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Minimally Invasive Veterinary Surgery Across Companion and Large-Animal Practice: A Scoping Review of Procedural Innovation, Patient Selection, Perioperative Outcomes, Complications, Training Requirements, and Clinical Translation, 2017–2025

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ABSTRACT

To map contemporary minimally invasive veterinary surgery across companion- and large-animal practice and examine how procedural innovation, patient selection, perioperative outcomes, complications, operator training, and evidence maturity constrain clinical interpretation. Peer-reviewed veterinary literature published from 2017 through 2025 was evaluated using a PRISMA-ScR-compatible approach. Evidence was charted by species, surgical specialty, procedural configuration, comparator structure, patient-selection features, perioperative outcomes, complications or conversion, training requirements, and degree of clinical evidential maturity. Laparoscopic, thoracoscopic, arthroscopic, endoscopic, image-guided, hybrid, and emerging minimally invasive procedures were retained as analytically distinct categories where their access routes, decision requirements, or failure modes differed. Selection-flow quantities that were not reproducibly available were not reconstructed. The mapped literature showed marked heterogeneity in procedure type and evidential maturity. Comparative clinical cohorts coexist with single-center case series, rare-indication reports, experimental instrumentation studies, and simulation-based training research. Companion-animal evidence spans multiple specialties, whereas large-animal evidence includes clinically substantive equine arthroscopy and laparoscopy and production-animal applications. Reported perioperative advantages cannot be separated consistently from patient selection, anesthetic management, operator experience, or procedure-specific factors. Training studies demonstrate acquisition of technical skills but provide more limited evidence regarding transfer to independent clinical performance. Veterinary minimally invasive surgery is best interpreted as a heterogeneous procedural field rather than a single intervention class. A proposed evidence-maturity and translation architecture separates technical feasibility, comparative clinical evidence, patient-selection boundaries, perioperative management, operator capability, and external transferability. Major limitations include uneven comparative evidence, small clinical series, rare-event uncertainty, and incomplete validation across species, procedures, and settings.

Keywords: Laparoscopy, Thoracoscopy, Arthroscopy, Veterinary endoscopy, Minimally invasive surgery, Surgical training

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Introduction

Minimally invasive veterinary practice now encompasses endoscopic, image-guided, laparoscopic, thoracoscopic, and related interventions, yet procedural expansion has outpaced the maturity of evidence supporting many applications [1]. Thoracoscopy illustrates this transition: contemporary clinical indications are well described, but suitability and expected benefit remain procedure- and case-dependent rather than intrinsic to minimally invasive access itself [2]. Large-animal evidence further prevents the field from being interpreted solely through small-animal surgery. Equine arthroscopy includes large clinical cohorts in which patient and lesion characteristics materially shape findings [3], while bovine laparoscopy has been evaluated against an open surgical alternative using production-relevant recovery outcomes [4]. This review therefore separates procedural innovation from evidence maturity, patient suitability, perioperative consequence, technical capability, and clinical translation.

Rationale for evidence mapping

A conventional aggregate judgment of whether minimally invasive surgery is "better" obscures substantial variation in procedure, species, clinical purpose, comparator quality, and evidence design. Existing veterinary interventional literature demonstrates both expanding procedural breadth and persistent concentration in lower-level evidence [1]. Scoping-review methodology is therefore appropriate for identifying concepts, evidence concentrations, and gaps when heterogeneous questions cannot be reduced meaningfully to one pooled effect [6]. The present mapping consequently treats technical feasibility, comparative outcome evidence, training validation, complication detection, and translational readiness as separate evidential problems. This approach does not assume that weaker designs are clinically uninformative; rather, it limits the claims that each design can support.

Review objectives and questions

The review aimed to characterize minimally invasive veterinary surgery across companion- and large-animal practice from 2017 through 2025. The principal questions were: which species and surgical specialties are represented; which laparoscopic, thoracoscopic, arthroscopic, endoscopic, image-guided, and hybrid procedures are described; how are patients selected; which perioperative outcomes, complications, and conversions are reported; and what evidence supports training or skill acquisition? A further objective was to distinguish technical innovation from clinical evidential maturity. The synthesis therefore asked not simply whether a procedure had been performed, but what type of inference its evidence permitted, which contextual boundaries constrained that inference, and what additional validation would be required for broader translation.

