

Hyperbaric oxygen therapy (HBOT) as an adjuvant to surgical treatment of musculoskeletal injuries: a scoping review

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Background: Hyperbaric oxygen therapy (HBOT) increases tissue oxygen tension and may modulate inflammation, angiogenesis, and collagen remodeling - mechanisms relevant to postoperative healing. Its use in musculoskeletal and sports settings has expanded, but perioperative evidence remains unclear.

Hypothesis/Purpose: To map and characterize the clinical and preclinical evidence on HBOT as an adjunct after musculoskeletal surgery (indications, protocols, comparators, outcomes, and gaps). We hypothesized that adjuvant HBOT would improve healing and, when assessed clinically, outcomes and failure rates.

Methods: PubMed/MEDLINE, Embase, and the Cochrane Library were searched from inception to the final search date (protocol registered on OSF; r2np7). We included primary clinical studies and animal surgical/repair models evaluating HBOT (supra-atmospheric oxygen) in musculoskeletal/orthopaedic operative contexts. Data were charted for study design, indication/model, HBOT regimen, comparators, and outcome domains. Risk-of-bias appraisal and meta-analysis were not performed.

Results: Fifteen primary studies were included: 7 clinical studies and 8 preclinical/animal experiments. Clinical studies largely addressed acute wound/trauma or perioperative recovery contexts (eg, grafts/flaps, crush injury, necrotizing fasciitis, complex open elbow injuries, and total knee arthroplasty) with substantial variability in HBOT dosing and outcomes. Preclinical studies most consistently evaluated tendon–bone interface healing (ACL reconstruction and rotator cuff repair) and generally reported improved interface maturation and/or biomechanical properties with HBOT versus controls. Protocols were highly heterogeneous (approximately 1.4–2.5 ATA; 60–120 minutes; 2 sessions to multiweek regimens), limiting cross-study comparability and clinical inference.

Conclusion: Evidence for perioperative HBOT in musculoskeletal surgery is limited and heterogeneous. Preclinical studies show the most consistent signal for improved tendon–bone healing, while clinical orthopaedic data are insufficient to support routine postoperative use. Indication-specific, adequately powered randomized trials with standardized HBOT regimens and clinically meaningful endpoints are needed.

Clinical Relevance: HBOT may be a promising adjunct for biologically challenging sports procedures requiring tendon–bone integration (eg, ACL reconstruction, rotator cuff repair), but clinical effectiveness remains unproven.

Study Design: Scoping review

Level of evidence: Level V

Keywords: Hyperbaric oxygen therapy; Tendon–bone interface; Anterior cruciate ligament reconstruction; Rotator cuff repair; Scoping review.

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INTRODUCTION

Hyperbaric oxygen therapy (HBOT) involves the administration of 100% oxygen at supra-atmospheric pressure, resulting in a marked increase in dissolved oxygen within plasma and tissues [1]. This physiological effect initiates a cascade of downstream responses - including attenuation of inflammatory signaling, modulation of cytokine activity, enhancement of angiogenesis, and promotion of fibroblast and collagen activity - that are directly relevant to surgical wound healing and tissue repair [2][3]. In several well-defined clinical contexts, HBOT is an established adjunctive therapy, particularly for compromised grafts and flaps threatened by hypoxia, ischemia, or prior irradiation, where it has been shown to improve tissue viability, reduce complications, and lower rates of failure and re-operation [4][5][6].

In contrast, the role of HBOT in musculoskeletal surgery remains far less clearly defined, despite a strong biological rationale. Poor soft-tissue biology at the Tendon–bone interface (TBI) continues to be a major determinant of suboptimal outcomes following tendon and ligament reconstruction, contributing to delayed healing, incomplete integration, and structural failure. This challenge is particularly evident in procedures such as anterior cruciate ligament reconstruction and rotator cuff repair, where the native enthesis must be biologically reconstituted rather than simply mechanically stabilized. Regeneration of the Tendon–bone interface (TBI) after a repair of a rotator cuff tear does not occur. Instead, even after successful healing there is scar formation instead of the regeneration of 4-histologic zone transition in TBI [7]. Preclinical studies suggest that HBOT may favorably influence insertional healing by enhancing vascular ingrowth, fibrocartilage formation, and collagen organization at the TBI [5][8][9]. Comparable findings in rotator cuff models further support a mechanistically plausible link between HBOT and improved tendon-to-bone integration [10][11][12].

