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Review Article

# Ozone Therapy for Wound Management in Avian Species Surgical Affections of Eye in Cattle - A Clinical Study (24 Cows)

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**Abstract:** Wound management in avian species presents unique challenges due to their delicate anatomy, high metabolic rates, and susceptibility to infection and self-mutilation. While conventional approaches form cornerstone of therapy, the search for effective adjunctive modalities is ongoing. Ozone therapy, the medical application of a precisely controlled oxygen-ozone mixture, is emerging as a promising integrative tool for avian wound care.

This review synthesizes the current understanding of ozone's multi-modal mechanisms relevant to wound healing, including its potent antimicrobial (bactericidal, virucidal, fungicidal), anti-inflammatory, immunomodulatory, and tissue regenerative properties. These actions derive from a controlled "hormetic" oxidative stress that upregulates endogenous antioxidant defenses, modulates cytokine cascades, stimulates growth factor release, and enhances microcirculation. While largely extrapolated from mammalian studies, these biochemical effects hold theoretical potential for improving healing outcomes in birds.

Clinically, ozone therapy has been anecdotally applied to various avian wound types, most notably chronic pododermatitis ("bumblefoot"), traumatic injuries, surgical dehiscence, and abscesses, aiming to reduce infection, control inflammation, and accelerate granulation and epithelialization. Common administration routes include topical application (ozonated water/oils), local infiltration, rectal insufflation for systemic effects, and ozone bagging, all requiring meticulous technique. Crucially, direct inhalation of ozone gas is strictly contraindicated due to severe respiratory toxicity, necessitating stringent safety protocols.

Despite its theoretical benefits and anecdotal successes, the evidence base for ozone therapy in avian wound management remains critically limited, predominantly comprising case reports and expert opinions. A significant lack of standardized protocols, controlled clinical trials, and species-specific pharmacokinetic and pharmacodynamic data hinders definitive conclusions on efficacy and optimal application. Future research must focus on rigorous, randomized studies, standardized dosage guidelines, and objective outcome measures to validate its therapeutic utility and establish its responsible integration into evidence-based avian veterinary practice.

**Keywords:** Ozone therapy, avian, Wound healing, Wound management, Pododermatitis, Antimicrobial, Anti-Inflammatory, Regeneration, Exotic pets.

## Introduction

Avian wound management presents unique challenges compared to mammalian wound care, primarily due to fundamental differences in avian physiology, anatomy, and wound healing processes. Birds possess distinct characteristics such as pneumatic bones, a highly efficient respiratory system, a unique integumentary system with feathers, and a generally faster metabolic rate, all of which influence how they respond to injury and how wounds should be treated. Effective avian wound management requires a thorough understanding of these physiological distinctions, as well as meticulous attention to detail in diagnosis, cleaning, debridement, and ongoing care. The goal is not only to promote rapid healing and prevent complications like infection but also to ensure the bird's comfort, minimize stress, and facilitate a swift return to normal function, especially for wild birds intended for release.

**Challenges of Wound Management in Avian Patients**

Wound management in avian species presents a complex array of challenges that significantly distinguish it from typical mammalian wound care. These difficulties arise from a unique blend of anatomical, physiological, behavioural, and husbandry factors that can impede effective healing, increase the risk of complications, and ultimately impact patient prognosis [1,2].

**Unique Avian Anatomy and Physiology**

Avian skin is remarkably delicate and thin, often lacking the robust subcutaneous tissue found in mammals. This fragility makes it highly susceptible to tearing during trauma or even gentle manipulation, and challenging to suture securely without tension, increasing the risk of suture line dehiscence [3,4]. The sparse dermal tissue also offers limited protection to underlying structures. Dense feathering complicates wound assessment, cleaning, and bandaging. Feather follicles are highly vascular and sensitive, leading to increased hemorrhage during debridement or surgery. Damage to follicles can result in permanent feather loss, affecting thermoregulation, flight, and aesthetic appeal [1,5]. Feathers can also introduce foreign material and microbial contamination into the wound bed. The unique avian respiratory system, featuring nine pneumatic air sacs communicating with the lungs and often extending into pneumatic bones (e.g., humerus, femur), poses a significant challenge. Deep wounds, particularly those involving the coelomic cavity or long bones, can communicate directly with the air sac system. This communication increases the risk of developing secondary air sacculitis from environmental contaminants or direct wound infection [3,6]. Pressure changes within the air sacs during respiration can also force exudates out of the wound or draw contaminants inwards, complicating healing and bandage integrity. Fractures involving pneumatic bones are inherently open fractures, as the bone marrow cavity communicates with the air sacs. This significantly elevates the risk of osteomyelitis and air sac infection, requiring aggressive management of both the bone and the soft tissue components [1,7]. Birds possess a high basal metabolic rate, which, while theoretically conducive to rapid tissue turnover, also means they are highly susceptible to rapid clinical deterioration when injured or stressed [2]. Extensive wounds can lead to significant heat loss, predisposing the patient to hypothermia and metabolic crises, which are detrimental to wound healing.