Materials and Methods

The review was structured using the PRISMA extension for scoping reviews, which provides reporting guidance for transparent identification, selection, and synthesis of scoping evidence [5]. Conduct principles were additionally aligned with updated methodological guidance emphasizing correspondence between review questions, eligibility criteria, data charting, and synthesis strategy [6]. Reporting of study identification and exclusion followed the broader transparency principles of PRISMA 2020 where applicable [7].
Evidence was charted descriptively rather than pooled across dissimilar procedures. The unit of interpretation remained the individual publication and its directly reported species, procedure, comparator, outcome, training construct, or methodological contribution. Missing design or outcome details were not inferred. Search and selection quantities that were not reproducibly captured were not estimated or reverse-engineered from the final bibliography.

Protocol and PRISMA-ScR approach

The review used a PRISMA-ScR-compatible structure to preserve transparency between identification, eligibility, charting, and synthesis [5]. Scoping methodology was selected because the article addresses breadth, procedural configuration, evidence maturity, and translational gaps rather than one narrowly defined intervention-effect question [6]. The flow-accounting principle was conservative: only reproducibly documented selection information could be represented numerically. Consequently, unavailable retrieval, deduplication, screening, or full-text quantities were retained as unavailable rather than reconstructed. This protects the distinction between the literature used to support the review and the numerical evidence units that would be required for a fully auditable selection-flow estimate.

Eligibility criteria

Eligible evidence comprised peer-reviewed veterinary publications within the prespecified period that directly informed minimally invasive procedural practice, patient selection, perioperative management, complications, training, evidence maturity, or review methodology. Scoping-review guidance informed alignment between these eligibility concepts and subsequent charting fields [6]. Clinical studies, comparative cohorts, case series, technically informative rare reports, training studies, experimental procedural research, and relevant evidence syntheses could therefore contribute different forms of information. Inclusion did not imply equal evidential weight. Sources lacking sufficient species, procedure, context, or outcome information for a bounded claim were unsuitable for substantive synthesis, and findings were not transferred beyond the population, technique, or setting actually represented.

Information Sources

Search coverage was designed to capture terminology that differs by species, specialty, and technical modality. Equine literature, for example, uses procedure- and organ-specific laparoscopic terminology that would be incompletely recovered by a single generic minimally invasive surgery phrase [8]. Contemporary interventional oncology similarly demonstrates that image-guided veterinary procedures extend beyond conventional surgical indexing [9]. Emerging robotic surgery adds a further technology domain whose translational relevance may precede mature comparative outcome evidence [10]. Information-source planning therefore incorporated surgical, interventional, endoscopic, imaging, specialty, and training concepts rather than treating “minimally invasive surgery” as a self-sufficient retrieval term.

Search strategy

Search concepts combined veterinary species terms with procedure families, including laparoscopy, thoracoscopy, arthroscopy, endoscopy, image-guided intervention, hybrid procedures, and emerging minimally invasive technologies. Methodological guidance supported an intentionally broad scoping strategy, while specialty-specific literature informed vocabulary expansion [6]. Equine laparoscopic terminology was retained separately because organ-system and procedural phrasing can determine retrieval [8]. Interventional and robotic terminology was likewise retained to prevent newer modalities from disappearing behind conventional surgical labels [9].
The central interpretive problem is that search breadth alters the apparent evidence landscape. **Table 1** presents search expansions required to recover distinct minimally invasive procedure families and species contexts.

Table 1. Search expansions required to recover distinct minimally invasive procedure families and species contexts

Search layer	Literature exposed by the expansion	Why the expansion is needed	Post-retrieval classification rule	Residual retrieval bias	Sensitivity check
Generic MIS terminology only	**Retrieved:** Conventional surgery dominates **Meaning:** Narrow procedural field	Species vocabulary varies	Expand terminology	Specialty undercapture	Recheck omitted modalities
Procedure-family expansion	**Retrieved:** Laparoscopy/endoscopy separated **Meaning:** Broader technical coverage	Access routes differ	Preserve procedure classes	Terminology overlap	Reclassify hybrids
Species-context expansion	**Retrieved:** Large-animal records emerge **Meaning:** Cross-species visibility	Companion, equine, production contexts	Keep species boundaries	Unequal publication density	Avoid frequency inference
Interventional/emerging expansion	**Retrieved:** Image-guided/robotic records appear **Meaning:** Captures nontraditional MIS	Imaging and technology dependent	Map maturity separately	Sparse comparative evidence	Reassess translation claims

Screening and study selection

Screening was designed to determine whether each record supported a directly chartable veterinary minimally invasive procedure, methodological decision, training construct, outcome, complication, or evidence-boundary claim. PRISMA-ScR reporting principles require transparent separation of selection stages [5], while PRISMA 2020 reinforces explicit accounting of exclusions when such quantities are reproducibly available [7]. Duplicate article versions were not treated as independent evidence. Importantly, bibliographic inclusion and review-flow enumeration were kept conceptually separate: the presence of an article in the evidential corpus does not itself establish a reproducible screening denominator. Numerical selection quantities were therefore not introduced where the underlying retrieval or screening records did not permit exact reconstruction.

