

PERSPECTIVE ARTICLE

Bridging two worlds: Infection-control lessons from the bidirectional exchange between veterinary and human orthopedic surgery

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Abstract

Orthopedic infection remains a critical challenge across species, directly compromising implant stability and fracture healing. While human orthopedic surgery is performed within highly controlled and technologically advanced environments, large-animal veterinary orthopedics routinely operates under conditions of elevated contamination, mechanical overload, and limited environmental control. This contrast transforms veterinary surgery into a natural stress test for infection-prevention strategies, exposing vulnerabilities that may remain concealed in optimized human operating rooms. Conversely, human orthopedics continues to drive innovations in implant surface engineering, local antimicrobial delivery, predictive modeling, and personalized prophylaxis that hold significant translational potential for veterinary practice. This perspective explores the lessons from bidirectional exchange between human and veterinary orthopedic surgery, emphasizing how comparative analysis of infection control, implant performance, and surgical environments can inform more resilient and context-adaptable strategies. By fostering intentional collaboration across disciplines, comparative orthopedics may emerge as a translational framework capable of advancing infection prevention and implant reliability in both human and veterinary medicine.

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1. Introduction

Orthopedic surgery across species shares a universal adversary: infection. Yet, the conditions under which this battle is fought could not be more different. While human orthopedic procedures unfold within highly controlled and technologically optimized surgical environments,¹ large-animal veterinary surgery is often performed under circumstances where microbial contamination is not a distant threat but an intrinsic characteristic of the setting.^{2,3} Dust, soil, bedding material, fecal debris, and the unpredictable behavior of the patient create a landscape where antisepsis protocols are continually stress-tested in ways that human medicine rarely encounters.⁴ Paradoxically, these challenges transform veterinary orthopedics into a natural laboratory for studying the real-world limitations of infection control, the stability of implants under biological and mechanical stress, and the interplay between microenvironment, host physiology,

and bacterial resilience.^{5,6}

This perspective article argues that meaningful translational benefits can emerge from a more explicit dialogue between human and veterinary orthopedic surgery. While human medicine provides advanced frameworks, ranging from implant coatings to precision prophylaxis, the veterinary field contributes insights from high-contamination, high-load contexts that reveal how techniques perform under extreme conditions. Understanding the reciprocal lessons available across these two fields offers an opportunity to refine both infection prevention and implant reliability. This article reflects a clinical and research perspective grounded in the daily realities of large-animal practice, proposing a future where comparative orthopedics becomes an intentional field of translational innovation.

2. Distinct surgical ecosystems: Contrasting human and veterinary realities

The main difference between human and veterinary orthopedic surgery lies in the operating environment. Human surgical facilities are designed to minimize microbial exposure through a combination of architectural planning, engineering controls, and strict procedural standardization. Positive-pressure ventilation, laminar airflow, controlled temperature and humidity, rigorous sterilization workflows, and continuous environmental monitoring collectively create a low-contamination ecosystem.⁷ Patient preparation follows highly refined protocols involving precise skin cleansing, hair removal strategies that eliminate microabrasions, antiseptic agents with proven residual activity, and a perioperative workflow governed by detailed checklists.⁸

In contrast, the veterinary large-animal environment presents challenges with few parallels in human orthopedics. Even modern hospital facilities face limitations inherent to treating animals weighing several hundred kilograms and presenting anatomical and behavioral constraints. Preoperative preparation must contend with thick skin, dense hair, complex microbial flora, and contamination from bedding and manure.⁴ Achieving optimal patient positioning may require mechanical assistance or compromise, increasing the risk of inadvertent contact between the surgical field and nonsterile surfaces.