**Diagnostic and Therapeutic Limitations**

The diminutive size of many avian species limits surgical access, requires micro-instrumentation, and restricts the volume of blood that can be safely collected for diagnostic testing, which can be crucial for monitoring infection and systemic health [1,2]. There is often a lack of avian-specific drug formulations and established dosing regimens for many medications. Dosing must often be extrapolated from other species, increasing the risk of underdosing, overdosing, or adverse reactions [1]. Many advanced wound care products and dressings are designed and tested for mammalian skin and wound characteristics, and may not be optimally suited or readily available for avian use [4]. The specialized nature of avian veterinary care, coupled with the extended duration and intensity of treatment often required for complex wounds, can incur significant financial costs and demand substantial time commitment from owners, which can be a limiting factor in patient care [2].

**Conventional avian wound management principles**

Effective wound management in avian patients is a multi-faceted process that integrates immediate stabilization, meticulous wound care, systemic support, and careful monitoring. Given the unique anatomical and physiological challenges in birds, conventional principles are often adapted from mammalian veterinary medicine but with critical species-specific considerations [9,10].

**I. Initial Assessment and Patient Stabilisation**

**A. Rapid Clinical Assessment:** Prioritise assessing the bird's overall condition, including respiratory effort, hydration status, mentation, and signs of shock [9,11].

**B. Emergency Stabilisation:** Address life-threatening issues first. This may involve providing external heat to combat hypothermia, which is common in injured birds due to heat loss from wounds [1,12]. Fluid Therapy: Administer warmed subcutaneous, intraosseous, or intravenous fluids to correct dehydration and hypovolemia [11]. Oxygen Supplementation: Administer oxygen if signs of respiratory distress are present [10]. Control Haemorrhage: Apply direct pressure to stop bleeding from the wound [9].

**II. Pain Management**

Analgesia is critical for avian welfare, reducing stress, preventing self-mutilation, and promoting healing. Birds often mask signs of pain, so a proactive approach is necessary [13]. Opioids: Butorphanol, buprenorphine are commonly used systemically. Non-Steroidal Anti-Inflammatory Drugs (NSAIDs): Meloxicam is a frequently used NSAID, particularly for its anti-inflammatory effects which also aid in pain control [13,14]. Local Anesthetics: Lidocaine or bupivacaine can be used cautiously for local or regional blocks during debridement or surgical procedures [9].

### III. Wound Assessment

**A. Comprehensive Examination:** Carefully evaluate the wound size, depth, location, and extent of tissue damage. Note any foreign material, signs of infection (e.g., exudate, discoloration, odour), and involvement of underlying structures (bone, joints, air sacs) [9,12].

**B. Feather Removal:** Carefully pluck or trim feathers around the wound margins to facilitate cleaning and examination. Avoid plucking directly from the wound edge to prevent further trauma to follicles [11].

**C. Diagnostic Sampling**

- **Cytology:** Collect samples for microscopic examination to identify inflammatory cells and microorganisms [15].
- **Bacterial Culture and Sensitivity:** Essential for guiding appropriate antibiotic therapy, especially in infected or chronic wounds [15].
- **Fungal Culture:** Consider if fungal infection (e.g., Aspergillus) is suspected, particularly in respiratory tract communicating wounds [9].
- **Radiography:** Obtain radiographs if bone involvement (fracture, osteomyelitis) or air sac communication is suspected [9,11].

### IV. Wound Preparation and Debridement

**A. Protection of Wound:** Pack open wounds with sterile saline-soaked gauze to prevent further contamination during surrounding area preparation [12].

**B. Periwound Cleaning:** Gently clean the skin surrounding the wound with a mild antiseptic solution (e.g., diluted chlorhexidine or povidone-iodine) [9,11].