Data charting

Data charting preserved the dimensions needed to prevent apparently similar procedures from being interpreted as equivalent. Consistent with scoping-review methodological guidance, extraction fields were aligned with the review questions rather than imposed as a post hoc summary template [6]. Charted dimensions included species or population, clinical setting, procedure and access configuration, comparator where present, patient-selection information, measured outcomes, complications or conversion, training or simulation design, and methodological limitations. Evidence type and transferability were recorded separately. Unreported information remained unreported. This structure permitted technically successful procedures, comparative clinical evidence, experimental instrumentation studies, and educational validation studies to occupy distinct evidential positions rather than being combined into a single undifferentiated category.

Procedural classification

The procedural map distinguished access route from the additional technology required to complete the intervention. Hybrid gastrointestinal procedures combining surgical access and endoscopic retrieval demonstrate why an open-versus-laparoscopic dichotomy is insufficient [11]. Biportal spinal endoscopy represents another configuration in which endoscopic access constitutes the principal operative architecture but current evidence remains primarily feasibility oriented [12]. Laparoscopic portosystemic-shunt treatment incorporating portal-pressure measurement and angiography illustrates a third category in which minimally invasive surgery is integrated with physiologic and imaging information used during operative decision making [13]. Accordingly, the proposed classification separates pure minimally invasive access, endoscopic or image-guided intervention, and multimodal hybrid procedures while retaining procedure-specific boundaries.

Evidence-maturity classification

Evidence maturity was interpreted multidimensionally rather than through study-design labels alone. Veterinary interventional literature demonstrates that procedural growth may coexist with low-level evidence [1], while scoping methodology cautions against erasing heterogeneity during synthesis [6]. A technically successful small series can establish feasibility but cannot supply the same inference as a comparative clinical cohort. The biportal spinal series, for example, supports reported short-term feasibility within its selected canine population but not comparative superiority or broad safety equivalence [12]. The proposed maturity classification therefore considers study design, comparator structure, sample breadth, validation, clinical outcome relevance, and transferability together. Evidence maturity is thus a boundary on permissible interpretation, not a numerical score or declaration of procedural worth.

Results and Discussion

The mapped evidence formed several analytically distinct states rather than one uniform body of “minimally invasive surgery” research. Comparative clinical studies permit bounded evaluation of selected perioperative or procedural outcomes, whereas uncontrolled series chiefly establish feasibility within selected patients. Rare case reports extend knowledge of procedural possibility or failure but cannot estimate incidence. Experimental and simulation studies address technical mechanisms or skill acquisition while remaining separated from patient-level clinical validation.

These states require different responses when evidence is interpreted clinically. **Table 2** presents claims supported by comparative studies, case series, rare cases, and training experiments.

Table 2. Claims supported by comparative studies, case series, rare cases, and training experiments

Study-design question	Comparative clinical evidence	Single-arm clinical series	Rare-case evidence	Experimental/training evidence
Clinical meaning	Outcome contrast possible	Feasibility supported	Possibility identified	Mechanism or skill signal

Selection or fidelity determinant	Case selection	Referral/operator selection	Unusual indication/event	Model fidelity
Empirical unit retrieved	Defined comparator	Procedure completed in cohort	Individual technical course	Technical performance measure
Claim permitted	Interpret bounded difference	Limit benefit claims	Do not estimate frequency	Separate from clinical competence
Claim withheld	Residual confounding	No counterfactual	Extreme imprecision	Transfer uncertain
Evidence expansion needed	Replicate across settings	Seek comparative data	Accumulate surveillance	Validate in patients/operators

Study-selection flow

The retained literature included clearly classifiable clinical procedural reports such as canine laparoscopic cholecystectomy cohorts [14], highly specialized hybrid interventions such as percutaneous-endoscopic biliary stenting [15], and thoracoscopic cohorts using distinct minimally invasive access configurations [16]. These examples illustrate why eligibility was determined by extractable procedural and evidential relevance rather than by study design alone. A rare case could inform procedural breadth while remaining low maturity for effectiveness claims; a larger cohort could support more extensive feasibility or complication interpretation without automatically providing causal evidence.

Because exact upstream retrieval and screening quantities were not reproducibly available, the selection figure preserves that reporting boundary rather than replacing absent values with reconstructed counts **(Figure 1)**.