Moreover, many surgical procedures, particularly those during emergencies, are performed in ambulatory or yard environments where controlling dust, airflow, humidity, or temperature is impossible. In these circumstances, even meticulous adherence to antiseptic protocols cannot replicate the barrier protection achievable in a human hospital. Rather than invalidating surgical attempts,

these conditions illuminate how antisepsis behaves under extreme microbial loads and how procedural robustness can compensate for environmental shortcomings.⁹ These contrasts underscore a key argument of this article: while human surgery operates under idealized conditions that may obscure the limits of infection prevention protocols, veterinary surgery exposes those limits, offering a critical lens through which both fields can refine their understanding of contamination risk.

3. Veterinary challenges as stress tests for human infection paradigms

Because large-animal orthopedic surgery unfolds in settings that frequently resemble worst-case scenarios, it offers insights into the vulnerabilities of conventional infection-control strategies. Human protocols for antisepsis and implant protection have been validated through clinical trials conducted in controlled hospital environments. However, real-world disasters, humanitarian crises, military trauma, and mass-casualty scenarios demonstrate that human orthopedic surgeons also encounter situations where contamination, instability, and resource limitations overcome.^{10,11} Veterinary experience provides a continuous source of practical data for such contexts. Several elements of large-animal surgery highlight this translational potential:

- (i) Variable and elevated microbial loads: Organic matter, soil particles, fecal contamination, and moisture create a microenvironment optimal for bacterial proliferation, including resistant and opportunistic species. The inability to eliminate these factors during preparation exposes the limits of antiseptic agents, particularly regarding residual efficacy and penetration through keratinized tissue.
- (ii) Procedural adaptations under suboptimal sterility: Veterinarians routinely develop strategies to maintain sterility despite environmental constraints, including redundant scrubbing, integrated mechanical barriers, strategic draping adapted to irregular surfaces, and rapid intraoperative contamination-response protocols. These pragmatic approaches may be valuable in human trauma surgery conducted outside operating theaters.
- (iii) The impact of time and efficiency: In contaminated environments, surgical duration correlates more strongly with infection risk. Veterinary surgeons thus emphasize operational efficiency and streamlined workflows that could inform human approaches in rigorous settings,

where minimizing exposure time is critical.

- (iv) Host behavior and movement: Large animals may shift weight, twitch, or respond to stimuli under sedation or anesthesia, increasing the chance of drape displacement or accidental field contamination. This reality mirrors human scenarios involving unstable or uncooperative patients, but veterinary strategies to manage such unpredictability remain underexamined translationally.

By understanding how orthopedic procedures succeed despite these constraints, human medicine gains access to empirical insights on the resilience and adaptability of infection-control practices.

4. Implant failure: A common language across species

Regardless of species, orthopedic implants share a central vulnerability: infection dramatically increases the likelihood of mechanical failure. Biofilm formation on implant surfaces represents the critical turning point where infection becomes chronic, reducing host bone-implant integration, impairing healing, and ultimately destabilizing the construct.^{12,13} Although the underlying biology is conserved, the contextual pressures differ significantly between humans and large animals.

In horses and cattle, implants must withstand exceptionally high loads from the outset. Even minor postoperative contamination can escalate into deep infection under these forces, accelerating implant loosening or plate breakage. Additionally, because these animals cannot meaningfully adhere to postoperative restrictions, early micromotion around the implant site compounds the challenge.¹⁴ When infection disrupts bone healing, the combination of mechanical overload and biological compromise results in construct failure far faster than typically observed in humans.¹⁵

Such conditions provide a high-intensity model for studying the interplay between bacterial colonization, mechanical load, and implant fatigue. For human orthopedics, this model has particular relevance to high-energy trauma, combat-related injuries, and cases where early mobilization is unavoidable.¹⁶ Veterinary cases also illuminate the importance of immediate mechanical stability, as even transient instability in the presence of bacteria can tip the balance toward biofilm formation. These convergent challenges highlight an underexplored opportunity: implant failure patterns in large animals may enable predictive modeling of infection-related mechanical failure in humans.

5. What human orthopedics can learn from veterinary surgery

While human orthopedics benefit from highly standardized operating rooms and advanced technological support, veterinary surgery, particularly in large animals, operates under inherently variable, and often suboptimal, conditions. This reality has fostered a pragmatic body of experiential knowledge that may be highly relevant to human orthopedic practice, especially in unpredictable or resource-limited settings.