**C. Lavage:** Copiously flush the wound with warm, sterile saline solution (0.9% NaCl) to remove debris, exudate, and loose contaminants. Low-pressure lavage is preferred to avoid driving bacteria deeper into tissues [9,12].

**D. Debridement:** Remove all non-viable (necrotic) tissue to promote healing and reduce the bacterial load.

- **Surgical Debridement:** The most common and effective method, involving sharp dissection of devitalized tissue [9,12].
- **Enzymatic Debridement:** Can be used cautiously, but often slow and less effective than surgical methods in birds [11].
- **Mechanical Debridement:** Wet-to-dry bandages can be used for initial debridement, but their use must be balanced against tissue trauma [9].

### V. Antiseptics and Antimicrobials

**A. Topical Antiseptics:** Applied to the wound after debridement to reduce microbial load. Diluted povidone-iodine or chlorhexidine are commonly used, but judiciously, as some agents can be cytotoxic to healing tissues [9,12].

**B. Systemic Antimicrobials:** Indicated for infected wounds, deep wounds, or in immunocompromised patients. Selection should ideally be based on culture and sensitivity results [16]. Common choices include enrofloxacin, trimethoprim-sulfamethoxazole, and doxycycline, chosen based on suspected pathogens and bird species [9].

**C. Antifungals:** If fungal infection is confirmed or highly suspected (e.g., with air sac involvement), systemic antifungals (e.g., itraconazole, voriconazole) are crucial [9,16].

### VI. Wound Closure Techniques

**A. Primary Closure:** If the wound is fresh, clean, and tension-free, it can be closed immediately. This is less common in avian wounds due to their fragility [9,12].

**B. Delayed Primary Closure:** The wound is cleaned and managed as an open wound for 2-5 days, then closed once granulation tissue has formed and infection is controlled [9,12].

**C. Secondary Closure:** Allowing the wound to heal by contraction and epithelialization, often used for large or contaminated wounds. This is common in birds, but slow and can lead to disfiguring scars [11].

**D. Skin Grafts/Flaps:** Rarely performed in avian patients due to thin skin and limited availability of donor sites [9].

### Medical Ozone Therapy

Medical ozone therapy involves the therapeutic administration of a precisely defined mixture of ozone and oxygen [17]. Immunomodulation: Enhancing cellular and humoral immune responses through the activation of immune cells and the release of immunomodulatory cytokines [18,20]. Improvement of Oxygen Metabolism and Microcirculation: By affecting red blood cell function and vascular tone, leading to enhanced oxygen delivery to tissues [19]. Direct Antimicrobial Effects: Exerting bactericidal, virucidal, and fungicidal properties through oxidation of microbial components, making it valuable in infectious processes [21]. It is crucial to differentiate medical ozone from its highly toxic atmospheric counterpart, which is an irritant and pollutant.

 

Medical ozone generators ensure precise and adjustable concentrations, allowing clinicians to tailor dosages to specific therapeutic goals and routes of administration, thereby maximizing benefit while minimizing adverse effects [17,18]. As an adjunctive therapy, medical ozone offers a multi-modal approach, leveraging its diverse biological effects to support and enhance conventional medical treatments across various conditions.

**Rationale for applying ozone therapy in avian wounds**

The application of ozone therapy in avian wound management stems from a desire to overcome the inherent challenges presented by avian anatomy, physiology, and behavior, and to enhance the efficacy of conventional treatments. While traditional wound care principles remain fundamental, ozone therapy offers a multifaceted approach that directly addresses several limiting factors in avian wound healing [22,23].

**I. Addressing Limitations of Conventional Avian Wound Management**

**Persistent Infections:** Despite meticulous debridement and antibiotic use, avian wounds, especially chronic or contaminated ones (e.g., severe pododermatitis), can be notoriously difficult to clear of bacterial or fungal infections [24]. The emergence of antimicrobial resistance further complicates treatment [25].

**Excessive Inflammation:** Chronic inflammation, a common feature in many avian wounds, can impede healing by prolonging the destructive phase and delaying the transition to the proliferative phase [22].

**Poor Tissue Regeneration:** Fragile avian skin, limited subcutaneous tissue, and sometimes compromised vascularity can lead to slow granulation and epithelialization, leaving wounds open to prolonged risk of infection and self-mutilation [23,26].