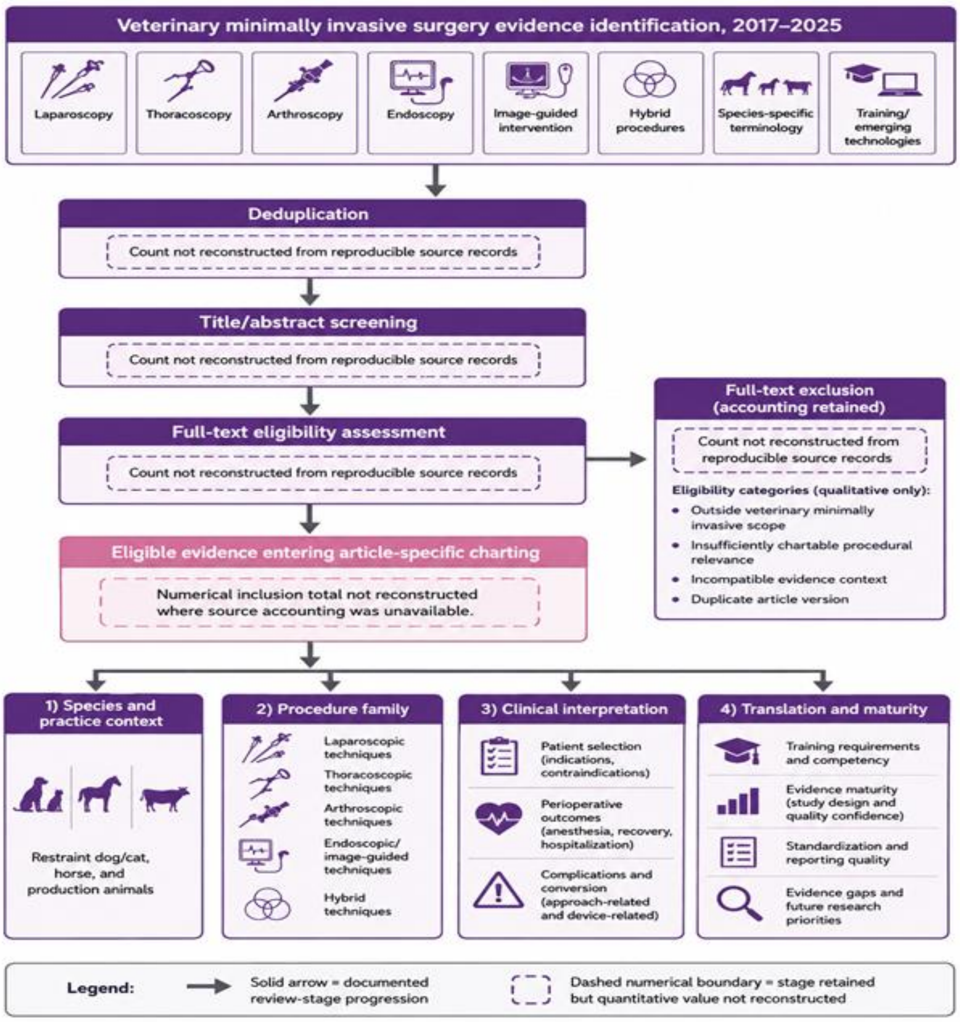

Figure 1. Auditable Selection Boundaries for Veterinary Minimally Invasive Surgery Evidence

PRISMA-ScR-compatible selection architecture for the 2017–2025 evidence map. Identification, deduplication, screening, eligibility assessment, exclusion, and inclusion remain structurally separated. Where numerical values were not reproducibly documented, the corresponding stage is explicitly marked “count not reconstructed.” Final eligible evidence proceeds to species, procedure, outcome, complication, training, and maturity charting. No unavailable selection quantity is inferred.

Top-to-bottom review-selection flow beginning with multi-domain veterinary literature identification, followed by deduplication, title/abstract screening, full-text eligibility assessment, exclusion handling, and final evidence charting. Numerical fields that cannot be verified are visibly marked as not reconstructed. The final branch divides charting into species context, minimally invasive procedure family, clinical outcomes and complications, and training/evidence-maturity domains.

Species distribution

The evidence base spans clinically different species contexts that should not be collapsed into a single veterinary population. Companion-animal studies predominate across many contemporary minimally invasive procedural examples, but substantive large-animal evidence is also represented. Equine arthroscopy includes large patient-level cohorts in which age, lameness, and lesion location can be examined in relation to cartilage injury [3]. Production-animal laparoscopy has likewise been studied in dairy cattle using a direct open-surgery comparator and a production-relevant recovery outcome [4]. These studies establish cross-species procedural breadth, not cross-species equivalence. Differences in anatomy, operative objectives, husbandry, economics, postoperative monitoring, and acceptable outcome definitions require species and practice setting to remain explicit boundaries throughout interpretation.