First, veterinary surgeons frequently adopt redundant antiseptic measures that exceed standard human protocols, including prolonged scrubbing, aggressive mechanical decontamination, and layered field preparation. Rather than representing excessive caution, these practices function as compensatory strategies for environmental variability and may offer valuable contingency models for field hospitals, disaster medicine, and trauma care performed outside conventional operating rooms.¹⁷

Second, large-animal orthopedics emphasizes procedural efficiency as a core infection-control strategy. The implicit understanding that each additional minute in a contaminated or semi-controlled environment increases infectious risk has shaped surgical workflows that prioritize decisiveness without compromising technical rigor.^{2,9} This mindset may inform human trauma and emergency surgery, where time-dependent contamination risk is often underestimated.

Third, veterinary surgery has driven the development of adaptive draping and field isolation techniques tailored to irregular anatomy, challenging positioning, and unpredictable patient movement. These solutions, born from necessity rather than protocol, may provide practical insights into managing complex human trauma cases, particularly in austere or prehospital environments.

Fourth, antibiotic prophylaxis in veterinary orthopedics is frequently guided by pragmatic considerations, including limited opportunities for close postoperative monitoring or immediate revision surgery.¹⁸ While not directly transferable, this approach highlights a risk-based framework for antibiotic decision-making that may be relevant in human settings where follow-up is uncertain or access to care is constrained.

Finally, veterinary implant selection prioritizes maximal mechanical robustness under high load and contamination risk, reflecting the realities of early uncontrolled weight-bearing and limited compliance.¹⁴ These considerations parallel emerging challenges in human orthopedics, particularly in trauma, geriatric populations, and

accelerated rehabilitation protocols.

Taken together, veterinary orthopedics routinely operates at the margins of what current infection-control paradigms can tolerate. As such, it offers a unique “stress-test” perspective that may help human orthopedics identify vulnerabilities in existing protocols and inspire more resilient, context-adaptable surgical strategies.

6. What veterinary orthopedics can learn from human medicine

While veterinary orthopedics offers unparalleled exposure to real-world contamination and extreme mechanical loading, human orthopedic surgery has driven technological innovations with clear translational potential for large-animal practice. Selective and context-aware adoption of these advances may substantially improve infection control and implant performance in veterinary patients.

One major contribution lies in implant surface engineering and anti-biofilm technologies. Human orthopedic research has advanced from silver-impregnated materials to antimicrobial peptides, nanostructured surfaces, and bioactive coatings designed to interfere with bacterial adhesion^{19–21}. Translating these technologies to veterinary implants could reduce infection rates and extend construct longevity, particularly in high-risk cases.

Another area of relevance is local antimicrobial delivery systems. Biodegradable carriers capable of releasing antibiotics directly at the implant–tissue interface offer a targeted strategy to overcome limitations of systemic antimicrobial administration in large animals, where dosage, handling, and welfare constraints often restrict therapeutic flexibility.^{21,22}

Human orthopedics has also moved toward personalized prophylactic strategies, integrating patient-specific risk factors, such as comorbidities, microbial exposure, and procedure-related variables.²³ Developing analogous, species-adapted risk stratification frameworks in veterinary medicine could optimize antibiotic selection and duration while contributing to antimicrobial stewardship.

Advances in operating room technologies represent an additional opportunity for translational gain. Portable laminar airflow units, adjunctive ultraviolet disinfection systems, and improved preoperative skin preparation protocols, originally designed for human surgical environments,⁷ may enhance sterility even in the veterinary field or semi-controlled surgical settings.

Finally, predictive modeling and artificial intelligence have become increasingly influential in human orthopedics for anticipating infection, implant failure, and postoperative complications.²³ Veterinary datasets, particularly in equine sports medicine, offer high-resolution biomechanical and outcome data that could both benefit from and enrich cross-species predictive models.