Evidence from outside orthopedic surgery reinforces this biological plausibility. Controlled animal studies have demonstrated that HBOT can improve the survival and integration of larger composite grafts, consistent with its pro-angiogenic and tissue-preserving effects [13]. However, translation of these mechanisms into consistent benefit after musculoskeletal surgery has been variable. Notably, in a lumbar fusion model, perioperative HBOT did not improve fusion rates or enhance the survival of implanted mesenchymal stem cells in vivo, suggesting that its efficacy may be context-dependent and limited when biological repair processes are already maximally stimulated [14][15].

Despite this uncertainty, the use of HBOT in musculoskeletal and sports-related contexts - particularly within elite and professional sport - has expanded substantially over the past decade. HBOT is increasingly employed for postoperative recovery and musculoskeletal injury management, often in the absence of standardized protocols or robust surgical trials demonstrating clear clinical benefit. A recent narrative review in sports medicine concluded that while the physiological rationale for HBOT is compelling, evidence of clinical efficacy remains inconclusive, underscoring the need for higher-quality, indication-specific studies [14][15]. This disconnect between strong mechanistic plausibility, selective preclinical support, and inconsistent clinical evidence makes it inappropriate to extrapolate benefit from other HBOT indications or non-surgical contexts to postoperative tendon and ligament healing without systematic evaluation [16].

Considering renewed scientific interest - reflected by a growing body of adjunctive HBOT publications - and its continued clinical use in high-performance and perioperative settings, a comprehensive mapping of the existing evidence is warranted. We therefore undertook a scoping review to systematically characterize the use of HBOT as an adjunct following musculoskeletal surgery. A scoping methodology was selected to accommodate the heterogeneity of surgical indications, HBOT dosing and timing protocols, outcome measures, and study designs, as well as the relative paucity of randomized, standardized trials precluding formal meta-analysis. The hypothesis of the present study was that adjuvant HBOT after musculoskeletal surgeries would improve the histological healing and biomechanical properties, thereby improving clinical outcomes and reducing failure rates attributable to impaired healing.

METHODS

We conducted a scoping review to map and characterise the available evidence on hyperbaric oxygen therapy (HBOT) used in musculoskeletal and orthopaedic surgical contexts, including both clinical studies and animal surgical/repair models. The protocol was developed a priori and registered on the Open Science Framework (OSF; r2np7), and the review is reported in accordance with PRISMA-ScR [17]. The review aimed to describe: (i) populations and surgical indications; (ii) perioperative timing and HBOT dose/pressure protocols; (iii) comparators; (iv) outcomes related to healing, complications, reoperation, and function; and (v) key knowledge gaps to inform priorities for future trials.

Eligibility criteria were defined a priori. We included primary research evaluating HBOT as an adjunct in musculoskeletal/orthopaedic surgery, as well as preclinical animal models designed to emulate operative repair or healing (e.g., tendon–bone integration, fracture healing,

cartilage/osteochondral repair, and infection-related surgical models when clearly linked to operative care). HBOT was defined as oxygen delivered under supra-atmospheric pressure in a hyperbaric chamber, with no restrictions on pressure (ATA), session duration, frequency, number of sessions, or timing relative to surgery. We included studies with any comparator (usual care/no HBOT, sham, normobaric oxygen, or alternative adjuncts) and charted any postoperative or healing-related outcomes reported, including clinical outcomes, complications, infection outcomes, biomarkers/inflammation, imaging/healing markers, and - where applicable - histologic or biomechanical outcomes in animal studies. We excluded non-original publications and studies in which HBOT was not used in a clearly musculoskeletal/orthopaedic surgical or surgical-repair context.

We searched PubMed/MEDLINE and Embase from inception to September 2025 (OSF protocol r2np7) (**Appendix**), and hand-searched the Cochrane review by Eskes et al. [3] for additional randomized trials. Two reviewers screened records and charted data in duplicate; a third reviewer settled disagreements. We included primary clinical studies and animal surgical/repair models of HBOT (supra-atmospheric oxygen) in musculoskeletal or orthopaedic operative settings. We did not perform risk-of-bias appraisal or meta-analysis - neither is required for scoping reviews.

We deduplicated records in a reference manager and uploaded them to Rayyan (Rayyan Systems Inc., Cambridge,

MA, USA). Two reviewers screened records in duplicate at the title/abstract stage and again at full text; a third senior reviewer adjudicated disagreements. We carried uncertain records forward to full-text review. **Figure 1** (the PRISMA-ScR flow diagram) lists the reasons for full-text exclusion.

Two reviewers charted data in duplicate using a standardized form, which we developed and piloted a priori. We reconciled discrepancies by consensus.

