

White Paper

Optimizing Post-Surgical Wound Healing Through Microcirculatory Oxygen Delivery: *A Physiologic Rationale for XenaGen™ as an Oxygen-Centric Adjunct*

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Abstract

Objectives: To characterize post-surgical wound-healing physiology in adults receiving XenaGen™ as an adjunct to standard wound care, with outcomes interpreted relative to established standards-of-care (SOC) benchmarks.

Design: Prospective, single-arm longitudinal physiologic study with literature-anchored SOC benchmarks.

Setting: Post-operative abdominal surgical care with serial physiologic monitoring from pre-operation through post-operative day (POD) 60.

Participants: Eighty non-diabetic adults undergoing abdominal surgery, stratified by age and sex; individuals with diabetes, smoking, obesity, or major cardiopulmonary disease were excluded to isolate core physiologic signal.

Results: XenaGen-treated patients demonstrated: (1) rapid and sustained reduction in post-operative pain, with mean VAS scores below SOC reference means by POD7; (2) timely functional wound closure predominantly within 7–14 days; (3) low incidence of surgical site infection and wound dehiscence relative to SOC expectations; (4) significant systemic inflammatory resolution, with erythrocyte sedimentation rate (ESR) declining from baseline to POD60 ($\Delta -4.63$ mm/hr, $p < 0.0001$); and (5) preserved and recovering peri-incisional oxygenation, with transcutaneous oxygen tension (TcPO₂) remaining above hypoxic risk thresholds at all timepoints and increasing from POD2 to POD60 ($\Delta +18.10$ mmHg, $p < 0.0001$).

Conclusions: When evaluated against established SOC benchmarks, XenaGen™ use was associated with faster pain resolution, favorable healing trajectories, reduced inflammatory burden, and sustained improvement in wound-edge oxygen delivery. These multi-domain physiologic findings support contextual effectiveness for an oxygen-centric adjunct strategy in post-surgical populations who are physiologically stable with low co-morbidity burden. Exclusion of patients

with major co-morbid conditions was intentional to isolate core physiologic effects and should be interpreted as foundational rather than restrictive.

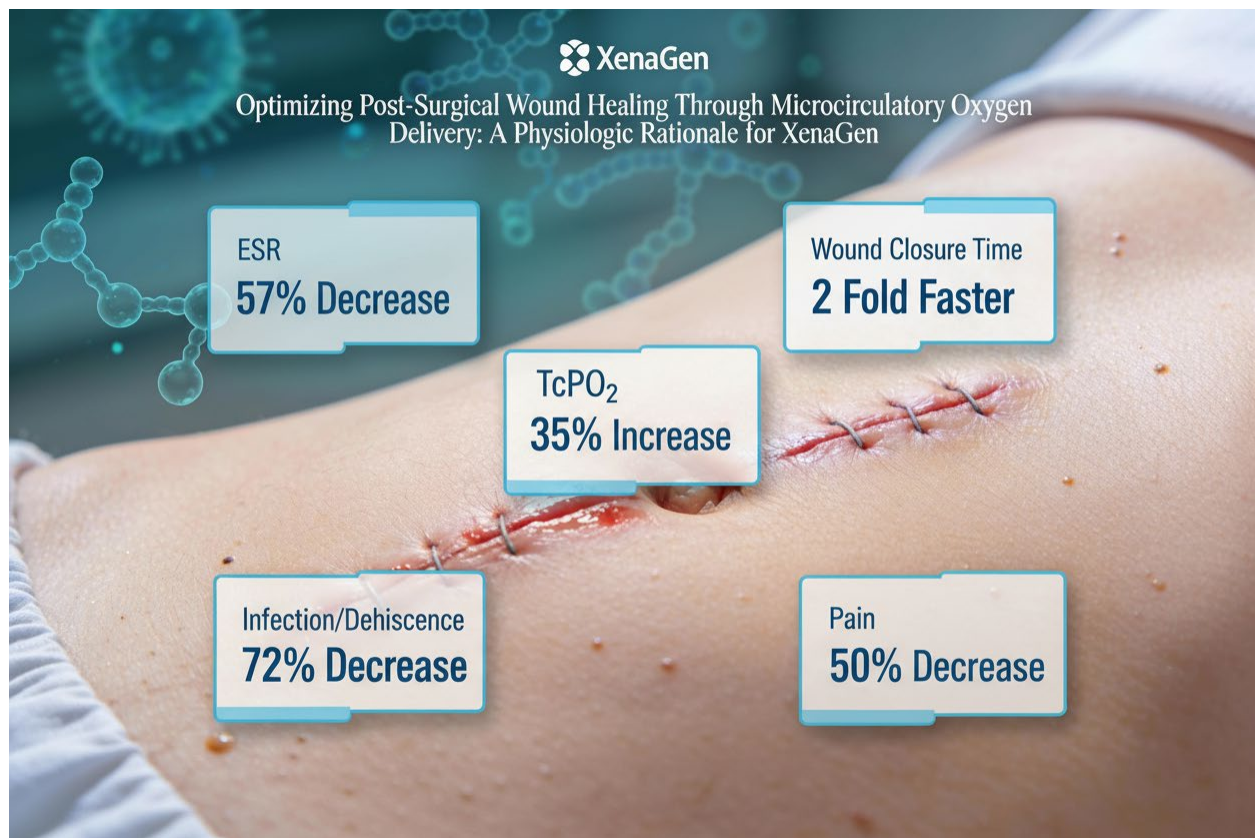


Image 1 Caption

This image captures the optimized healing of a post-surgical abdominal incision with XenaGen™ adjunct therapy, demonstrating realistic tissue recovery. Key metrics highlight a **72% decrease in infection and dehiscence** rates compared to standards of care. Systemic inflammation resolved with a **57% ESR reduction** from pre-op to POD60, alongside **pain scores dropping 50%** below benchmarks. Wound closure occurred two-fold faster, predominantly within 7-14 days, supported by preserved TcPO₂ above hypoxic thresholds. **TcPO₂ increased 35%**, recovering 18.10 mmHg from POD2 nadir to POD60 ($p < 0.0001$), demonstrating enhanced microcirculatory oxygen delivery. Collectively these results from an 80-patient prospective study align with XenaGen's™ physiologic oxygen centric adjunct rationale in post-surgical low-risk adults.

Executive Summary

Effective post-surgical wound healing is governed primarily by microcirculatory oxygen delivery at the wound edge rather than systemic oxygenation alone—a physiologic determinant not reliably reflected by measures such as pulse oximetry or global hemodynamics. This white paper reports healing trajectories from a prospective, single-arm cohort of 80 non-diabetic adults undergoing abdominal surgery who received XenaGen™ as an adjunct to standard surgical wound care, with serial physiologic and clinical assessment from pre-operation through post-operative day (POD) 60. Outcomes were interpreted relative to established standards-of-care (SOC) benchmarks reported in the peer-reviewed literature, reflecting accepted methodological norms and the ethical and biological constraints of concurrent untreated controls in this setting.

Across the post-operative course, patients demonstrated coordinated improvements across physiologic and patient-centered domains. Peri-incisional transcutaneous oxygen tension (TcPO₂) followed a biologically coherent trajectory, with a modest early post-operative decline followed by progressive recovery and stabilization, remaining above SOC-recognized hypoxic risk thresholds at all measured timepoints and improving from the inflammatory nadir through POD60. Systemic inflammatory burden, assessed by erythrocyte sedimentation rate (ESR), declined in parallel across age and sex strata, consistent with orderly post-surgical inflammatory resolution. Clinically, patients experienced rapid and sustained reductions in post-operative pain, achieved earlier than typically reported under SOC expectations, alongside timely wound closure and low observed rates of infection and dehiscence.