7. A future for comparative and translational infection research

The interface between human and veterinary orthopedics remains surprisingly underdeveloped. Nevertheless, a coordinated and intentional dialogue between these fields could give rise to a distinct translational discipline, one grounded in shared biological mechanisms of infection and healing, while explicitly accounting for divergent environmental, mechanical, and logistical constraints.

Several strategic directions could catalyze this evolution. Joint registries of implant-related complications and failures would enable cross-species pattern recognition, identifying failure modes that emerge only under extreme mechanical loading or high contamination pressure. Comparative evaluation of novel coatings, biomaterials, and local antimicrobial strategies could leverage large-animal models as biologically relevant, high-stress test systems that bridge the gap between laboratory research and human clinical application.

Similarly important is the development of integrated research networks that combine clinical expertise with biomechanics, microbiology, and materials science across both disciplines. Such networks would provide the foundation for machine learning models trained on multispecies datasets, capable of predicting infection risk under varying contamination loads, surgical environments, and postoperative constraints. In human orthopedics, large-scale registry studies, such as national analyses of fixation trends in hip arthroplasty,²⁴ illustrate the power of population-based data to generate clinically actionable insights, while also highlighting the distinct evidentiary frameworks that would need to be aligned for true human–veterinary translational modeling.

Finally, the co-development of context-adaptable infection-control guidelines, applicable to low-resource, field-based, or high-contamination settings, represents a tangible and immediately relevant outcome of this collaboration. By formalizing and institutionalizing this bidirectional exchange, human and veterinary orthopedics may move beyond parallel innovation toward genuinely shared advances, achieving breakthroughs in infection

control that neither field is likely to accomplish in isolation.

8. Ethical, regulatory, and economic issues

The bidirectional translational exchange proposed here also faces ethical, regulatory, and economic limitations that merit explicit attention. Cross-species translation of surgical practices and implant technologies is subject to differing ethical frameworks for animal research, including requirements for justification of animal use, welfare oversight, and minimization of injury, which are more strict in some jurisdictions than in others.^{25,26} In addition, regulatory pathways for medical devices and biomaterials differ markedly between human and veterinary applications, with human implants typically requiring comprehensive clinical evidence and conformity with international standards.^{27,28} In contrast, veterinary devices may follow less rigorous approval processes depending on the country and species.²⁹ These differences can impede direct technology transfer and complicate collaborative research unless harmonized guidance and mutual recognition policies are developed. Moreover, the economic realities of healthcare systems and veterinary practice, including reimbursement structures, market size, and cost-benefit thresholds (mainly in large animals), influence the feasibility of adopting innovations cross-contextually. Acknowledging these barriers is essential to realistically frame the translational potential of comparative infection-control strategies and to identify pathways for aligning ethical and regulatory frameworks in both fields.

9. Conclusion

Despite operating under dramatically different conditions, human and veterinary orthopedic surgery confront the same fundamental threat: infection and its capacity to undermine implant stability and fracture healing. Veterinary surgery, particularly in large animals, exposes the limits of antisepsis by functioning within inherently contaminated and unpredictable environments, revealing vulnerabilities that may remain hidden in human operating rooms. Conversely, human orthopedics continues to drive technological innovation that could meaningfully elevate infection control and implant performance in veterinary medicine.

Bridging these fields through intentional translational collaboration offers a path toward more resilient antiseptic protocols, more effective implant designs, and a deeper understanding of how contamination and mechanical stress shape surgical outcomes. In practical terms, this collaboration could begin through the formation of joint human–veterinary working groups, the development of shared registries of implant-related infections and failures,

and the design of comparative translational studies that leverage both controlled clinical environments and high-contamination, high-load veterinary settings. By operationalizing this bidirectional exchange, comparative orthopedics has the potential to move beyond parallel innovation toward genuinely shared advances, improving patient welfare and surgical success across species.

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Conflict of interest

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