Charting captured study characteristics, population/model and surgical context, HBOT protocol parameters (timing, ATA, session duration, frequency, number of sessions), comparators, and outcome domains with assessment time points. AI-assisted tools (e.g., NotebookLM) were used only to support reading and organisation; all extracted fields were verified against the original articles. When key details were missing, values were recorded as “not reported,” and corresponding authors were contacted selectively when essential protocol information could plausibly be clarified.

Consistent with scoping review methodology [18], we did not perform formal risk-of-bias appraisal and did not plan quantitative pooling. Instead, we synthesised findings descriptively, tabulating studies by evidence type (clinical vs animal), procedure/indication, design, and HBOT regimen characteristics, and mapping outcome domains to identify evidence clusters and gaps.

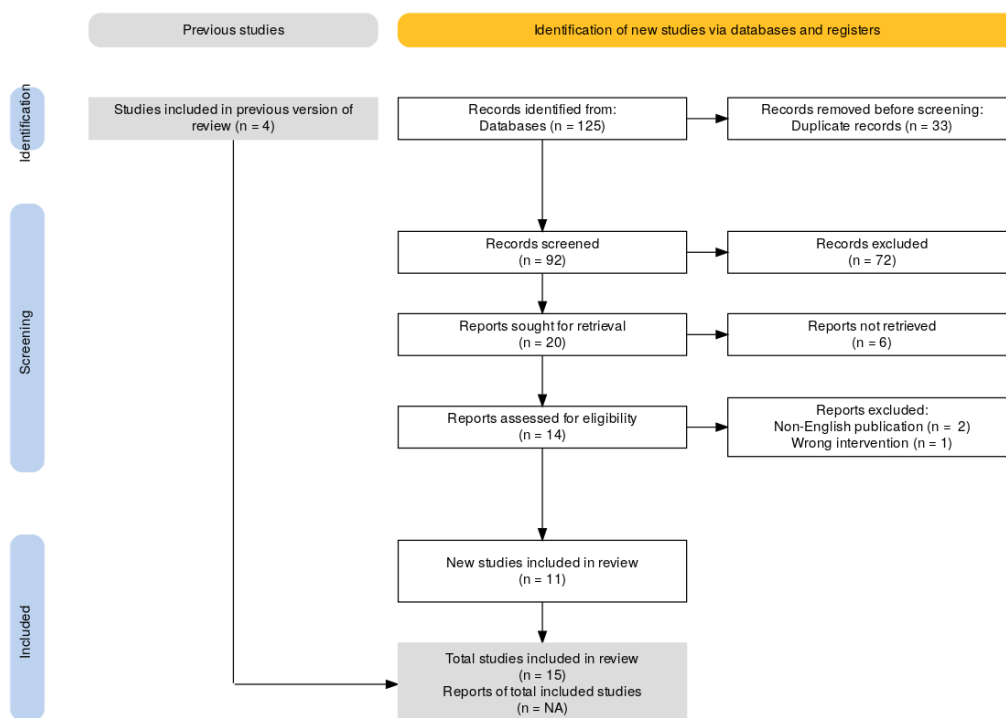


Figure 1. PRISMA Flow Diagram

RESULTS

Study Selection

The initial search, conducted in PubMed, Embase, and the Cochrane Library, identified 125 records. After removal of 33 duplicate records, 92 records were screened by title and abstract. Of these, 72 records were excluded, and 20 reports were sought for retrieval. Six reports could not be retrieved, leaving 14 full-text articles assessed for eligibility. Three full-text articles were excluded (two due to non-English language and one due to wrong intervention), resulting in 11 studies included in the review [19][3][15][20][21][22][23][8][11][9][24]. The study selection process is summarized in the PRISMA [17] flow diagram (**Figure 1**). Additionally, four randomized controlled trials [25][26][27][28] with extractable outcome data, identified within the systematic review by Eskes et al. (2013) [3], were included individually in the synthesis. This resulted in a total of 15 primary studies.

Study Characteristics

We included 15 primary studies: 7 clinical studies in humans and 8 preclinical animal studies (**Table 1**). Of the clinical studies, five were randomized controlled trials [25][26][27][28][24], one a retrospective cohort, and one a prospective case series [22]. The animal studies used rabbit (n = 6) [14][15][20][8][11][9] and rat (n = 2) [19][23] models. The Cochrane review by Eskes et al. [3] helped us identify additional trials but does not count among the 15 primary studies.

