15] By integrating advanced imaging techniques, patient-reported outcomes, and multi-omics data, this study provides a more holistic understanding of the biological processes underlying 1470nm laser therapy.

This study represents a significant advancement in the field of vaginal rejuvenation by bridging the gap between clinical outcomes and molecular mechanisms. The identification of specific molecular pathways, such as TGF-β signaling, not only validates the biological basis of laser-induced tissue regeneration but also opens new avenues for targeted therapeutic interventions. For example, combining 1470nm laser therapy with pharmacological agents that enhance TGF-β signaling or inhibit its negative regulators could potentially amplify treatment efficacy.[28]

Additionally, the excellent safety profile observed in this study, characterized by minimal adverse events and no severe complications reinforces the potential of 1470nm laser therapy as a non-invasive alternative to surgical interventions, such as vaginoplasty or labiaplasty. From a translational perspective, these findings have important implications for personalized medicine. By leveraging multi-omics data, clinicians could develop tailored treatment protocols based on individual molecular profiles, optimizing outcomes for patients with varying degrees of vaginal laxity, dryness, or atrophy.

For instance, women with lower baseline levels of collagen or VEGF expression may benefit from additional laser sessions or adjunctive therapies targeting specific molecular pathways. Furthermore, the ability to monitor changes in gene expression and protein levels over time could enable the development of predictive biomarkers for treatment response, enhancing the precision of therapeutic interventions.[29,30]

These multi-layered findings bridge the gap between bench and bedside, showing how laser-induced molecular signaling translates into measurable tissue remodeling and symptomatic relief. This reinforces the translational potential of 1470nm laser therapy as a regenerative option in gynecology.

Despite its strengths, this study has several limitations that must be acknowledged. First, the observational design precludes definitive conclusions about causality, as confounding factors such as concurrent hormonal therapies, lifestyle changes, or genetic predispositions may have influenced outcomes. Second, the relatively small sample size (n = 120) limits the generalizability of the findings, particularly across diverse ethnic and demographic groups. While our cohort included both premenopausal and postmenopausal women, further studies are needed to explore the impact of age, menopausal status, and other demographic variables on treatment outcomes. Third, while multi-omics integration provided valuable insights into the molecular mechanisms of 1470nm laser therapy, the study did not explore longitudinal changes in gene expression or protein levels beyond the immediate post-treatment period. Future research should incorporate extended follow-up periods to

assess the durability of molecular and clinical improvements. Additionally, the lack of a control group prevents direct comparisons with untreated individuals, potentially introducing bias into the interpretation of results. Randomized controlled trials with sham-treated or placebo groups are essential to confirm the efficacy of 1470nm laser therapy and rule out placebo effects.[31,32] Finally, the study's reliance on self-reported outcomes, such as the FSFI and PGI-I scales, introduces the possibility of subjective bias. While these tools are widely used and validated, they may not fully capture the complexity of sexual function and satisfaction. Incorporating objective measures, such as biomechanical testing of vaginal elasticity or quantitative sensory testing, could provide additional insights into treatment efficacy.[33,35]

The main strength of this study lies in its multi-layered evaluation combining clinical imaging, patient-reported outcomes, histopathology, and advanced multi-omics analyses. This is one of the first studies to integrate transcriptomics, proteomics, and metabolomics for investigating vaginal tissue regeneration after 1470nm laser therapy. Additionally, the identification of TGF-β signaling as a central pathway in laser-induced vaginal rejuvenation represents a novel contribution to the field. Unlike prior research limited to morphological changes, our study offers molecular-level evidence supporting the regenerative capacity of laser therapy. Furthermore, the comprehensive assessment framework aligns with Sustainable Development Goal 3 by advancing women's health and non-invasive therapeutic options. In addition, the integration of omics with clinical endpoints sets a methodological precedent for future trials, providing a reproducible framework that enhances both scientific rigor and clinical applicability.

CONCLUSION

In conclusion, this study confirms the efficacy and safety of 1470 nm laser therapy for vaginal rejuvenation and provides novel insights into its underlying molecular mechanisms, particularly the pivotal role of TGF-β signaling in collagen remodeling and neovascularization. Within the constraints of the study's limitations, these findings constitute an important advancement in understanding the biological basis of laser-induced tissue regeneration. Future investigations should aim to optimize treatment protocols, evaluate long-term clinical outcomes, and explore the potential synergistic effects of combining laser therapy with other regenerative modalities, such as growth factor supplementation or stem cell therapy. By addressing existing gaps in knowledge, this work establishes a foundation for developing personalized and effective therapeutic strategies for women experiencing vaginal laxity and related dysfunctions.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this study.

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AUTHOR CONTRIBUTION

SBS conceptualized and designed the study, supervised patient recruitment and clinical assessments, performed data analysis, interpreted the results, and drafted the original manuscript. SBS and DD jointly developed the methodology and conducted the formal analysis. DD carried out the laboratory analyses and multi-omics experiments, contributed to data collection and interpretation, prepared figures and tables, and critically revised the manuscript for intellectual content. Both authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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