Surgical-specialty distribution

The mapped literature crosses surgical specialties whose technical objectives and outcome definitions are not interchangeable. Thoracic minimally invasive surgery emphasizes access, visualization, conversion, and cardiopulmonary management [2]. Equine arthroscopy addresses joint pathology and lesion-associated tissue injury within a fundamentally different biomechanical and performance context [3]. Hepatobiliary and vascular laparoscopy may incorporate intraoperative physiologic or imaging information that directly influences procedural decisions [13]. Gastrointestinal, reproductive, neurologic, oncologic, and interventional procedures add further configurations. Specialty distribution should therefore be interpreted as evidence heterogeneity rather than simply procedural variety. Publication density within one specialty cannot establish greater clinical utility, maturity, or transferability than a less frequently represented specialty.

Laparoscopic procedures

Comparative laparoscopic evidence illustrates why technical access, perioperative recovery, and disease-specific outcomes require separate interpretation. In dogs undergoing adrenalectomy, laparoscopic cases had shorter hospitalization, whereas survival and recurrence did not differ significantly; nonrandom allocation limits causal attribution [17]. Selected dogs with insulinoma have undergone laparoscopic partial pancreatectomy, supporting feasibility but not population-wide suitability [18]. Feline laparoscopic-assisted ovariohysterectomy has also been compared with open surgery using postoperative pain and stress measures, demonstrating that recovery outcomes remain species- and protocol-dependent [19]. Comparative canine ovariectomy data further show that complication assessment constitutes a distinct endpoint from pain or technical feasibility [20]. Collectively, laparoscopy cannot be treated as a single exposure with one expected clinical effect.

Thoracoscopic procedures

Thoracoscopy occupies a comparatively mature technical position within small-animal minimally invasive surgery, but evidence remains indication- and configuration-specific. Contemporary reviews describe applications ranging from diagnostic exploration to therapeutic thoracic procedures while emphasizing case selection and operative planning [2]. Single-incision subxiphoid video-assisted thoracoscopic surgery demonstrates how access configuration itself can become an object of procedural innovation [16]. Such series provide clinically useful feasibility and complication information but cannot determine whether a novel access route is superior to conventional multiport thoracoscopy or thoracotomy. Interpretation should therefore retain indication, access architecture, conversion possibility, operator experience, and cardiopulmonary constraints instead of assigning thoracoscopy an undifferentiated benefit profile.

Arthroscopic procedures

Equine arthroscopy demonstrates a different evidential pattern from many small-animal minimally invasive procedures. Large clinical cohorts permit analysis of patient- and lesion-level variables rather than merely documenting technical feasibility. In metacarpo-/metatarsophalangeal joints containing osteochondral fragments, cartilage injury was associated with age, lameness, and fragment location, while fragment size was not associated with the same outcome [3]. These findings support clinically relevant stratification within the studied population but do not establish that intervention timing causally prevents later cartilage injury. Arthroscopic interpretation must also separate patient-level clinical evidence from instrument-level or ex vivo experimentation. This boundary is particularly important when technical settings appear precise but their relationship to live-horse outcomes remains uncertain.

Table 3 presents arthroscopic evidence units and the level of patient inference they support.

Table 3. Arthroscopic evidence units and the level of patient inference they support

Arthroscopic evidence unit	Patient population or technical substrate	Clinical question answered	Use in synthesis	Transfer limit	Replication needed
Large clinical joint cohort	**Setting:** Age, lameness, lesion location **Observed:** Charted arthroscopic findings	Patient-level associations estimable	Inform bounded case interpretation	Observational confounding	Validate prospectively
Lesion-specific subgroup	**Setting:** Joint and fragment context **Observed:** Differential cartilage injury	Heterogeneity becomes visible	Avoid pooled generalization	Subgroup instability	Replicate across populations
Instrument/tissue experiment	**Setting:** Device and operating setting **Observed:** Ex vivo tissue response	Technical mechanism examined	Inform technical hypothesis	Live-patient transfer uncertain	Clinical validation required
Rare procedural application	**Setting:** Indication and operator expertise **Observed:** Successful technical execution	Feasibility documented	Restrict inference to possibility	Incidence/outcome precision absent	Accumulate comparative evidence