Clinical studies predominantly evaluated hyperbaric oxygen therapy in acute surgical or traumatic settings. Indications included skin graft or flap survival (four randomized trials), acute crush injuries (one randomized trial), postoperative muscle damage and inflammation following total knee arthroplasty (one randomized trial), complex open elbow injuries (one prospective case series), and necrotizing fasciitis (one retrospective cohort study). Sample sizes ranged from 10 to 135 participants, with follow-up durations varying from 7 days to complete wound healing, and extending to 12 months in studies reporting functional outcomes after severe musculoskeletal trauma.

The animal studies addressed several musculoskeletal targets. Three rabbit studies evaluated the tendon–bone interface (two ACL reconstructions [8][9], one rotator cuff repair [11]). Two further rabbit studies examined spinal fusion

[14][15] (one with mesenchymal stem cell augmentation), and one examined bone healing in a critical-sized diaphyseal defect [20]. Two rat studies addressed soft tissue: one muscle adaptation during distraction osteogenesis [23], the other cartilage repair after microfracture [19]. Follow-up ranged from 5 days to 18 weeks, capturing early biological responses and intermediate phases of tissue repair.

Across the included studies, hyperbaric oxygen therapy (HBOT) protocols demonstrated substantial heterogeneity in terms of pressure level, timing of initiation, session duration, and total treatment exposure, reflecting differences in tissue targets, biological objectives, and translational stage. In experimental animal models and early translational studies focused on bone healing, tendon–bone integration, and spinal fusion, higher pressures - most commonly 2.5 ATA - were frequently employed, typically in repeated daily sessions over several weeks [5][16][9]. These protocols aimed to enhance angiogenesis, osteogenesis, collagen organization, and interface maturation during prolonged healing phases.

In contrast, human clinical studies, particularly those conducted in postoperative settings, generally adopted more conservative and time-limited protocols. For example, in patients undergoing total knee arthroplasty, HBOT was applied at lower pressures (approximately 1.6 ATA) [24] and delivered in a small number of sessions within the first 48 hours after surgery, targeting acute ischemia–reperfusion injury, muscle damage, and early inflammatory responses rather than long-term structural remodeling. Similarly, clinical trials involving skin grafts, flaps, and acute soft-tissue trauma typically initiated HBOT early after injury or surgery, with treatment continued until wound stabilization or healing milestones were reached.

Session duration and treatment frequency also varied considerably across studies. Individual sessions lasted 60 to 120 minutes, with shorter durations reported in small-animal cartilage and muscle models and longer sessions used in studies of severe trauma, complex open injuries, or reconstructive surgery. Treatment frequency ranged from once-daily sessions in most musculoskeletal regeneration models to twice-daily applications in acute, high-risk conditions such as crush injuries and necrotizing soft-tissue infections. Several experimental studies explicitly reported protocol modifications - such as air breaks or controlled compression and decompression phases - to reduce the risk of oxygen toxicity, particularly in high-dose animal protocols.

Table 1. Identification and Methodological Characteristics

Author (Year)	Study Design	Population / Species	Study Objective	Sample Size (N)	Anatomical Site / Tissue	Control Group	Follow-up
Eskes et al. (2013)	Cochrane Systematic Review	Humans	Determine the effects of HBOT on the healing of acute surgical and traumatic wounds	4 RCTs (229 participants total)	Skin / Traumatic or surgical wounds	Varies (Dressings, steroids, or sham HBO)	Varies (6 days to complete healing)
Perrins (1967)	RCT (Sub-study in Cochrane)	Humans	Influence of HBOT on survival of split skin grafts	48 participants	Split skin graft site (donor and operation sites)	Usual care with closed dressings	7 days
Bouachour (1996)	RCT (Sub-study in Cochrane)	Humans	HBOT for management of acute crush injuries	36 participants	Limbs (Type 2 or 3 acute crush injury)	Sham HBOT (21% O ₂ at 1.1 ATA)	To complete wound healing
Xie (2007)	RCT (Sub-study in Cochrane)	Humans	Improve arterial inflow following flap grafting	135 participants	Limbs (Skin defects)	Dexamethasone or local injection of heparin	7 days
Vishwanath (2011)	RCT (Sub-study in Cochrane)	Humans	HBOT in free flap surgery	10 participants	Major defect requiring a free flap	Usual care	14 days
Zhang et al. (2025)	Randomized Controlled Trial	Humans (Primary knee osteoarthritis)	Investigate HBOT effects on muscle damage and inflammation after TKA	80 patients	Knee (Quadriceps muscle)	Normobaric oxygen therapy (nasal cannula)	14 days (lab work); HSS up to 12 weeks
Fu et al. (2010)	Experimental Study	New Zealand Rabbits	Clarify HBOT effects on MSCs regarding bone formation and maturation	27 rabbits (23 analyzed)	Lumbar spine (L4-L5 level)	Alginate only; Alginate-MSCs without HBO	12 weeks
Yeh et al. (2007)	Experimental Study	New Zealand Rabbits	Effect of HBOT on neovascularization and tendon-bone integration in ACL reconstruction	40 rabbits	Knee (ACL reconstruction tunnel)	Cages exposed to normal air	6, 12, and 18 weeks
Huang et al. (2007)	Prospective Consecutive Series	Humans	HBOT to facilitate immediate internal fixation for complex open elbow injuries	16 patients	Elbow (Bone and soft tissue)	None (Series design compared to standard literature)	Minimum 12 months
Li et al. (2025)	Experimental Study	New Zealand White Rabbits	Impact of HBOT on tendon-bone interface healing in rotator cuff tears	32 rabbits	Shoulder (Supraspinatus and infraspinatus tendons)	Model group subjected to normal air	4, 8, and 12 weeks