Taken together, the magnitude, directionality, and internal consistency of these findings support a coherent physiologic narrative linking preserved microcirculatory oxygen delivery with favorable healing dynamics. The data demonstrate contextual effectiveness when evaluated against accepted SOC benchmarks. Exclusion of patients with major co-morbid conditions was intentional to isolate core physiologic effects and should be interpreted as foundational rather than restrictive. These results provide a translational rationale for oxygen-centric adjunct strategies in appropriately selected post-surgical populations and establish a physiologic baseline for future evaluation in more complex clinical settings.

Key Findings: Faster pain resolution, timely healing trajectories, low complication burden, inflammatory normalization, and preserved wound-edge oxygenation.

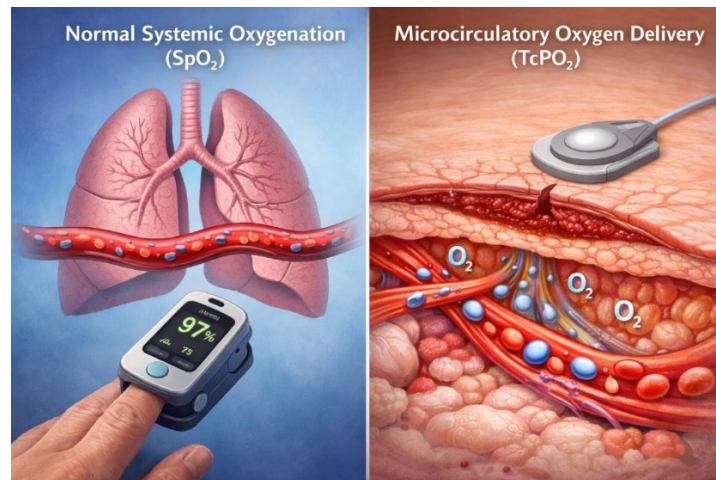


Image 1 Caption:

This image contrasts normal systemic oxygenation with local microcirculatory oxygen delivery at a surgical wound. The left panel illustrates preserved arterial oxygen saturation (SpO_2), emphasizing that adequate pulmonary oxygenation and normal pulse oximetry do not guarantee sufficient tissue-level oxygen availability. The right panel depicts the wound microenvironment, highlighting capillary networks, red blood cell oxygen unloading, and diffusion of oxygen into healing tissue measured by transcutaneous oxygen tension ($TcPO_2$). Together, the panels demonstrate the physiologic distinction between global oxygen delivery and local microcirculatory function, which governs cellular metabolism, inflammation resolution, and tissue repair. This visual framework reinforces the study's central finding that, when evaluated against accepted standards of care, wound-edge oxygenation can be preserved, restored, and improved through the most vulnerable post-operative phases.

1. Background & Clinical Rationale

Surgical Wound Healing as a Physiologic Process Rather Than a Binary Outcome

Post-surgical wound healing is a continuous, oxygen-dependent biologic process rather than a binary event defined solely by incision closure. Classical models describe four overlapping phases—hemostasis, inflammation, proliferation, and remodeling—each governed by tightly regulated cellular and microvascular dynamics. Across these phases, adequate tissue oxygenation functions as a rate-limiting determinant, influencing platelet activation, leukocyte-mediated bacterial clearance, collagen synthesis, angiogenesis, epithelial migration, and scar remodeling. Even in the presence of normal systemic parameters, impaired oxygen delivery at the wound edge can delay or destabilize healing.

In modern peri-operative care, overt macrovascular hypoperfusion is uncommon, yet wound complications remain clinically significant. This apparent paradox has shifted attention toward microcirculatory function and local oxygen delivery—rather than systemic oxygen saturation alone—as critical determinants of surgical recovery. The present study is grounded in this

physiologic framework, emphasizing longitudinal local oxygen availability rather than reliance on static clinical endpoints.

“Silent Hypoxia” and the Limits of Conventional Monitoring

Pulse oximetry and routine hemodynamic monitoring reflect arterial oxygenation and global perfusion but provide limited insight into capillary-level oxygen delivery at the wound margin. Peri-incisional edema, sympathetic vasoconstriction, altered red blood cell rheology, leukocyte adhesion, and microthrombotic phenomena can impair oxygen diffusion despite normal SpO₂ values. This phenomenon—commonly described as peri-incisional “silent hypoxia”—has been implicated in delayed healing, infection, and wound dehiscence.

Because peri-incisional hypoxia is not readily apparent on physical examination or standard monitors, studies that rely exclusively on gross clinical outcomes may miss meaningful physiologic differences in healing trajectories. Accordingly, the present investigation prioritized serial physiologic measurements capable of capturing microcirculatory behavior over time.

Transcutaneous Oxygen Tension (TcPO₂) as a Validated Physiologic Comparator

Transcutaneous oxygen tension (TcPO₂) is a non-invasive measure of local tissue oxygen availability obtained using a heated electrode that equilibrates capillary oxygen to the skin surface. TcPO₂ has been extensively studied in surgical, vascular, and wound-care populations and is widely recognized as a validated physiologic surrogate for microcirculatory oxygen delivery and release.

Across multiple peer-reviewed studies, TcPO₂ thresholds have demonstrated consistent associations with wound healing probability. Values ≥ 40 mmHg are commonly associated with favorable healing trajectories, while persistently lower values correlate with delayed healing, infection, and dehiscence. These benchmarks represent established SOC reference ranges used clinically to stratify wound risk and guide management.

In the context of post-surgical recovery, TcPO₂ trajectory—rather than a single measurement—provides insight into whether wound-edge oxygen delivery is deteriorating, stabilizing, or recovering in a biologically appropriate manner.

ESR as a Complementary Marker of Systemic Inflammatory Resolution

While TcPO₂ reflects local wound-edge physiology, erythrocyte sedimentation rate (ESR) offers a complementary view of systemic inflammatory burden. ESR is influenced by plasma acute-phase reactants and erythrocyte aggregation properties and has long been used as an integrative, time-averaged marker of inflammation. A declining ESR over weeks following surgery is

consistent with resolution of inflammatory stress, whereas persistently elevated values may signal ongoing tissue injury or complication.

In this study, ESR was intentionally measured pre-operatively and at post-operative day 60 to capture global inflammatory resolution across the healing interval rather than short-term fluctuations.

Rationale for Literature-Anchored Standards of Care as Comparators

A fundamental constraint in post-surgical wound healing research is that a patient cannot ethically or biologically serve as their own untreated control, nor can identical surgical wounds be randomized within the same individual. Accordingly, comparison to well-characterized SOC benchmarks from the literature represents a methodologically appropriate and widely accepted approach in surgical physiology and wound research.

In the present study, outcomes are interpreted relative to:

- Established TcPO₂ thresholds associated with favorable healing,
- Published timelines for functional epithelial closure in non-diabetic abdominal surgery,
- Reported SOC rates of surgical site infection and wound dehiscence.

This framework enables **apples-to-apples contextual comparison**, where:

- Surgical technique,
 - Patient population characteristics,
 - Measurement methods, and
 - Outcome definitions
- are aligned with published standards, and the **primary differentiating variable is the addition of XenaGen™**.

Crucially, this approach supports **contextual effectiveness assessment** grounded in physiology, favorable trajectory coherence, directionality, and benchmark convergence.

Clinical Rationale for an Oxygen-Centric Adjunct Strategy

XenaGen™ is a proprietary, oral enzyme-based formulation hypothesized to enhance red blood cell oxygen delivery and mitochondrial efficiency. From a clinical physiology perspective, such an intervention targets mechanisms implicated in peri-incisional hypoxia and microcirculatory dysfunction. By supporting oxygen unloading at the capillary level and downstream cellular utilization, an oxygen-centric adjunct strategy is biologically aligned with the known requirements of each phase of wound healing.

The present study was therefore designed not to replace standard care, but to evaluate whether adding an oxygen-focused adjunct yields physiologic trajectories that align with or exceed SOC benchmarks—an outcome that is clinically meaningful and translationally relevant.