Endoscopic and image-guided procedures

Endoscopic innovation commonly enters practice through small technical series. Magnet-assisted gastric foreign-body retrieval was reported in four dogs, supporting technical possibility rather than comparative effectiveness [21]. Endoscopic treatment of canine proximal duodenal ulceration combines anatomical evidence with a small clinical treatment series, illustrating how mechanistic rationale and clinical outcome evidence can coexist at different maturities [22]. Ultrasound-guided foreign-body removal in dogs and cats similarly demonstrates image-dependent minimally invasive access without establishing comparative superiority [23]. By contrast, laparotomy-assisted orogastric retrieval has been compared with gastrotomy; short-term outcomes were broadly similar while gastrotomy required greater operative time in that cohort [24]. These modalities should therefore remain distinct because imaging dependency, access, rescue options, and failure modes differ.

Patient selection

Patient selection is not merely a prerequisite to minimally invasive surgery; it can determine the apparent feasibility and outcomes reported by the literature. Laparoscopic treatment of congenital portosystemic shunts integrates portal-pressure measurement and angiography into intraoperative decision making [13]. Comparative adrenalectomy evidence is vulnerable to differences in case complexity between laparoscopic and open groups [17], while pancreatic laparoscopy has been described in deliberately selected insulinoma cases [18]. The synthesis therefore proposes three separable selection dimensions: anatomical and technical feasibility, disease-specific appropriateness, and physiological/perioperative tolerance. These dimensions should not be collapsed into a single candidacy label, because a patient may satisfy one while remaining uncertain or unsuitable on another.

Perioperative outcomes

Perioperative outcomes should be interpreted as multiple domains rather than a composite concept of “faster recovery.” Comparative adrenalectomy evidence suggests that hospitalization may differ without a corresponding detectable difference in long-term survival or recurrence [17]. Feline reproductive surgery studies additionally demonstrate that postoperative pain and stress can be measured independently from technical success [19]. Outcomes such as nausea, analgesic requirements, respiratory physiology, hemorrhagic risk, discharge timing, and complications may each respond to different surgical, anesthetic, and patient factors. Consequently, apparent benefits associated with minimally invasive access should not automatically be attributed to incision size or operative approach when perioperative protocols, case selection, and outcome instruments also differ.

Complications and conversion

Complication evidence requires explicit separation of probability from possibility. Comparative clinical cohorts can estimate observed complication frequency within their study populations, as illustrated by open versus laparoscopic ovariectomy comparisons [20]. Hybrid gastrointestinal studies can similarly provide short-term comparative complication data within selected cases [24]. However, small case series that report no complications cannot exclude uncommon serious events, and conversion to an open procedure should not automatically be treated as procedural failure when conversion constitutes an appropriate rescue strategy. The proposed interpretation therefore distinguishes routine complications, rare catastrophic events, technical conversion, and incomplete therapeutic success. Their denominators, clinical meanings, and evidential requirements differ and should not be merged into one generic safety endpoint.

Learning curves and training requirements

Simulation studies provide direct evidence that minimally invasive technical skills can be trained outside the operating room. Non-experts have demonstrated acquisition of laparoscopic ovariectomy skills using a veterinary simulator [25], and advanced canine laparoscopic simulators have undergone development and validation for procedural training [26]. A systematic review of veterinary simulation-based clinical-skills education nevertheless shows that educational evidence varies substantially in design and validation depth [27]. Endoscopic training also requires modality-specific tasks; a rigid rhinoscopy model illustrates the procedural specificity of simulation design [28]. These findings support technical skill acquisition but do not establish independent operative competence or improved patient outcomes. Training maturity must therefore include transfer beyond the simulator.

Table 4 presents training environments and transfer gates from simulator exposure to independent minimally invasive practice.

Table 4. Training environments and transfer gates from simulator exposure to independent minimally invasive practice

Progression	**Learning conditions**		**Transfer to responsibility**		
Progression stage	**Training environment**	**Performance proof**	**Responsibility change**	**Transfer uncertainty**	**Next gate**
Initial simulator exposure	**Requirement:** Basic task familiarization **Learner/system:** Prior surgical experience	Task completion	Continue deliberate practice	Novelty effect	Repeat across sessions
Demonstrated simulator improvement	**Requirement:** Structured repeated training **Learner/system:** Simulator fidelity	Improved technical metrics	Progress training complexity	Clinical transfer unknown	Test retention/transfer
Procedure-specific model proficiency	**Requirement:** Modality-specific simulation **Learner/system:** Laparoscopic vs endoscopic task demands	Stable model performance	Consider supervised clinical progression	Predictive validity uncertain	Assess live-case performance
Supervised clinical performance	**Requirement:** Case selection and expert oversight **Learner/system:** Patient complexity, mentor availability	Real-patient procedural performance	Gradual responsibility	Case-mix dependence	Multicase competency review