Grassmann et al. (2015)	Experimental Study	New Zealand White Rabbits	Evaluate HBOT effects on bone defects treated with autologous bone grafting	24 rabbits	Radius (15mm critical-sized diaphyseal bone defect)	Autograft bone transplantation only (No HBO)	3 and 6 weeks
Kaynar et al. (2014)	Experimental Study	Wistar Albino Rats	Effect of HBOT on muscle adaptation during tibial distraction osteogenesis	46 rats	Tibia (Gastrocnemius muscle)	Sham-operated (Group 5) and normoxia distracted groups	5 and 9 days
Hassan et al. (2010)	Retrospective Chart Review	Humans	Compare outcomes of adjuvant HBO2 therapy vs. non-HBO2 for necrotizing fasciitis	67 patients	Deep soft tissue / Fascia (Extremities or Trunks)	Surgery and standards of care without HBO2	Length of hospital stay (Avg. 28-29 days)
Başçı et al. (2018)	Experimental Study	Wistar Albino Rats	HBOT combined with microfracture technique for cartilage lesions	44 rats	Knee (Femoral sulcus patellar groove)	Standard microfracture treatment without HBO2	2 and 4 weeks
Leite et al (2024)	Experimental Study	New Zealand White Rabbits	Effect of HBOT on tendon-bone integration and strength in ACL reconstruction	12 rabbits	Knee (Anterior cruciate ligament)	Usual care	12 weeks

Effects of Interventions

Arthroplasty (Total knee arthroplasty)

The arthroplasty evidence comes from a single randomized controlled trial (Zhang et al., 2025) [24] evaluating HBOT as an early postoperative adjunct after total knee arthroplasty. The study compared HBOT to a normobaric oxygen control and focused on short-term physiological outcomes (biomarkers of muscle injury and systemic inflammation) alongside early clinical recovery measures (pain, swelling, strength, and range of motion). This design is well suited to test whether HBOT can attenuate the immediate postoperative effects of tourniquet-related ischemia–reperfusion and surgical tissue trauma.

In that trial, the HBOT group showed statistically significant reductions in several muscle injury biomarkers (e.g., creatine kinase, myoglobin, lactate dehydrogenase) and inflammatory markers (e.g., C-reactive protein, interleukin-6) during early follow-up, with parallel short-term improvements in quadriceps strength recovery, swelling, and pain scores. The

authors concluded that HBOT may be a safe and effective early adjunct to reduce muscle injury and inflammation after TKA, while acknowledging that longer-term functional differences were not clearly demonstrated within the available follow-up window.

Bone Repair and Osteogenesis

Bone-related indications were addressed primarily through preclinical rabbit models and include (i) critical-sized diaphyseal bone defects treated with autograft [20], and (ii) posterolateral lumbar fusion augmented with mesenchymal stem cells [15]. These studies target distinct biological problems—segmental defect regeneration versus fusion maturation—and therefore used different endpoints (radiographic/ μ CT metrics, histology, and vascular measures). A third study, while often grouped in “bone repair,” is more precisely a muscle adaptation study within a distraction osteogenesis model (gastrocnemius changes during tibial lengthening) [21], so its outcomes are primarily muscular/biochemical.