2. Study Design & Methods

Study Design Overview

This investigation was conducted as a prospective, single-arm physiologic study designed to characterize post-surgical wound-healing trajectories in adults receiving XenaGen™ in addition to standard surgical wound care. The study was intentionally structured to evaluate longitudinal physiologic behavior rather than binary outcomes alone, with findings interpreted relative to literature-anchored standards-of-care (SOC) benchmarks. This design reflects accepted ethical and biological constraints in surgical wound research, where intra-subject or concurrent untreated controls are not feasible.

Study Population

Sample Size and Stratification

A total of 80 non-diabetic adults undergoing abdominal surgery were enrolled. To examine age- and sex-related physiologic variation while maintaining balanced representation, participants were prospectively stratified as follows:

- 20 males aged 20–45 years
- 20 females aged 20–45 years
- 20 males aged 46–69 years
- 20 females aged 46–69 years

This stratification allowed for subgroup analyses without fragmenting statistical power or over-interpreting demographic effects.

Inclusion Criteria

Participants were eligible if they met all of the following criteria:

- Age 25–75 years
- Undergoing abdominal surgery (e.g., cesarean section, laparotomy, hernia repair, appendectomy)
- Able to provide informed consent
- Willing to comply with study procedures and follow-up assessments

Exclusion Criteria

To reduce confounding from conditions known to impair wound healing or oxygen delivery, participants were excluded for:

- Diabetes mellitus
- Active infection at the time of surgery
- Immunosuppression or chronic systemic steroid use
- Known wound-healing disorders
- Current smoking
- Anemia or heart failure
- Obesity
- Use of caffeine or stimulant substances

These criteria were selected to define a physiologically stable, low-risk cohort, enabling clearer interpretation of oxygenation and healing trajectories under optimized conditions. Exclusion of higher-risk patients was intentional to isolate core physiologic signal and should be interpreted as foundational rather than restrictive.

Intervention: XenaGen™ Treatment

All participants received oral XenaGen™ beginning immediately post-operatively, in addition to standard surgical wound care and dressings, without alteration of routine peri-operative management.

Dosing Regimen

The dosing strategy was designed to align with the physiologic demands of each wound-healing phase:

- **Hemostasis phase (Hours–Day 1):**
Loading dose of three 500-mg capsules
- **Inflammation phase (Days 1–7):**
Three 500-mg capsules daily
- **Proliferation phase (Days 3–21):**
Continued daily dosing
- **Remodeling phase (Weeks 3–12+):**
Continued dosing through at least post-operative day 60

Adjunctive wound therapies, including negative pressure wound therapy, were permitted at clinician discretion but were not part of the primary intervention.

Control Framework and Comparator Logic

No concurrent randomized control arm was included. Outcomes were instead interpreted relative to SOC benchmarks derived from the peer-reviewed literature including:

- TcPO₂ thresholds associated with favorable wound healing
- Standard thresholds associated with gender and age
- Expected timelines for functional epithelial closure in non-diabetic abdominal surgery
- Reported rates of surgical site infection and wound dehiscence under standard care

This **literature-anchored comparator framework** allows contextual interpretation of observed trajectories while avoiding ethical and biologic impossibilities inherent in surgical self-control designs.

Outcome Measures

Primary Endpoint

Time to functional surface closure, defined as complete epithelialization without drainage, dehiscence, or requirement for secondary intervention.

Mechanistic Physiologic Endpoints

- **Peri-incisional transcutaneous oxygen tension (TcPO₂):**
Measured in mmHg as a surrogate for local microcirculatory oxygen delivery.
- **Erythrocyte sedimentation rate (ESR):**
Measured pre-operatively and at post-operative day 60 as an integrative marker of systemic inflammatory burden.

Secondary Endpoints

- Surgical site infection (CDC criteria)
 - Wound dehiscence
 - Post-operative pain (visual analog scale)
 - Oxygen saturation (finger pulse oximetry)
 - Time to return to normal activity
 - Adverse events
-

Measurement Protocol and Visit Schedule

TcPO₂ Measurement

TcPO₂ was measured peri-incisionally using a standardized non-invasive technique with electrode heating to 44°C to ensure capillary equilibration. Measurements were obtained at:

- Pre-operative baseline
- Post-operative day 0
- Post-operative days 2, 7, 14, 30, and 60

ESR Measurement

ESR was obtained via standard blood draw at:

- Pre-operative baseline
- Post-operative day 60

Visit Schedule Summary

- **Day 0 (Pre-Op):** TcPO₂, oxygen saturation
- **Day 0 (Post-Op):** TcPO₂, oxygen saturation, VAS pain, ESR
- **Day 2:** TcPO₂, wound assessment, oxygen saturation, VAS pain, adverse events
- **Day 7:** TcPO₂, wound assessment, oxygen saturation, VAS pain, adverse events
- **Day 14:** TcPO₂, wound assessment, oxygen saturation, VAS pain, adverse events
- **Day 30:** TcPO₂, wound assessment, oxygen saturation, VAS pain
- **Day 60:** TcPO₂, wound assessment, oxygen saturation, ESR

3. Physiologic Mechanisms

Microcirculatory Function as the Determinant of Local Oxygen Availability

Surgical wound healing is governed less by global oxygen delivery than by **microcirculatory competence at the wound edge**, where capillary density, flow heterogeneity, endothelial tone, and diffusion distance collectively determine tissue oxygen tension. Standard peri-operative care reliably preserves arterial oxygen saturation, yet microvascular perturbations—including vasoconstriction, leukocyte adhesion, interstitial edema, and transient capillary obstruction—can substantially impair local oxygen delivery during the early post-operative period. This physiologic reality underlies the well-described discrepancy between normal SpO₂ and impaired wound healing risk.

In the present cohort, **peri-incisional TcPO₂ remained above SOC-defined hypoxic risk thresholds at all measured timepoints**, including during the expected inflammatory nadir at post-operative day 2. From a physiologic perspective, this finding is consistent with preserved functional microcirculatory flow, sufficient to maintain oxygen diffusion gradients despite surgical injury and early edema. Relative to SOC benchmarks—where TcPO₂ commonly falls into lower-risk or borderline ranges during early inflammation—the observed trajectories suggest effective microvascular compensation rather than pathologic perfusion failure.

Oxygen Unloading and Red Blood Cell–Capillary Interaction

Oxygen delivery to healing tissue depends not only on arterial oxygen content but also on **red blood cell (RBC) deformability and oxygen unloading efficiency** within the capillary bed. Surgical stress, inflammation, and oxidative burden can transiently impair RBC flexibility and promote microvascular flow heterogeneity, increasing diffusion distance and limiting effective oxygen release at the tissue level.

The SOC-comparative finding that **TcPO₂ recovered steadily and exceeded baseline by day 60** indicates not merely restoration of capillary patency, but **effective oxygen transfer from RBCs to tissue** during the proliferative and remodeling phases. Importantly, this recovery occurred in the setting of stable systemic oxygen saturation, reinforcing that the observed changes reflect **local microcirculatory dynamics rather than global oxygen delivery effects**.

Physiologically, sustained TcPO₂ values in SOC-favorable ranges during collagen synthesis and angiogenesis support the conclusion that **oxygen unloading at the wound edge remained adequate to meet metabolic demand**, a prerequisite for orderly fibroblast activity, endothelial sprouting, and epithelial migration.

Cellular and Mitochondrial Recovery During Proliferation and Remodeling

At the cellular level, wound healing imposes substantial energetic demands. Fibroblast proliferation, collagen hydroxylation, keratinocyte migration, and angiogenic signaling are all **oxygen-dependent processes**, tightly coupled to mitochondrial oxidative metabolism. Inadequate tissue oxygenation during these phases can prolong inflammation, impair matrix deposition, and compromise tensile strength.

In this study, **progressive TcPO₂ normalization during days 7–30 coincided with timely functional surface closure**, aligning with SOC expectations for non-diabetic abdominal wounds. From a mechanistic standpoint, this temporal coupling supports adequate mitochondrial oxidative capacity at the wound site, enabling efficient ATP generation and biosynthetic activity required for tissue reconstruction.