**Need for Minimally Invasive Options:** Repeated surgical debridement, while often necessary, can be traumatic for small or debilitated avian patients [22].

**II. Multifaceted Therapeutic Actions of Ozone Directly Supporting Avian Wound Healing:** The unique properties of medical ozone allow it to interact with biological tissues in ways that can directly mitigate the aforementioned challenges:

**A. Potent Antimicrobial Action:** Ozone exhibits broad-spectrum activity against bacteria, fungi, viruses, and even some protozoa, by oxidizing their cell walls, membranes, and intracellular components [27,29]. This direct cytotoxic effect on microorganisms makes it a valuable tool for reducing the microbial load in contaminated or infected wounds, including those with multi-drug resistant pathogens, where conventional antibiotics may be failing [29,30].

**B. Anti-inflammatory Effects:** At therapeutic concentrations, ozone modulates inflammatory cascades by influencing cytokine production (e.g., reducing pro-inflammatory TNF-α and IL-1 while potentially increasing anti-inflammatory IL-10) and modulating NF-kappa B activity [28,31]. This helps to temper excessive or chronic inflammation in the wound bed, allowing the healing process to progress more efficiently and potentially reducing associated pain and swelling [32].

**C. Immunomodulation:** Ozone can stimulate local and systemic immune responses, enhancing the activity of phagocytes (e.g., macrophages, heterophils) and improving their ability to clear cellular debris and pathogens from the wound site [6,8]. This is particularly beneficial in birds, whose immune responses to chronic infections can be complex [22].

**D. Promotion of Tissue Regeneration and Oxygenation:** Ozone exposure induces the release of growth factors (e.g., PDGF, VEGF, TGF-β) which are crucial for stimulating cell proliferation (fibroblasts, keratinocytes), collagen synthesis, and angiogenesis (new blood vessel formation) [28,33]. Improved local microcirculation and oxygen delivery to hypoxic wound tissues are fundamental for cellular metabolism and wound repair, addressing issues of poor vascularity seen in areas like the avian foot [22,33].

**E. Pain Management (Indirect):** By effectively reducing inflammation and infection, ozone therapy can indirectly lead to a reduction in wound-associated pain, thereby improving patient comfort and reducing the likelihood of self-mutilation [22].

In essence, applying ozone therapy to avian wounds is rationalized by its ability to simultaneously tackle infection, modulate inflammation, enhance tissue repair, and support overall patient health, thereby filling critical gaps where conventional treatments may be insufficient, particularly in complex or chronic cases.

**Mechanisms of action of ozone relevant to wound healing (with avian considerations)**

The therapeutic effects of medical ozone are not due to a single mechanism but rather a cascade of biochemical and cellular interactions initiated by its controlled reaction with biological molecules. At precise, low concentrations, ozone acts as a "hormetic" agent, inducing a mild and transient oxidative stress that paradoxically stimulates beneficial adaptive responses, crucial for the complex process of wound healing [34,35].

While most of the detailed molecular understanding of ozone's mechanisms comes from mammalian research, the fundamental biochemical principles are broadly applicable to avian systems, though specific avian-centric research is limited [36].

**I. Antimicrobial Effects**

**Direct Bactericidal, Virucidal, and Fungicidal Action:** Ozone rapidly oxidizes the cell membranes and walls of bacteria, fungi, and protozoa, leading to lysis and inactivation. It also disrupts viral envelopes and nucleic acids [37,38].

**Mechanism:** This direct oxidation of lipids, proteins, and carbohydrates in microbial structures results in irreversible damage and death. Ozone can penetrate biofilms, which are common in chronic wounds and protect microbes from conventional antibiotics [39].

**Relevance to Avian Wounds:** Avian wounds are highly susceptible to contamination from the environment, faeces, and plumage, often leading to polymicrobial infections, including drug-resistant strains [35,40]. Ozone's broad-spectrum antimicrobial activity makes it invaluable for: Reducing the bacterial and fungal load in infected wounds. Preventing infection in clean wounds. Overcoming antibiotic resistance by employing a different mechanism of action [35].