Table 2. HBOT Protocols Grouped by Indication

Indication	Author (Year)	Pressure (ATA/Other)	Oxygen (%)	Duration (per session)	Frequency and Total Sessions
Arthroplasty	Zhang et al. (2025)	1.6 ATA	100%	1 hour total*	Applied once at 24h and again at 48h postoperatively (2 sessions total).
Bone Repair & Osteogenesis	Fu et al. (2010)	2.5 atm	100%	2 hours	Daily, 5x/week; 60 rounds total over 12 weeks.
	Grassmann et al. (2015)	2.4 ATA	100%	90 minutes	Daily (Mon–Fri); 15 total units (3-week group) or 30 units (6-week group).
	Kaynar et al. (2014)	2.5 ATA	100%	80 minutes**	Once daily; 4 sessions (5-day group) or 8 sessions (9-day group).
Cartilage Repair	Başçı et al. (2018)	141.85 kPa (~1.4 ATA)	100%	60 minutes	Daily, 6x/week; 12 sessions (2-week group) or 24 sessions (4-week group).
Soft Tissue Trauma & Infection	Huang et al. (2007)	2.5 bars	100%	120 minutes	2 sessions within 48 hours after surgery; includes air breaks.
	Hassan et al. (2010)	2.2–2.5 ATA	Not stated***	90 minutes	Avg. 1.89 treatments/day; total average of 13.37 treatments.
Tendon-Bone Integration	Yeh et al. (2007)	2.5 atm	100%	2 hours	Daily, 5 consecutive days per week.
	Li et al. (2025)	2.0 ATA	100%	2 hours	Daily for 5 successive days.
	Leite et al (2024)		100%	2 hours	Daily for 5 successive days.
Wounds, Grafts & Flaps (Cochrane)	Eskes et al. (2013)				
	Bouachour (1996)	2.5 ATA	100%	90 minutes	Twice daily for 6 days.
	Perrins (1967)	2.0 ATA	100%	2 hours	Twice on day 1; once daily for the next 3 days.
	Vishwanath (2011)	2.5 ATA	Not stated	Not stated	Once daily for 7 days starting POD 1.
	Xie (2007)	Not stated	Not stated	Not stated	Twice daily for 3 days, then once daily (6 to 12 total).

*Zhang et al.: Includes 15 min pressurization, 45 min stable pressure, and 15 min depressurization. **Kaynar et al.: 80 min total includes 10 min each for compression and decompression. ***Hassan et al.: Clinical adjuvant HBOT generally uses 100% O₂, but text focuses on pressure/frequency.

In critical-sized defects, Grassmann et al. [20] reported significant improvements in bone regeneration metrics (e.g., trabecular bone parameters and vascularity/microvessel density) in HBOT-treated animals compared with controls,

supporting a pro-angiogenic environment during early bone repair. In contrast, Fu et al. [15] reported no statistically significant improvement in fusion success when HBOT was added to an MSC-based fusion strategy ($P = 0.7997$), suggesting that HBOT did not meaningfully increase fusion

rates in that specific biologic construct. Kaynar et al. [23] reported HBOT-associated improvements in muscle oxidative/inflammatory profiles during distraction, but these findings should be interpreted as adjacent soft-tissue protection rather than direct evidence of improved bone union. Taken together, the preclinical bone literature suggests benefit in some defect-healing contexts, but not uniformly across all osteogenic applications.

Cartilage Repair

Cartilage repair was evaluated in a single experimental rat study (Başçı et al., 2018) [19], in which HBOT was used as an adjunct to microfracture for full-thickness cartilage defects. The study relied primarily on histological outcomes (defect filling, tissue morphology, cartilage quality, and subchondral changes) assessed at short follow-up intervals, which fits the purpose of detecting early differences in repair tissue maturation rather than long-term durability.

The authors reported statistically significant improvements in overall histopathology early point ($p = 0.0007$ at 2 weeks), driven by better defect fill and reparative tissue characteristics. By later follow-up, the between-group differences narrowed for some global scores but selected structural features (notably subchondral bone and microfracture-related parameters) remained more favorable in the HBOT arm. The study conclusion was that adjunctive HBOT may accelerate early cartilage repair after microfracture in this model; however, the short observation period and animal setting limit conclusions about long-term mechanical performance or clinical translation.

Soft Tissue Trauma and Infection

Soft tissue trauma/infection indications included (i) a prospective consecutive case series in complex open elbow injuries (Huang et al., 2007) [9] and (ii) a retrospective cohort in necrotizing fasciitis (Hassan et al., 2010) [21]. In addition, the Cochrane review [3] provides a broader synthesis of acute surgical/traumatic wound indications but aggregates heterogeneous clinical scenarios and protocols. Across these sources, the core outcomes of interest are infection control, wound viability, limb salvage/amputation, and functional recovery, with study designs ranging from uncontrolled series to retrospective comparison and small RCTs in wound contexts.