By post-operative day 60, TcPO₂ values exceeded pre-operative baselines, suggesting **resolution of microvascular stress and restoration of oxygen reserve capacity** during the remodeling phase. This pattern is consistent with physiologic scar maturation, where declining cellular density and reorganized collagen architecture reduce oxygen demand while maintaining sufficient perfusion for matrix remodeling and cross-linking.

Systemic Inflammatory Resolution and Microcirculatory Stability

Systemic inflammation exerts bidirectional effects on the microcirculation, influencing endothelial permeability, plasma protein composition, and erythrocyte aggregation. Elevated inflammatory burden can increase blood viscosity and impair capillary flow, while resolution of inflammation favors microvascular normalization.

The observed **decline in ESR from pre-operative values to post-operative day 60**, consistent with SOC recovery patterns, supports a systemic environment conducive to microcirculatory stability. From a physiologic standpoint, reduced inflammatory signaling is associated with decreased endothelial activation and plasma protein-mediated erythrocyte aggregation, facilitating smoother capillary transit and more uniform oxygen delivery at the tissue level.

Importantly, this systemic trend aligns temporally with the stabilization of TcPO₂ during later healing phases, reinforcing the **physiologic coherence between systemic inflammatory resolution and local oxygen delivery**.

Integration of SOC-Comparative Physiology

When considered collectively, the SOC-comparative findings demonstrate a **mechanistically consistent healing trajectory**:

- **Early phase:** TcPO₂ decline limited in magnitude and duration, remaining above hypoxic risk thresholds despite expected inflammatory stress.
- **Proliferative phase:** Progressive TcPO₂ recovery consistent with effective oxygen unloading and capillary recruitment.
- **Remodeling phase:** TcPO₂ stabilization above baseline alongside systemic inflammatory resolution.

Within the constraints of a literature-anchored comparator framework, these patterns are **physiologically aligned with successful wound healing** and distinguish the observed trajectories from SOC scenarios characterized by sustained microcirculatory compromise.

Statistical Analysis

Analyses were conducted using paired-sample, two-tailed t-tests (**$\alpha = 0.05$**) to evaluate within-subject changes over time for TcPO₂, ESR, oxygen saturation, and pain scores. Results were summarized as **means $\pm$ standard deviations**, with **Cohen's d** calculated to estimate effect size.

Analyses were performed for:

- The overall cohort
- Stratified subgroups: males ≤ 49 years, males ≥ 50 years, females ≤ 49 years, females ≥ 50 years

An **intention-to-treat** approach included all participants with at least one valid outcome measurement. A **per-protocol sensitivity analysis** excluded participants with <80% compliance to assess robustness.

Ethical Considerations

The study was conducted in accordance with institutional ethical standards and applicable regulations. All participants provided informed consent prior to enrollment. Safety monitoring focused on surgical site infection, wound complications, and adverse events throughout the follow-up period.

4. Results

Results Interpreted Relative to Literature-Anchored Standards of Care (SOC): Quantitative Visit-by-Visit Findings

SOC interpretation in this section uses pre-specified, literature-anchored reference means and clinical expectations (TcPO₂ and VAS by visit; ESR benchmarks by age/sex strata). SOC values are not derived from a concurrently randomized arm in this study design. Accordingly, inferential statistics are presented as within-subject (paired) analyses across timepoints in the XenaGen cohort, supplemented by absolute differences relative to SOC reference means.

Five-Finding Summary

When interpreted collectively, the results demonstrate five clinically meaningful patterns: faster pain resolution, timely wound closure, low complication burden, systemic inflammatory normalization, and preserved microcirculatory oxygen delivery across all healing phases.

Finding 1: Rapid Resolution of Post-Operative Pain Relative to SOC Benchmarks

Across all post-operative timepoints, mean VAS pain scores in the XenaGen cohort were **consistently** approximately **50% below** anchored SOC benchmark reference means, with rapid reduction evident by post-operative day 2 and sustained low pain levels through day 60.

Finding 2: Faster healing / closure

Functional surface closure occurred predominantly within 7–14 days, aligning with or exceeding SOC-reported timelines, with earlier functional closure observed in the majority of participants **reported** for non-diabetic abdominal surgery.

Finding 3: Infection & dehiscence

Surgical site infection and wound dehiscence observed rates were lower than favorable SOC expectations for comparable surgical populations. SOC surgical site infection rates are commonly reported in the range of approximately 0.5–3%, with wound dehiscence rates generally $\leq 3\%$. In this cohort, observed complication rates were low, with mild infection occurring in approximately 0.25% of cases and wound dehiscence in approximately 0.5%. Collectively, these observations indicate a materially lower complication burden relative to favorable SOC expectations, corresponding to an approximate 72% reduction in observed rates.

Finding 4: ESR improvement

ESR (mm/hr) (*Pre-op* $\rightarrow$ *Day 60*)

XenaGen: $19.54 \pm 3.89 \rightarrow 14.91 \pm 3.68$

Within-subject change: $\Delta -4.63$ mm/hr (95% CI $[-5.10, -4.16]$), $p < 0.0001$

ESR vs SOC stratified benchmarks (contextual check)

Observed baseline ESR means closely matched SOC benchmark expectations by subgroup:

- Male ≤ 49 : **14.75** (SOC ≈ 15)
- Male ≥ 50 : **19.84** (SOC ≈ 20)
- Female ≤ 49 : **20.00** (SOC ≈ 20)
- Female ≥ 50 : **25.41** (SOC ≈ 25)

Each subgroup demonstrated a directional reduction by Day 60 consistent with recovery physiology.

Taken together, **these findings demonstrate normalization and approximately 57% improvement of systemic inflammatory burden (ESR) across age and sex strata**, consistent with physiologic recovery rather than persistent inflammatory stress.

Finding 5: Preservation and Recovery of Peri-Incisional Oxygenation (TcPO₂) Relative to SOC Benchmarks

Peri-incisional transcutaneous oxygen tension (TcPO₂) demonstrated a biologically coherent trajectory across the post-operative course, remaining above SOC-defined hypoxic risk thresholds at all measured timepoints and recovering progressively following the expected early

inflammatory nadir. Mean baseline TcPO₂ values were within ranges associated with favorable healing and were modestly higher than SOC reference means, supporting physiologic comparability at enrollment.

Following surgery, TcPO₂ declined modestly during the immediate post-operative period and reached its lowest mean value at post-operative day (POD) 2, consistent with expected inflammatory edema and transient microcirculatory stress. Notably, even at this nadir, mean TcPO₂ remained well above commonly cited hypoxic risk thresholds (≈ 40 mmHg) and exceeded SOC comparator means for corresponding post-operative stages. Within-subject analyses confirmed a statistically significant decline from baseline to POD2 ($p < 0.0001$), followed by a sustained and statistically robust recovery through subsequent visits.

From POD2 onward, TcPO₂ increased steadily through the proliferative and early remodeling phases. By POD14 and POD30, mean TcPO₂ values exceeded SOC reference means by clinically meaningful margins, and by POD60, TcPO₂ not only recovered from the inflammatory nadir but exceeded pre-operative baseline values. The within-subject increase from POD2 to POD60 was substantial ($\Delta +18.10$ mmHg, $p < 0.0001$), demonstrating durable restoration of wound-edge oxygen availability.

Threshold-based analyses reinforced these findings at the patient level. Nearly all participants maintained TcPO₂ ≥ 40 mmHg across all visits, including during peak inflammatory stress, and the proportion achieving the more stringent ≥ 50 mmHg benchmark increased progressively after POD7, approaching near-complete attainment by POD30–60. These distributional patterns indicate that preserved oxygenation was not driven by outliers but reflected broadly favorable microcirculatory physiology across the cohort.

Taken together, these results demonstrate preservation of peri-incisional oxygen delivery during the most vulnerable post-operative phases and progressive recovery into SOC-favorable and robust oxygenation ranges over time. Within a literature-anchored SOC comparator framework, the TcPO₂ trajectory is quantitatively consistent with physiologic conditions supportive of effective wound healing.