Independent practice readiness	**Requirement:** Validated competence evidence **Learner/system:** Institutional credentialing	Consistent clinical performance	Credential only if locally justified	Universal threshold absent	Continued outcomes monitoring

Evidence gaps

Several gaps recur across procedure families. Veterinary interventional evidence has expanded despite persistent concentration in comparatively low-level designs [1]. Simulation scholarship identifies limitations in validation and transfer from educational performance to clinical practice [27], while emerging robotic surgery illustrates how technological capability can precede comparative veterinary outcomes [10]. Other unresolved domains include multicenter replication, rare-complication surveillance, standardized outcome definitions, conversion reporting, large-animal representation, and separation of operator effects from procedure effects.

These gaps are better represented as interacting translational boundaries than as a list of missing studies. **Figure 2** therefore maps how evidence maturity, patient selection, perioperative context, and operator capability jointly constrain the movement from technical innovation to defensible clinical interpretation.

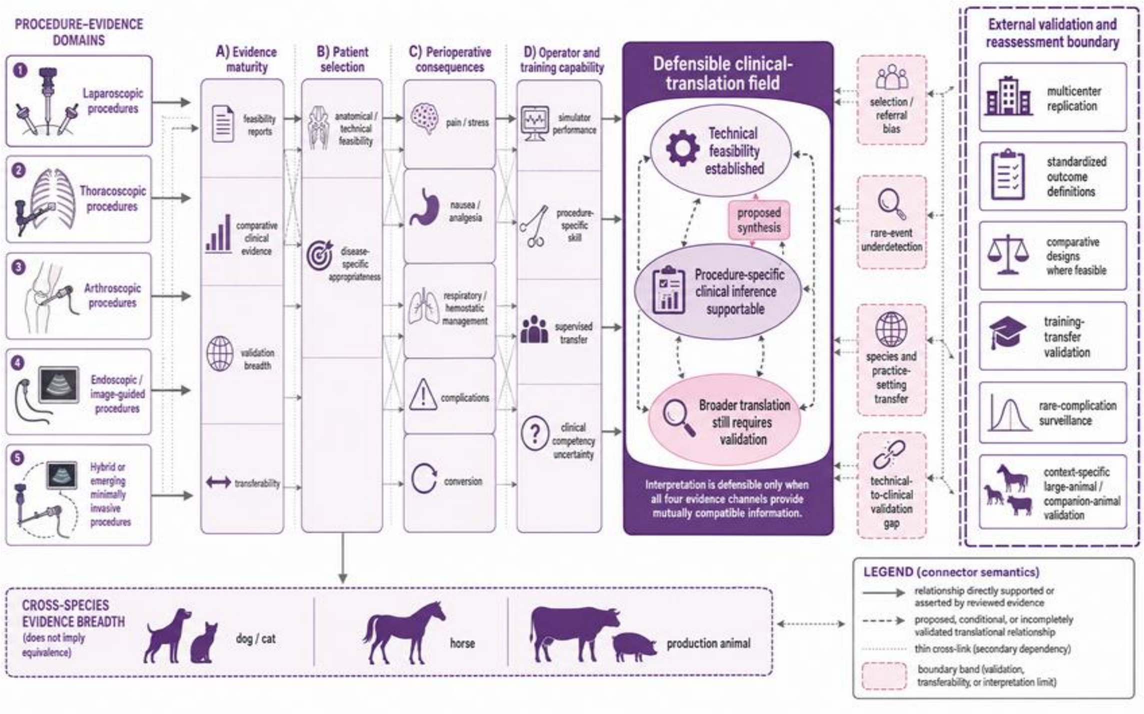

Figure 2. Evidence Bottlenecks Governing Clinical Translation of Veterinary Minimally Invasive Procedures

Layered synthesis of the principal evidence gaps identified across veterinary minimally invasive surgery. Evidence-supported domains include procedural evidence, patient-selection information, perioperative outcomes, complications, and training research. Dashed relationships denote the proposed synthesis that clinical translation requires concordance across evidence maturity, patient suitability, perioperative manageability, and operator capability. The external validation boundary indicates that technical feasibility alone does not establish comparative benefit, safety generalizability, or implementation readiness.