In the elbow series [20], favorable outcomes were reported (including functional recovery and low deep infection rates), but the absence of a control group means the evidence is hypothesis-generating rather than causal.

In necrotizing fasciitis, Hassan et al. [21] reported no statistically significant differences in mortality or length of

stay, while describing a lower amputation rate in the HBOT group (5% vs 25%), which may indicate a potential limb-salvage signal but remains vulnerable to confounding and selection bias.

In the category of wounds, grafts, and flaps, findings from the Cochrane systematic review by Eskes et al. (2013) [3] suggest a potential but inconsistent benefit of hyperbaric oxygen therapy (HBOT) that appears to vary by injury type. Two small randomized trials reported statistically significant advantages in specific clinical contexts. Bouachour et al. (1996) [25] showed that patients with acute crush injuries treated with HBOT at 2.5 ATA experienced higher rates of complete wound healing (risk ratio [RR] 1.70) and a significant reduction in tissue necrosis (RR 0.13) compared with sham treatment. Similarly, Perrins (1967) [26] demonstrated that HBOT at 2.0 ATA significantly improved split-thickness skin graft survival, with the probability of achieving $\geq 95\%$ graft take being approximately 3.5 times higher in the HBOT group than in controls.

In contrast, evidence supporting HBOT for other reconstructive applications was less robust. Randomized trials evaluating flap grafting and free-flap surgery [27][28] found no statistically significant differences in graft survival when HBOT was compared with standard care or alternative adjuncts such as heparin or corticosteroids.

Tendon–Bone Integration

Tendon–bone integration has been investigated in three experimental studies involving rabbits: anterior cruciate ligament (ACL) reconstruction [8][9] and rotator cuff repair [11]. These models evaluated healing at the enthesis-like interface through a combination of histological analysis (including fibrocartilage organization and interface maturation), vascular assessments, and biomechanical testing (e.g., pull-out or failure strength).

In the study by Yeh et al. [9], HBOT was linked to enhanced histological features of interface healing, such as more organized interface tissue and characteristics indicative of stronger anchorage, as well as increased mechanical strength at later stages compared to normoxic controls. Leite et al. [8] found that the adjuvant HBOT group exhibited improved graft maturation and bone integration, reduced tunnel widening, and superior biomechanical tensile resistance. Similarly, in the research by Li et al. [11], HBOT-treated repairs showed more favorable structural organization and greater tensile properties than controls, aligning with accelerated maturation of the tendon–bone interface. All authors concluded that HBOT can enhance tendon–bone healing in controlled preclinical settings; however, these findings remain preclinical, and factors such as protocol intensity, species differences, and short-to-

intermediate follow-up limit direct extrapolation to late clinical settings following ACL or rotator cuff repair.

After completion of our study screening and data extraction, an additional clinical study evaluating HBOT after ACL reconstruction was published and therefore was not captured within our original search window. In a matched cohort pilot study [29] of patients undergoing primary anatomic ACL reconstruction with hamstring autografts (26 receiving adjuvant HBOT and 26 controls), postoperative MRI at 4 months demonstrated significantly lower graft signal-to-noise quotient (SNQ) in the HBOT group, interpreted as more advanced graft maturation, along with reduced bone marrow edema at the graft–bone tunnel interface, suggesting improved early graft integration.

DISCUSSION

Although the broader literature on hyperbaric oxygen therapy (HBOT) is substantial, its focused evaluation as a perioperative adjunct in orthopedic and musculoskeletal surgery remains comparatively sparse. The findings of the present scoping review reveal a notably consistent pattern: across diverse surgical models and tissue types, HBOT is associated with reproducible biological and early functional benefits predominantly in preclinical and short-term clinical settings. These effects appear to extend beyond anecdotal or isolated observations, suggesting that HBOT reliably targets fundamental, rate-limiting processes in surgical healing - namely, tissue hypoxia, impaired angiogenesis, collagen disorganization, and inflammation. Collectively, these findings support the rationale for considering HBOT as a biologically plausible and potentially high-impact adjunct in carefully selected perioperative contexts.

Across three rabbit studies, HBOT produced the most consistent preclinical signal at the tendon–bone interface - the histologically complex zone that determines the success of ligament reconstruction and rotator cuff repair [8][11][5]. In two ACL reconstruction models [8][9] and one rotator cuff repair model [11], HBOT increased neovascularization, produced more organized fibrocartilage at the enthesis, improved collagen alignment, and yielded higher load-to-failure at intermediate time points. These findings converge across two surgical models and three methodologies - histology, ultrastructural analysis, and biomechanical testing - which makes model-specific artefact an unlikely explanation and strengthens the biological case for HBOT at the enthesis. This evidence is preclinical. No randomized controlled trial has tested adjunctive HBOT in patients undergoing ACL reconstruction or rotator cuff repair. The only available human signal is a matched-cohort pilot [29] in primary hamstring-autograft ACL reconstruction: 26 HBOT-treated patients had better early MRI-based graft maturation than 26

matched controls. This is hypothesis-generating - the design is not randomized, the sample is modest, and the endpoint is an imaging surrogate, not a clinical outcome. Without randomized trials, the preclinical effect cannot yet be extrapolated to clinical practice.