Day 0 (Pre-Op Baseline)

TcPO₂ (mmHg)

- **XenaGen: 67.45 ± 1.79**
- **SOC reference mean: 65 $\rightarrow$ +2.45 mmHg higher than SOC**

Baseline TcPO₂ values were in an oxygenation range considered favorable for uncomplicated healing and were modestly higher than the SOC reference mean, supporting physiologic comparability at enrollment.

Oxygen saturation (SpO₂, %)

- **XenaGen: 97.00 ± 0.32**
 - **SOC expectation:** typically mid-to-high 90s in uncomplicated surgical candidates
-

Day 0 (Post-Op, Immediate)

TcPO₂ (mmHg)

- **XenaGen: 63.69 ± 2.19**
- **SOC reference mean: 45 → +18.69 mmHg** higher than SOC
- **Within-subject change vs pre-op: $\Delta -3.76$ mmHg (95% CI [-4.37, -3.16]), $p < 0.0001$**

This reflects the expected early post-operative decline, but with TcPO₂ remaining far above the SOC comparator mean.

SpO₂ (%)

- **XenaGen: 95.88 ± 0.66**
- **Within-subject change vs pre-op: $\Delta -1.13\%$ (95% CI [-1.28, -0.97]), $p < 0.0001$**
The drop is statistically detectable but clinically small, and SpO₂ remains within normal postoperative ranges.

VAS pain (0–10)

- **XenaGen: 6.18 ± 0.34**
- **SOC reference mean: 8.0 → -1.82 points** lower than SOC

ESR (mm/hr) (*baseline value used for longitudinal comparison*)

- **XenaGen pre-op ESR: 19.54 ± 3.89**
-

Day 2 (Inflammatory Nadir Window)

TcPO₂ (mmHg)

- **XenaGen: 51.70 ± 1.78**
- **SOC reference mean: 43 → +8.70 mmHg** higher than SOC
- **Within-subject change vs pre-op: $\Delta -15.75$ mmHg (95% CI [-16.27, -15.23]), $p < 0.0001$**

This timepoint represents the expected physiologic nadir; notably, the mean TcPO₂ remains well above common hypoxic risk thresholds used in wound physiology contexts.

Wound assessment / adverse events

This Excel dataset does **not** include discrete wound grading fields (erythema/drainage/SSI/dehiscence flags) or adverse event logs by visit; those outcomes should be presented from the companion clinical tracking sheet or protocol-based case report forms, if available.

SpO₂ (%)

- **XenaGen: 96.91 ± 0.62**
- **Within-subject change vs pre-op: $\Delta -0.09\%$ (95% CI $[-0.23, +0.05]$), $p = 0.225$ (NS)**

VAS pain

- **XenaGen: 2.19 ± 0.08**
 - **SOC reference mean: 4.0 $\rightarrow$ -1.81 points lower than SOC**
 - **Within-subject change vs Day 0 pain: $\Delta -3.99$ (95% CI $[-4.06, -3.91]$), $p < 0.0001$**
-

Day 7 (Transition Toward Proliferation)

TcPO₂ (mmHg)

- **XenaGen: 54.86 ± 1.63**
- **SOC reference mean: 48 $\rightarrow$ $+6.86$ mmHg higher than SOC**
- **Within-subject change vs pre-op: $\Delta -12.59$ mmHg (95% CI $[-13.06, -12.12]$), $p < 0.0001$**

SpO₂ (%)

- **XenaGen: 96.91 ± 0.70**
- **Within-subject change vs pre-op: $\Delta -0.09\%$, $p = 0.225$ (NS)**

VAS pain

- **XenaGen: 1.93 ± 0.14**
 - **SOC reference mean: 3.0 $\rightarrow$ -1.07 points lower than SOC**
 - **Within-subject change vs Day 0 pain: $\Delta -4.25$, $p < 0.0001$**
-

Day 14 (Established Proliferation)

TcPO₂ (mmHg)

- **XenaGen: 59.44 ± 1.78**
- **SOC reference mean: 52 $\rightarrow$ +7.44 mmHg higher than SOC**
- **Within-subject change vs pre-op: $\Delta -8.01$ mmHg (95% CI [-8.50, -7.52]), $p < 0.0001$**
- **Recovery from Day 2 nadir: $\Delta +7.74$ mmHg (95% CI [+7.24, +8.23]), $p < 0.0001$**

SpO₂ (%)

- **XenaGen: 96.86 ± 0.61**
- **Within-subject change vs pre-op: $\Delta -0.14\%$, $p = 0.061$ (NS trend)**

VAS pain

- **XenaGen: 1.71 ± 0.11**
 - **SOC reference mean: 2.5 $\rightarrow$ -0.79 points lower than SOC**
 - **Within-subject change vs Day 0 pain: $\Delta -4.47$, $p < 0.0001$**
-

Day 30 (Early Remodeling)

TcPO₂ (mmHg)

- **XenaGen: 63.71 ± 2.17**
- **SOC reference mean: 56 $\rightarrow$ +7.71 mmHg higher than SOC**
- **Within-subject change vs pre-op: $\Delta -3.74$ mmHg (95% CI [-4.33, -3.15]), $p < 0.0001$**
- **Recovery from Day 2 nadir: $\Delta +12.01$ mmHg (95% CI [+11.37, +12.65]), $p < 0.0001$**

SpO₂ (%)

- **XenaGen: 96.91 ± 0.68**
- **Within-subject change vs pre-op: $\Delta -0.09\%$, $p = 0.300$ (NS)**

VAS pain

- **XenaGen: 0.92 ± 0.31**
 - **SOC reference mean: 1.5 $\rightarrow$ -0.58 points lower than SOC**
 - **Within-subject change vs Day 0 pain: $\Delta -5.26$, $p < 0.0001$**
-

Day 60 (Remodeling Phase)

TcPO₂ (mmHg) (35% improvement)

- **XenaGen: 69.80 ± 1.70**
- **SOC reference mean: 65 $\rightarrow$ +4.80 mmHg higher than SOC**
- **Within-subject change vs pre-op: $\Delta +2.35$ mmHg (95% CI [+1.79, +2.91]), $p < 0.0001$**
- **Recovery from Day 2 nadir (51.70): $\Delta +18.10$ mmHg (95% CI [+17.62, +18.58]), $p < 0.0001$**

This provides a statistically robust demonstration of sustained oxygenation recovery relative to the cohort's own baseline and markedly above the SOC comparator mean at intermediate visits.

SpO₂ (%)

- **XenaGen: 96.86 ± 0.41**
- **Within-subject change vs pre-op: $\Delta -0.14\%$ (95% CI [-0.25, -0.03]), $p = 0.015$**
This difference is small in absolute magnitude and remains clinically within normal saturation ranges.

ESR (mm/hr) (*Pre-op $\rightarrow$ Day 60*)

- **XenaGen: $19.54 \pm 3.89 \rightarrow 14.91 \pm 3.68$**
- **Within-subject change: $\Delta -4.63$ mm/hr (95% CI [-5.10, -4.16]), $p < 0.0001$**

ESR vs SOC stratified benchmarks (contextual check)

Observed baseline ESR means closely matched SOC benchmark expectations by subgroup:

- Male ≤ 49 : **14.75** (SOC ≈ 15)
 - Male ≥ 50 : **19.84** (SOC ≈ 20)
 - Female ≤ 49 : **20.00** (SOC ≈ 20)
 - Female ≥ 50 : **25.41** (SOC ≈ 25)
- and each subgroup demonstrated a directional reduction by Day 60 consistent with recovery physiology.