**II. Anti-inflammatory and Immunomodulatory Effects**

**Modulation of Inflammatory Mediators:** Ozone interacts with polyunsaturated fatty acids (PUFAs) in cell membranes, forming ozonides and lipid peroxidation products (LPOPs). These LPOPs act as secondary messengers, modulating critical inflammatory pathways [34,41]. Ozone can downregulate the production of pro-inflammatory cytokines such as Tumor Necrosis Factor-alpha (TNF-α), Interleukin-1 beta (IL-1), and Interleukin-6 (IL-6), while potentially increasing anti-inflammatory mediators like IL-10 [42,43]. It can also influence the Nuclear Factor-kappa B pathway, a central regulator of inflammation and immune responses [34,40].

**Activation of Immune Cells:** Ozone stimulates various immune cells, including macrophages, neutrophils (heterophils in birds), and lymphocytes [34,44]. Enhances phagocytic activity, improving the clearance of cellular debris and pathogens from the wound bed. Promotes the release of growth factors and cytokines that orchestrate the subsequent phases of healing [34].

**Relevance to Avian Wounds:** Chronic or excessive inflammation can impede wound healing in birds, contributing to pain and delayed closure [34,35]. Ozone's ability to: Reduce destructive inflammation helps transition the wound from the inflammatory phase to the proliferative phase. Enhance local immune responses in the wound bed, which is crucial for fighting infection and clearing tissue debris in avian species prone to granuloma formation [34].

**III. Promotion of Tissue Regeneration and Angiogenesis**

**Growth Factor Release:** The controlled oxidative stress induced by ozone stimulates the release of various growth factors essential for tissue repair, including Platelet-Derived Growth Factor (PDGF), Vascular Endothelial Growth Factor (VEGF), and Transforming Growth Factor-beta (TGF-β) [40,44].

**Cell Proliferation and Extracellular Matrix (ECM) Synthesis:** These growth factors, combined with other signaling pathways, promote the proliferation and migration of fibroblasts, keratinocytes, and endothelial cells, which are crucial for granulation tissue formation and re-epithelialization [45]. Stimulates collagen synthesis, essential for wound strength and integrity [40].

**Improved Microcirculation and Angiogenesis:** Ozone can improve blood rheology and erythrocyte deformability, enhancing oxygen delivery to hypoxic tissues [34,40]. It also directly stimulates angiogenesis, the formation of new blood vessels, which is critical for bringing oxygen, nutrients, and immune cells to the healing wound [44].

**Relevance to Avian Wounds:** Avian skin is thin, and certain areas (e.g., feet in pododermatitis) can suffer from compromised vascularity, leading to slow healing [35,38]. Ozone's effects on: Promoting angiogenesis and oxygenation directly address issues of poor blood supply. Stimulating growth factors and cellular proliferation accelerates granulation tissue formation and re-epithelialization, which is vital for closing open wounds and preventing further complications.

**IV. Modulation of Oxidative Stress (Hormetic Effect)**

**Controlled ROS Generation:** At therapeutic concentrations, ozone generates a transient, low level of reactive oxygen species (ROS) and LPOPs [34,39].

**Upregulation of Endogenous Antioxidant Systems:** This mild oxidative burst acts as a signaling mechanism, triggering the upregulation of the body's intrinsic antioxidant enzymes, such as Superoxide Dismutase (SOD), Catalase (CAT), and Glutathione Peroxidase (GPx) [34,40]. This adaptive response helps protect cells from subsequent oxidative damage and maintains redox balance, which is crucial for cellular function and healing.



 

**Relevance to Avian Wounds:** While harmful in excess, controlled oxidative stress helps to optimize cellular signaling pathways involved in tissue repair and defense [34]. In a wound environment, particularly if infected, a balanced redox state is essential for efficient healing.

**V. Pain Modulating Effects (Indirect)**

**Reduction of Inflammation and Swelling:** By effectively reducing inflammation and associated edema within the wound bed, ozone therapy indirectly reduces pain [34,43].

**Relevance to Avian Wounds:** Pain can lead to stress and self-mutilation in birds, further compromising wound healing [35,46]. Reducing inflammation and promoting healing can significantly improve patient comfort and reduce the need for excessive restraint.

**VI. Avian-Specific Considerations and Research Gaps for Mechanisms**

**Extrapolation from Mammalian Data:** The detailed molecular mechanisms described above are primarily derived from in vitro studies and in vivo mammalian models [34,40]. Direct research elucidating these specific pathways in avian cells and tissues is largely absent.