In the context of bone repair and osteogenesis, similarly favorable effects are observed in scenarios where vascular insufficiency constitutes the dominant biological constraint. Specifically, in critical-sized diaphyseal defect models - where spontaneous healing is minimal - HBOT consistently augments both angiogenesis and new bone formation [20]. By contrast, its lack of additive benefit in mesenchymal stem cell-augmented spinal fusion models [15] likely reflects a biological ceiling already attained through potent regenerative stimuli. This finding highlights a clinically salient principle: HBOT appears most efficacious in settings characterized by compromised or suboptimal healing, rather than as an adjunct in already optimized regenerative protocols.

A single randomized trial in total knee arthroplasty [24] found that early postoperative HBOT lowered muscle-injury and systemic inflammatory markers, sped quadriceps recovery, reduced swelling, and lowered pain scores in the first postoperative week. Tourniquet-related ischemia–reperfusion injury plausibly explains these effects. This is an isolated trial; the finding requires independent replication before any inference about routine clinical adoption.

The evolution of HBOT protocols over time should be viewed not as inconsistency, but as progressive refinement. Earlier preclinical studies employed high pressures and prolonged exposures to stimulate structural regeneration, whereas contemporary clinical trials have adopted shorter, lower-pressure protocols aimed at modulating inflammation and mitigating ischemia–reperfusion injury. This dose-responsiveness reflects the intervention's versatility and highlights the weight of tailoring HBOT parameters to the dominant pathophysiological processes of specific surgical scenarios.

This review has four principal limitations. First, the clinical evidence base is small and heterogeneous, which prevents us from pooling effect estimates. Second, HBOT regimens varied substantially across studies - in pressure, session duration, frequency, and total exposure - which makes the studies hard to compare. Third, the most consistent positive signal, at the tendon–bone interface, is preclinical; no randomized clinical trial has tested HBOT after ACL reconstruction or rotator cuff repair. Fourth, we identified four of the included randomized trials through hand-search of the Cochrane review by Eskes et al. [3], and for some of these trials we relied on data summarized within the review rather than extracting them de novo from the full texts.

This scoping review supports the biological plausibility of HBOT as a perioperative adjunct in scenarios where hypoxia, inadequate vascularity, or impaired tissue integration compromise healing. It does not yet support HBOT's clinical effectiveness in any orthopaedic indication. The field is limited by the absence of large, indication-specific randomized trials with clinically meaningful endpoints, not by the absence of a biological signal. Future research should prioritize three settings: tendon–bone reconstruction, high-risk soft-tissue compromise, and early recovery after major joint surgery. Until trial-grade evidence exists, clinicians should not adopt HBOT as a routine perioperative strategy in orthopaedic surgery.

CONCLUSION

This scoping review identified a small, heterogeneous evidence base on the use of HBOT as an adjunct in musculoskeletal surgery, with wide variations in protocols and outcomes. Preclinical studies have shown the most consistent benefits at the tendon–bone interface (ACL and rotator cuff models), with improved interface maturation and biomechanical strength, whereas bone-related effects appear context-dependent and not uniformly additive.

No randomized controlled trial has confirmed clinical effectiveness in any orthopaedic indication. The clinical evidence does not support routine perioperative HBOT in any indication. This review maps evidence; it does not provide clinical guidance. The field needs indication-specific randomized trials with standardized HBOT protocols and clinically meaningful endpoints - structural healing, complications and reoperation, function, and patient-reported outcome measures.

Open access statement

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Conflict of interest statement

The authors have declared that there are no conflicts of interest in the authorship and publication of this contribution. The authors also disclose the use of ChatGPT (OpenAI; GPT-5.2 Thinking) for academic English language editing only. Specifically, the tool was used to improve grammar, sentence structure, clarity, and readability of the manuscript text. The AI was not used to generate original scientific content, extract data, perform statistical analyses, interpret results, or

make clinical conclusions. All intellectual content, study design, screening decisions, data synthesis, and final manuscript revisions were performed and verified by the authors.

Ethics statement

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