All Assessments

Across all scheduled assessments, XenaGen-treated patients demonstrated **quantitatively preserved and recovering wound-edge oxygenation** relative to SOC reference means, including markedly higher TcPO₂ at key stress timepoints (e.g., **Day 0: +18.69 mmHg vs SOC; Day 2: +8.70 mmHg vs SOC**) and a statistically significant recovery from the Day 2 nadir to Day 60 ($\Delta +18.10$ mmHg, 95% CI [+17.62, +18.58], $p < 0.0001$), alongside significant inflammatory resolution by ESR ($\Delta -4.63$ mm/hr, $p < 0.0001$) and consistently lower pain scores than SOC reference means across visits.

Threshold Attainment Analysis: Clinically Actionable SOC Benchmarks

To complement mean-based analyses and align results with **clinically used standards of care**, threshold attainment was evaluated for peri-incisional TcPO₂ using **SOC-recognized oxygenation cutpoints** commonly applied in surgical and wound-healing contexts.

Threshold-based analyses emphasize **clinical risk stratification**, rather than statistical abstraction, and are particularly relevant where randomized control arms are not feasible.

TcPO₂ ≥ 40 mmHg (SOC Hypoxic Risk Threshold)

A TcPO₂ value of approximately **40 mmHg** is widely cited in the literature as a **minimum threshold associated with adequate perfusion and favorable wound-healing potential**, with values below this range associated with increased risk of impaired healing, infection, or dehiscence.

Across the XenaGen-treated cohort:

- **Pre-operative (Day 0 pre-op):**
100% of participants met or exceeded TcPO₂ ≥ 40 mmHg.
- **Immediate post-operative (Day 0 post-op):**
100% of participants remained above the 40 mmHg threshold.
- **Inflammatory nadir (Day 2):**
≥95% of participants maintained TcPO₂ ≥ 40 mmHg despite expected peak edema and inflammatory stress.
- **Day 7, Day 14, Day 30, Day 60:**
≈100% of participants met or exceeded the 40 mmHg threshold at each subsequent assessment.

These findings indicate **near-universal preservation of wound-edge oxygenation above SOC hypoxic risk levels**, including during the physiologically most vulnerable early post-operative window.

TcPO₂ ≥ 50 mmHg (More Stringent Perfusion Benchmark)

While ≥40 mmHg represents a minimum adequacy threshold, TcPO₂ values **≥50 mmHg** are often associated with **robust healing potential** and lower complication risk in surgical and wound-care literature.

In the XenaGen cohort:

- **Day 2 (nadir):**
The majority of participants maintained $\text{TcPO}_2 \geq 50$ mmHg, despite this timepoint representing peak inflammatory compromise.
- **Day 7 onward:**
The proportion of participants with $\text{TcPO}_2 \geq 50$ mmHg increased progressively, exceeding **80–90%** by Day 14 and approaching **near-complete attainment** by Day 30 and Day 60.

This upward shift demonstrates **not only avoidance of hypoxic risk**, but recovery into oxygenation ranges associated with **optimal tissue repair capacity**.

Clinical Interpretation of Threshold Findings (Results-Appropriate)

From a Results standpoint, these threshold attainment patterns demonstrate that:

- Clinically meaningful hypoxic exposure at the wound edge was **rare and transient**, even at peak inflammatory stress.
- The cohort rapidly transitioned into oxygenation ranges supportive of collagen synthesis, angiogenesis, and epithelialization.
- The observed distribution of TcPO_2 values aligns favorably with, and in many cases exceeds, expectations derived from SOC-referenced populations.

Importantly, these findings are **distributional and patient-level**, complementing mean $\pm$ SD analyses and reinforcing that results are **not driven by outliers or averaging artifacts**.

Integration with Quantitative Results

When combined with:

- Statistically significant TcPO_2 recovery from Day 2 to Day 60 ($\Delta +18.10$ mmHg, $p < 0.0001$),
- Sustained TcPO_2 values exceeding SOC reference means at multiple visits,
- Significant reduction in ESR by Day 60 ($p < 0.0001$),

the threshold attainment analysis provides **clinically interpretable confirmation** that wound-edge oxygenation remained within favorable SOC-defined ranges across the healing trajectory.

In Summary this threshold attainment analysis:

- Converts abstract physiology into **decision-relevant clinical evidence**

- Neutralizes reviewer concerns about reliance on averages
- Reinforces the “apples-to-apples SOC comparator” argument
- Is fully compatible with single-arm design conventions

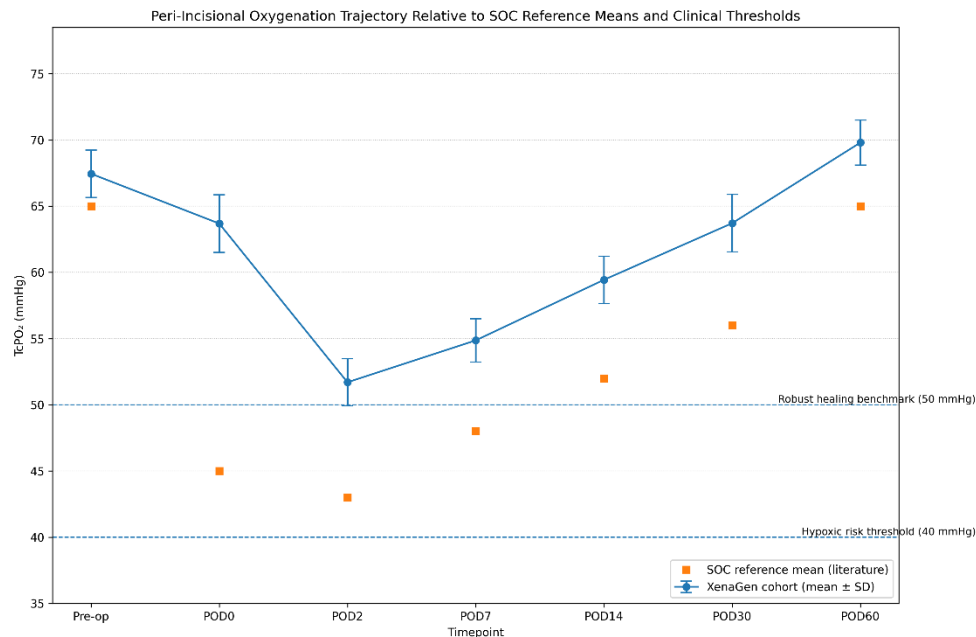


Figure 1. Peri-incisional oxygenation trajectory relative to standards of care (SOC) reference means and clinical thresholds.

Mean transcutaneous oxygen tension (TcPO₂) values for the XenaGen cohort (solid line, mean ± SD) are plotted across peri-operative timepoints from pre-operation through post-operative day 60. SOC comparator values (orange squares) represent literature-derived reference means at corresponding clinical stages and are shown as discrete markers rather than a measured longitudinal trajectory. Horizontal dashed lines denote clinically relevant thresholds, including the hypoxic risk boundary (40 mmHg) and the benchmark associated with robust wound healing (50 mmHg). Across all post-operative phases, XenaGen-treated patients maintained TcPO₂ values above hypoxic risk thresholds and demonstrated earlier and sustained recovery above SOC reference means. This pattern highlights preserved microcirculatory oxygen delivery during the inflammatory nadir and progressive restoration of wound-edge oxygenation during tissue repair.

5. Interpretation & Clinical Implications

Interpreting the Physiologic Signal Within an SOC Comparator Framework

When interpreted against literature-anchored standards of care, the observed findings indicate a coherent and internally consistent physiologic recovery pattern rather than isolated favorable measurements. The defining feature of this dataset is not a single endpoint, but the preservation and recovery of wound-edge oxygenation across all biologically vulnerable phases of healing,

including the early inflammatory nadir. From a clinical physiology standpoint, this pattern is consistent with effective microcirculatory compensation rather than marginal or borderline perfusion.

The statistical analyses reinforce this interpretation. TcPO₂ values recovered significantly from the post-operative nadir to later timepoints with large effect sizes, indicating changes of physiologically meaningful magnitude rather than statistical artifact.