Left-to-right layered architecture beginning with separate laparoscopic, thoracoscopic, arthroscopic, endoscopic/image-guided, and hybrid procedure domains. These feed a central clinical-translation field through four separate channels: evidence maturity, patient selection, perioperative consequences, and operator/training capability. Uncertainty channels for rare complications, selection bias, species transfer, and technical-to-clinical validation surround the central field. A final external boundary represents multicenter validation and context-specific reassessment.

The literature supports a field characterized by genuine procedural innovation but uneven evidential maturity. Comparative cohorts provide stronger clinical contrasts than feasibility series, yet they remain vulnerable to case selection, perioperative management, referral patterns, and procedure-specific confounding. Small technical reports remain valuable for identifying new indications or complications but cannot establish incidence or comparative benefit. The review therefore proposes that veterinary minimally invasive evidence be interpreted simultaneously across procedure configuration, patient suitability, perioperative consequence, operator capability, and transferability. This synthesis does not constitute a validated clinical decision rule. Its purpose is to prevent evidence generated at one level—technical, educational, experimental, or clinical—from being transferred automatically to another. Such separation is particularly important when technologies develop faster than comparative validation.

Clinical translation

Perioperative management illustrates why technically successful minimally invasive procedures cannot be interpreted independently of anesthesia and supportive care. In healthy dogs undergoing laparoscopic gastropexy and castration, preoperative ondansetron did not significantly reduce postoperative nausea under the studied conditions [29]. During laparoscopic ovariectomy, opioid-free and opioid-sparing anesthetic strategies produced different rescue-analgesia and early pain patterns within a randomized trial [30]. Platelet aggregometry around laparoscopic liver biopsy demonstrates that hemostatic monitoring can constitute a separate safety question [31]. Respiratory-management studies during laparoscopy likewise show that pneumoperitoneum creates specific ventilatory considerations [32]. Clinical translation therefore requires integration of operative technique with patient physiology, monitoring capacity, and perioperative protocol rather than attribution of outcomes solely to access route.

Procedural standardization

Standardization should distinguish what can reasonably be harmonized from what must remain procedure- or context-specific. Simulation platforms can standardize discrete laparoscopic tasks [25], while advanced veterinary simulators provide structured environments for repeated technical training [26]. Endoscopic training models demonstrate that competency exercises must also reflect modality-specific demands [28]. Standardization priorities therefore include procedural terminology, access descriptions, conversion definitions, outcome timing, complication reporting, training tasks, and documentation of operator experience. The proposed aim is not to enforce identical operative technique across heterogeneous indications. Rather, standardized reporting should make differences interpretable and allow technical modifications, training approaches, and clinical outcomes to be compared without concealing meaningful species, procedure, or institutional variation.

Research priorities

Research should concentrate on questions capable of changing interpretation rather than merely expanding the number of reported procedures. Existing evidence mapping demonstrates the need for stronger maturity in veterinary interventional research [1], and simulation research requires further validation of transfer from model performance to clinical skill [27]. Emerging robotic surgery provides a particularly clear example of technology whose potential currently exceeds the breadth of veterinary comparative evidence [10]. Priorities therefore include multicenter comparative cohorts, prospective validation of patient-selection criteria, standardized complication and conversion definitions, longer follow-up, training-transfer studies, rare-event surveillance, and broader large-animal investigation. Randomized trials may be valuable where feasible, but methodological appropriateness should depend on the clinical question rather than a universal design hierarchy.

Limitations

Interpretation is constrained by heterogeneous designs and uneven ability to detect uncommon harm. A fatal pneumopericardium reported after canine laparoscopic ovariectomy demonstrates that rare catastrophic complications may exist even when small series report none [33]. Comparative minimally invasive liver-biopsy techniques also show that technical execution and diagnostic specimen performance are not necessarily equivalent outcome constructs [34]. Experimental equine arthroscopy research demonstrates that instrument settings can alter tissue effects, but ex vivo findings cannot automatically define optimal live-patient practice [35]. Finally, laparoscopic treatment of paraprostatic cysts in two dogs illustrates how rare-indication reports expand procedural possibility while providing extremely limited generalizability [36]. Publication bias, specialist-center concentration, species heterogeneity, and incomplete comparative validation further constrain synthesis.

Conclusion

Veterinary minimally invasive surgery encompasses multiple procedure families whose evidential maturity, patient-selection requirements, perioperative consequences, complication profiles, and training demands differ substantially. Technical feasibility should therefore not be treated as synonymous with comparative benefit or broad clinical readiness. The synthesis developed here proposes explicit boundaries between innovation, clinical inference, operator capability, and external validation. Future progress depends less on procedural novelty alone than on evidence capable of defining where, for whom, and under which conditions minimally invasive approaches can be interpreted confidently.

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