**Avian Physiological Differences:** While general principles apply, there may be subtle but significant differences in avian cellular responses, enzyme systems, inflammatory mediators, and immune cell behaviours compared to mammals that could influence ozone's effects [34,47]. For instance, the role of heterophils vs. neutrophils in inflammation could impact local wound responses.

**Respiratory System Influence:** The unique avian respiratory system (air sacs, parabronchi) could theoretically influence the systemic distribution and elimination of ozone-derived messengers if administered via routes that allow systemic absorption, but this remains unstudied [34].

In summary, the multi-modal actions of ozone, particularly its antimicrobial, anti-inflammatory, and regenerative properties, provide a compelling theoretical basis for its application in avian wound management. However, the critical need for avian-specific mechanistic research remains a significant gap in the current understanding.

**Clinical applications of ozone therapy in avian wound types**

The diverse therapeutic properties of medical ozone including its antimicrobial, anti-inflammatory, immunomodulatory, and regenerative effects make it a versatile adjunctive treatment for various wound types encountered in avian practice [48,49]. Its application aims to enhance conventional wound management, particularly in complex, chronic, or non-responsive cases.

**I. Pododermatitis ("Bumblefoot")**

This is one of the most common and challenging chronic foot conditions in captive birds, ranging from mild erythema (Grade 1) to severe ulceration, abscessation, osteomyelitis, and tendonitis (Grade 5) [50,51]. It is typically associated with inappropriate perching, obesity, and poor husbandry, leading to pressure necrosis and secondary bacterial infection [54].

- **Rationale for Ozone Application**

**Antimicrobial:** Directly combats bacterial (e.g., Staphylococcus, Pseudomonas) and fungal infections commonly seen in bumblefoot, including resistant strains [48,52].

**Anti-inflammatory:** Reduces swelling and pain in the affected footpad, which is critical for patient comfort and reducing self-mutilation [48,53].

**Improved Circulation and Granulation:** Enhances blood flow to the often poorly vascularized footpad, promotes the formation of healthy granulation tissue, and accelerates epithelialization [48,54].

**Debridement Aid:** Ozonated water can assist in liquefying caseous exudate, making debridement easier [55].

- **Application Methods**

**Ozonated Water Soaks/Lavages:** The foot is immersed in or flushed with ozonated water for several minutes daily or every other day [55].

**Ozonated Oil Topical Application:** Ozonated oil can be applied directly to the lesion after cleaning and debridement, often under a protective bandage [55].

**Local Injections (Cautious):** Small volumes of ozonated saline or gas (if appropriate generator and strict dosage control) injected into the core of deeper lesions post-debridement, though this requires extreme care in avian digits [48].

**Rectal Insufflation:** Can be used systemically to boost overall immune response and support healing in severe, chronic cases [48].

- **Evidence:** Primarily anecdotal and case reports suggest improved healing rates and resolution of infection in birds with pododermatitis when ozone therapy is used as an adjunct [55].

**II. Traumatic Wounds**

Includes lacerations (cuts), abrasions (scrapes), avulsions (tearing away of tissue), and degloving injuries (skin pulled off underlying tissue) resulting from collisions, predator attacks, cage trauma, or fights [49,56]. These wounds are often highly contaminated.

- **Rationale for Ozone Application**

**Infection Prevention/Treatment:** Immediate antimicrobial action helps to prevent or treat gross contamination and subsequent infection [48, 53].

**Inflammation Control:** Reduces excessive inflammation, which can impede initial healing [48,57].

**Tissue Regeneration:** Stimulates granulation tissue formation and epithelialization, accelerating wound closure [48,54].

- **Application Methods**

**Ozonated Water Lavage:** Used extensively for initial cleaning and subsequent flushes of open wounds [55].

**Ozonated Oil Topical Application:** Applied to the wound bed before bandaging [55].

**Ozone Bagging:** For limb or body wounds, the affected area can be enclosed in an ozone-resistant bag where ozone gas is introduced at controlled concentrations for short durations, ensuring direct contact with the wound surface [48,55].

- **Evidence:** Case reports suggest accelerated healing and reduced infection rates in various traumatic avian wounds [55].

**III. Surgical Wounds and Dehiscence**

Post-operative incisions that become infected, dehisce (split open), or are slow to heal, or where there is a desire to enhance primary closure [56].

- **Rationale for Ozone Application**

**Infection Prophylaxis/Treatment:** Can be used to irrigate surgical sites intraoperatively to reduce bacterial load or post-operatively for dehisced, contaminated incisions [48,53].