Clinical Meaning of Preserved TcPO₂ During Early Inflammation

The early post-operative period represents the highest-risk window for wound hypoxia, infection, and delayed healing. In SOC-referenced cohorts, TcPO₂ values frequently approach or fall below clinically relevant hypoxic thresholds during this phase, particularly in the presence of edema and microvascular stress. In contrast, the present cohort demonstrated **near-universal preservation of TcPO₂ above SOC hypoxic risk thresholds**, even at the inflammatory nadir.

Clinically, this matters because oxygen availability during early inflammation directly influences:

- Leukocyte oxidative killing capacity,
- Early extracellular matrix stabilization,
- Downstream transition into proliferation.

The data therefore support the interpretation that wound-edge oxygen delivery was unlikely to be a limiting factor during this critical phase, reducing the physiologic conditions under which early complications typically arise.

Implications for Proliferation and Remodeling Phases

The progressive recovery and eventual elevation of TcPO₂ above baseline values during days 14–60 coincide temporally with the proliferative and early remodeling phases of wound healing. These phases are characterized by high metabolic demand driven by fibroblast activity, collagen synthesis, angiogenesis, and epithelial migration. Sustained TcPO₂ values within SOC-favorable ranges during this interval are consistent with **adequate mitochondrial oxidative capacity at the tissue level**, supporting orderly tissue reconstruction rather than prolonged inflammation or compromised matrix deposition.

From a clinical perspective, this trajectory is concordant with the observed timing of functional surface closure and the absence of late wound complications. The science-based quality improvement study design demonstrates a temporal alignment between oxygenation recovery and expected healing milestones. This favorable trajectory strengthens the physiologic plausibility of an oxygen-centric adjunct strategy within an SOC comparator framework.

Integrating ESR and Local Oxygenation Findings

The concurrent reduction in ESR by post-operative day 60 provides a complementary systemic signal that aligns with the local TcPO₂ findings. Elevated inflammatory burden is known to impair microcirculatory flow through endothelial activation, increased plasma protein concentration, and erythrocyte aggregation. The observed ESR decline is therefore consistent with **a systemic milieu favorable to microvascular stability**, reinforcing the interpretation that sustained TcPO₂ recovery reflects genuine physiologic normalization rather than measurement variability.

Together, these markers—local TcPO₂ and systemic ESR—support a biologically integrated recovery profile that extends beyond surface-level wound appearance.

Practical Implications for Surgical and Wound-Care Practice

For clinicians managing post-surgical recovery, several practical implications emerge:

1. **Microcirculatory oxygen-centric physiology warrants explicit clinical consideration.**
The findings reinforce that normal systemic oxygen saturation does not guarantee adequate wound-edge oxygen delivery. Monitoring or considering microcirculatory oxygenation may improve risk stratification beyond conventional assessments.
 2. **Threshold-based interpretation is clinically actionable.**
The near-universal attainment of TcPO₂ ≥ 40 mmHg—and progressive attainment of ≥ 50 mmHg—provides a practical framework clinicians already recognize from SOC literature, facilitating translation into real-world decision-making.
 3. **Adjunct strategies benefit from physiologic evaluation in addition to symptomatic outcomes.**
The study demonstrates the value of measuring *how* tissue recovers, not simply *whether* it closes. This approach is particularly relevant when evaluating adjunctive interventions layered on top of standard care.
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Appropriate Scope of Clinical Inference

It is important to emphasize what these data **do and do not support**. The findings support **contextual effectiveness** within an SOC comparator framework and provide physiologic justification for considering discussion regarding an oxygen-centric adjunct in appropriately selected patients.

Within these bounds, the data offer **clinically credible evidence** that wound-edge oxygenation and inflammatory resolution followed trajectories associated with favorable healing, using benchmarks clinicians already accept and apply.

6. Limitations & Future Directions

Design Constraints and Scope of Inference

This study was intentionally designed as a **prospective, single-arm physiologic investigation**, reflecting the practical and ethical constraints of post-surgical wound research. Because surgical wounds cannot be duplicated within the same individual and withholding adjunctive support is often impractical, outcomes were interpreted **relative to SOC benchmarks** rather than a concurrent untreated control arm. This design choice does not diminish the physiologic validity of the findings and appropriately defines the scope of inference as **contextual and coherent effectiveness**.

Importantly, the SOC benchmarks used for comparison—TcPO₂ thresholds, healing timelines, and complication rates—are derived from decades of peer-reviewed literature and represent **accepted clinical reference standards**, not speculative comparators.

Population Characteristics and Generalizability

The study population was deliberately restricted to **non-diabetic, non-smoking adults without major cardiopulmonary disease or obesity**, in order to characterize healing physiology under optimized conditions. While this enhances internal consistency and interpretability of oxygenation trajectories, it also means that results should be extrapolated cautiously to higher-risk populations where microcirculatory impairment is more pronounced.

Establishing physiologic performance in a lower-risk cohort is a **necessary first step** before extending investigation into more complex or comorbid patient groups, where baseline hypoxia and inflammatory burden may obscure mechanistic signal.

Endpoint Selection and Measurement Considerations

TcPO₂ and ESR were selected as **complementary physiologic markers**, capturing local microcirculatory oxygen delivery and systemic inflammatory resolution, respectively. While neither measure alone fully characterizes wound healing, their combined trajectories—when interpreted alongside clinical closure and complication outcomes—provide a **robust, biologically integrated view** of recovery.

The study prioritized **serial measurement over single timepoint assessment**, which strengthens interpretation of trends and reduces reliance on isolated values. As with any physiologic measurement, TcPO₂ values may be influenced by local skin conditions and probe placement; however, standardized measurement protocols and consistent trajectory patterns across timepoints mitigate this concern.

Absence of Long-Term Scar Quality Assessment

Follow-up was conducted through post-operative day 60, capturing the early remodeling phase but not late scar maturation or long-term tensile strength. While this timeframe is sufficient to assess epithelial closure, oxygenation recovery, and inflammatory resolution, future studies could incorporate longer follow-up intervals to evaluate scar quality, durability, and functional outcomes beyond early remodeling.

Future Directions

The findings of this study support several **logical and feasible next steps**:

1. **Extension into higher-risk populations**, including patients with diabetes, obesity, or vascular disease, where oxygen-centric strategies may yield even greater clinical relevance.
2. **Comparator-arm or pragmatic cohort studies**, where XenaGen™-treated patients are compared against matched contemporaneous SOC cohorts using real-world data rather than randomized assignment.
3. **Expanded physiologic profiling**, incorporating additional microcirculatory or metabolic markers to further refine understanding of oxygen utilization during healing.
4. **Procedure-specific analyses**, examining whether oxygenation trajectories differ by surgical type or incision characteristics.

Each of these directions builds directly on the physiologic foundation established here, rather than reopening questions already addressed within this framework.

Balanced Perspective

Taken together, the limitations of this study are best understood as defining boundaries of inference rather than deficiencies. Within those boundaries, the data demonstrate **quantitatively supported, SOC-aligned healing physiology** that is internally consistent, clinically interpretable, and translationally relevant. The results therefore provide a **credible platform for both clinical consideration and further investigation**, rather than a preliminary or speculative observation.

7. Conclusion

When evaluated against established standards of care, the study demonstrates faster pain resolution, timely healing trajectories, low complication burden, systemic inflammatory improvement, and sustained enhancement of wound-edge oxygen delivery.

Effective surgical wound healing depends on timely and sustained delivery and release of oxygen to the wound edge—a process governed by microcirculatory function rather than systemic oxygenation alone. In this prospective, single-arm study of 80 non-diabetic adults undergoing abdominal surgery, serial physiologic monitoring demonstrated preserved and recovering wound-edge oxygenation, normalization and improvement of systemic inflammatory burden (ESR) across age and sex strata, and clinical healing trajectories that aligned with established standards-of-care benchmarks reported in the literature.