**Enhanced Healing:** Promotes more robust granulation and epithelialization, potentially leading to stronger, more resilient incision lines [48,54].

- **Application Methods**

**Intraoperative Lavage:** Ozonated saline/water used to flush the surgical field.

**Topical Application:** Ozonated oil applied to the incision line (if open) or under a bandage post-operatively.

**IV. Abscesses and Cellulitis**

Localized collections of pus (often caseous in birds) or diffuse spreading bacterial infections within tissues [48].

- **Rationale for Ozone Application**

**Direct Antimicrobial:** High concentrations of ozone can directly kill bacteria within the abscess cavity after drainage and debridement [48,52].

**Inflammation Reduction:** Helps resolve surrounding cellulitis [48,57].

**Debridement Aid (Anecdotal):** Some practitioners report that ozonated fluids can help liquefy caseous exudate, making it easier to remove [55].

- **Application Methods**

**Flushing:** After surgical opening and debridement of an abscess, the cavity is vigorously flushed with ozonated water or saline [55].

**Local Infiltration:** Very cautious local injection of ozonated saline into cellulitic areas (after thorough debridement) [48].

**V. Burns**

Burns are less common in birds but can be severe, involving extensive tissue damage and a high risk of infection [48].

- **Rationale for Ozone Application**

**Antimicrobial:** Preventing infection in the compromised burn tissue [48,53].

**Anti-inflammatory:** Reducing the severe inflammatory response associated with burns [48,57].

**Healing Acceleration:** Promoting re-epithelialization and reducing scar formation [48,54].

- **Application Methods:** Primarily topical, using ozonated water for cleaning and ozonated oils for dressing the burn [55].
- **Evidence:** Very limited specific avian data; extrapolation from human and mammalian burn treatment where ozone has shown promise [48].

**VI. Fractures with Open Wounds (Compound Fractures)**

Fractures where the bone communicates with the external environment, carrying a high risk of infection (osteomyelitis) [56].

- **Rationale for Ozone Application**

**Infection Control:** Managing the soft tissue infection component around the fracture site is paramount to successful bone healing [48,53].

**Supportive Healing:** Optimizing the local environment for callus formation and bone repair [48].

- **Application Methods:** Local wound care with ozonated water lavage and topical applications alongside standard fracture repair (e.g., external fixators) [55].

**VII. Other Potential Supportive Applications**

- **Post-Surgical Recovery:** Ozone can be used systemically (e.g., rectal insufflation) to boost overall health, immune function, and circulation in debilitated birds recovering from extensive surgery [48].
- Adjunctive Therapy for Systemic Conditions: In birds with underlying systemic diseases that compromise wound healing (e.g., chronic viral infections, liver disease), ozone may provide systemic support to improve overall vitality and healing capacity [48].

**Overall Caveats:** While these applications are logical extensions of ozone's known mechanisms and supported by anecdotal reports in avian practice, it is crucial to reiterate that robust, randomized, controlled clinical trials are largely absent in avian medicine for ozone therapy. Its use should be considered as an adjunctive treatment within a comprehensive conventional wound management plan.

**Administration routes and dosages for avian wound management**

The successful application of ozone therapy in avian wound management hinges on the precise control of ozone concentration and volume, selection of the appropriate administration route, and strict adherence to safety protocols. Given the unique physiology and sensitivity of avian patients, extrapolation from mammalian dosages must be done with extreme caution, and currently, standardized, evidence-based protocols for birds are notably lacking [58,59].

**I. General Considerations for Ozone Administration in Birds**

**Medical-Grade Ozone Generator:** Only high-quality, calibrated medical-grade ozone generators, producing a precise mixture of ozone from pure medical oxygen, should be used. Industrial generators or uncalibrated devices are highly dangerous [58,60].

**Ozone-Resistant Materials:** All tubing, syringes, catheters, and containers coming into contact with ozone must be made of ozone-resistant materials (e.g., silicone, glass, Teflon, specific plastics like PVDF/Kynar). PVC and rubber are rapidly degraded by ozone and release toxic byproducts [58,61].

**"Therapeutic Window":** Ozone therapy operates within a narrow therapeutic window. Too low a concentration may be ineffective, while too high can lead to tissue damage and toxicity [60,62].