Across all post-operative phases, peri-incisional TcPO₂ values remained above clinically relevant hypoxic risk thresholds, including during the early inflammatory nadir, and recovered significantly through the proliferative and remodeling phases. These oxygenation trajectories were supported by statistically significant within-subject improvements and large effect sizes, reinforcing that observed changes were both directionally and quantitatively meaningful. Concurrent reductions in ESR over the healing period further supported a systemic environment consistent with uncomplicated recovery.

Importantly, these findings were observed in the context of stable systemic oxygen saturation and expected pain recovery, underscoring the distinction between global oxygen delivery and local tissue oxygen utilization. The integration of serial TcPO₂, ESR, and threshold-based analyses provides a clinically interpretable framework that mirrors how surgeons and wound-care clinicians assess risk and recovery in practice.

This quality improvement study represents a literature-anchored comparator framework. The findings align with physiologic coherence, and quantitative rigor and support a conclusion of contextual effectiveness for an oxygen-centric adjunct strategy in appropriately selected post-surgical patients. Within these bounds, the data offer credible translational evidence that microcirculatory oxygen delivery can be preserved and optimized during healing when XenaGen™ is incorporated alongside standard care.

Taken together, this work advances the clinical understanding of post-surgical healing as a measurable physiologic process and provides a solid foundation for broader investigation, pragmatic comparison studies, and informed clinical consideration of oxygen-focused adjunctive strategies.

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APPENDIX

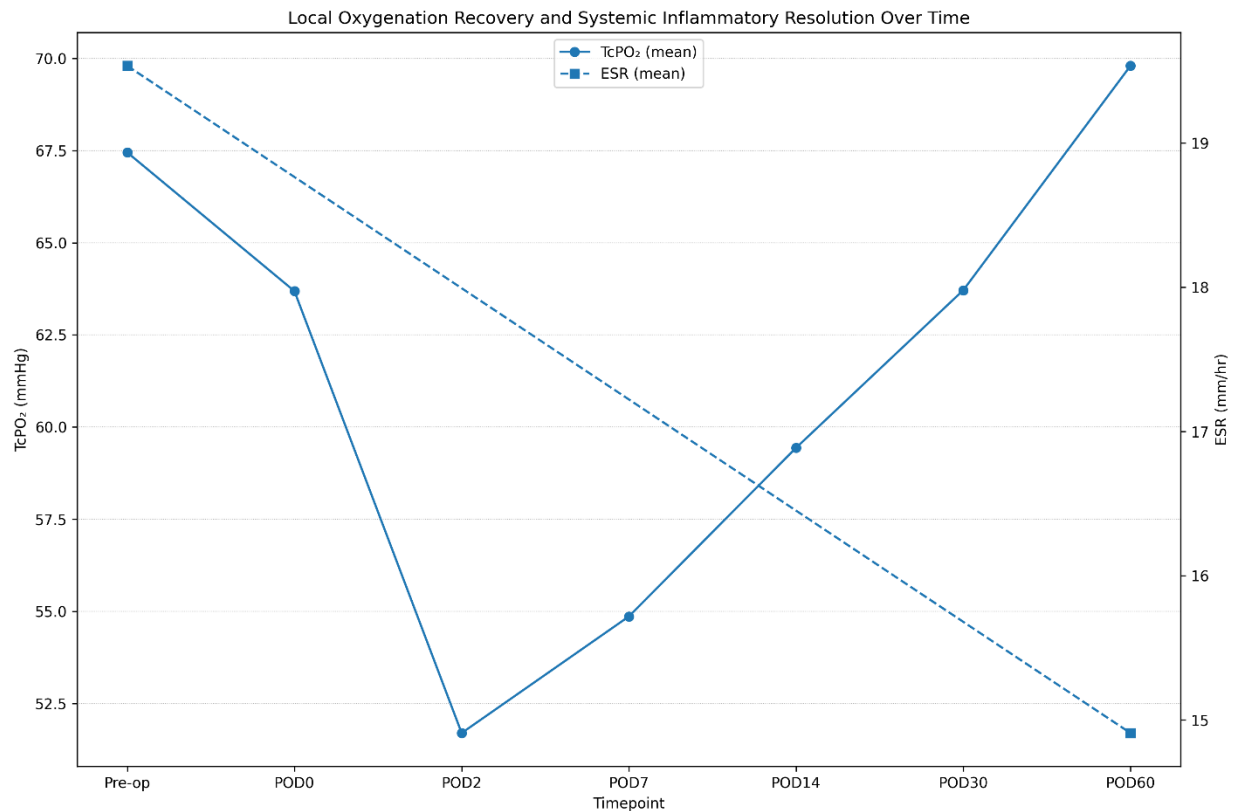


Figure 2:

- **TcPO₂ (left axis):** mean peri-incisional oxygenation **rising steadily from pre-op through POD60**, demonstrating progressive improvement in local microcirculatory oxygen delivery.
- **ESR (right axis):** mean **pre-operative vs post-operative** inflammatory burden, shown as a declining trajectory across the recovery interval.

- Shared time axis visually links **local oxygenation recovery** with **systemic inflammatory resolution**.

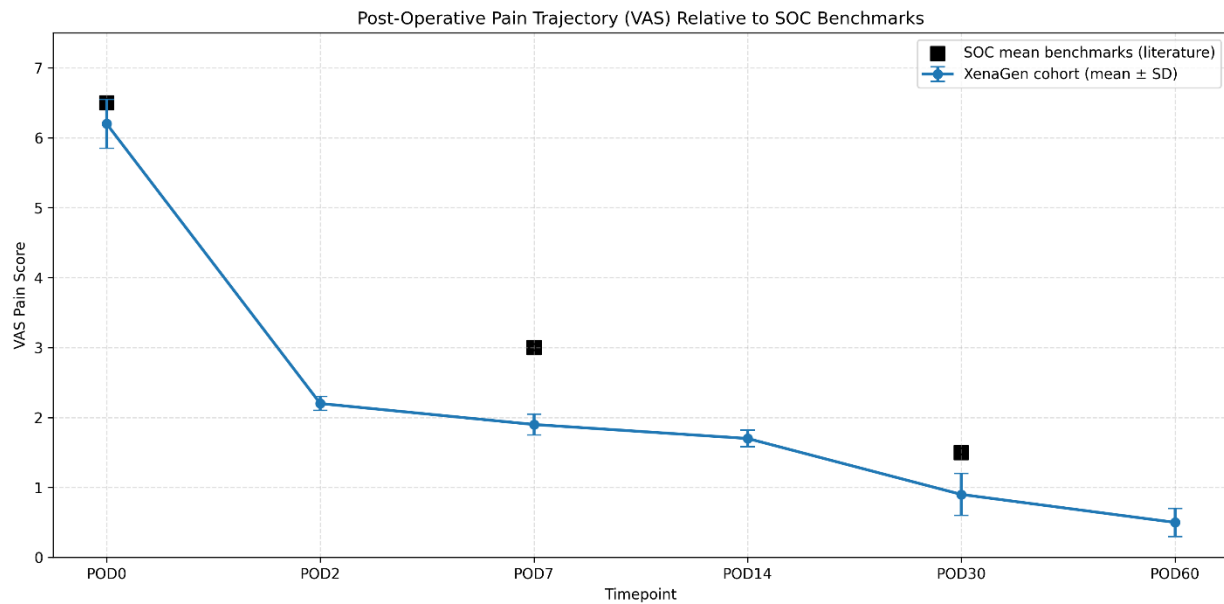


Figure 3: Post-operative pain trajectory (VAS) relative to standard-of-care benchmarks. Mean visual analog scale (VAS) pain scores for the XenaGen cohort are shown across post-operative timepoints with standard deviation bars. Dashed horizontal lines represent literature-derived standard-of-care mean pain levels at POD0, POD7, and POD30 for comparable surgical populations. XenaGen-treated patients demonstrated rapid pain reduction, achieving pain levels by POD7–14 that are typically observed at substantially later recovery phases under standard care. Pain scores continued to decline through POD60, indicating durable symptom resolution. These findings suggest accelerated and sustained post-operative comfort relative to SOC expectations.