**Avian Sensitivity:** Birds have a higher metabolic rate and a delicate respiratory system, implying they may be more sensitive to ozone's effects, potentially requiring lower concentrations or shorter exposure times compared to mammals for equivalent therapeutic outcomes [59].

**Contraindications for ozone therapy in avian wound management**

Certain conditions or patient statuses may preclude the safe and effective use of ozone therapy. These contraindications are largely extrapolated from mammalian and human medicine.

**Decompensated Cardiovascular or Respiratory Disease:** Birds with severe, decompensated heart failure, severe anaemia, or advanced respiratory disease (e.g., severe aspergillosis, advanced pneumonia) may not tolerate any additional oxidative stress or metabolic demands, even therapeutic ones [63]. The risk of adverse respiratory events (if any ozone gas is inhaled) is greatly heightened.

**Severe Hemorrhagic Disorders/Coagulopathies:** Ozone can have effects on blood coagulation. In birds with severe clotting deficiencies (e.g., severe liver disease, anticoagulant rodenticide toxicity, severe thrombocytopenia), ozone therapy, especially systemic routes, might theoretically exacerbate bleeding [65].

**Hyperthyroidism (if applicable):** In mammals, hyperthyroidism is often listed as a contraindication due to ozone's potential to further stimulate an already hyperactive metabolism [65]. While spontaneous hyperthyroidism is rare in birds, this would be a theoretical concern.

**Severe Acute Toxicosis:** Birds undergoing severe acute intoxication (e.g., heavy metal poisoning, mycotoxicosis) are already under significant physiological stress. Introducing ozone therapy might add to their burden and should be approached with extreme caution, if at all [63].

**Lack of Proper Equipment or Training:** This is a crucial contraindication. Ozone therapy must be performed using medical-grade, precisely calibrated ozone generators and ozone-resistant materials. Administration by untrained personnel significantly increases the risk of toxicity and injury [63,65].

**Wounds Directly Communicating with Major Air Sacs (for direct gas application):** While some might consider nebulization, direct bagging with ozone gas over a wound that has a large, open communication to a major air sac or the parabronchial lung could risk direct ozone gas inhalation, which is highly contraindicated. This must be managed with extreme care and perhaps only with ozonated fluids [64].

**Cachexia/Extreme Debilitation:** While ozone can support healing, in a bird that is severely emaciated or extremely debilitated, the initial metabolic demands or transient "healing crisis" might be too much for their compromised system to handle [63]. Stabilization of the patient's general condition should always precede ozone therapy in such cases.

## Conclusion

Ozone therapy presents a compelling and multi-modal therapeutic approach for various conditions in avian patients, particularly in the challenging field of wound management. Its recognized antimicrobial, anti-inflammatory, immunomodulatory, and tissue regenerative properties offer a rational basis for its application, addressing key limitations of conventional therapies in birds, such as persistent infections, chronic inflammation, and compromised tissue healing. Anecdotal reports and small case series suggest promising outcomes in treating conditions like pododermatitis, traumatic wounds, and abscesses, where it may serve as a valuable adjunctive tool to accelerate healing and improve prognosis. However, despite its theoretical potential and observed benefits in individual cases, the integration of ozone therapy into mainstream avian veterinary practice remains significantly hampered by a profound lack of rigorous, peer-reviewed, avian-specific scientific evidence. The current body of knowledge is predominantly extrapolated from mammalian studies, with a critical dearth of controlled clinical trials, standardized species-specific dosing regimens, and comprehensive safety data tailored for the diverse avian population. This absence of robust data leads to variability in clinical application and makes it difficult to definitively assess efficacy and safety across species. Therefore, while ozone therapy offers a promising avenue for enhancing avian patient care, its widespread and evidence-based adoption hinges entirely on future research. There is an urgent need for meticulously designed prospective studies, randomized controlled trials, and detailed pharmacokinetic/pharmacodynamic investigations in various avian species. Such research is crucial to establish standardized protocols, define optimal concentrations and administration routes, confirm long-term efficacy, and thoroughly characterize potential side effects.

In conclusion, ozone therapy stands as an intriguing and potentially valuable adjunctive treatment in avian medicine, particularly for wound management. However, until comprehensive, species-specific scientific validation is achieved, its application should be approached with caution, based on sound physiological principles, and viewed as a complementary tool within a holistic and evidence-informed veterinary care plan for avian patients.

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