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The Best Surgical Technique Depends on the Failure Mode: A Comparative Veterinary Decision Architecture for Matching Open, Arthroscopic, Laparoscopic, and Image-Guided Intervention to Patient, Lesion, and Procedural Risk

Ahmed Ben Ali[1]*, Samira Gharbi[1], Nabil Jebali[2]

[1]Department of Veterinary Surgical Techniques and Decision-Making, Faculty of Veterinary Medicine, University of Tunis, Tunis, Tunisia.
[2]Department of Comparative Surgical Outcomes, Faculty of Veterinary Medicine, University of Sfax, Sfax, Tunisia.

***E-mail** ✉ ahmed.benali@fpharm.u-tunis.tn

ABSTRACT

Surgical technique selection in veterinary medicine is frequently framed as a comparison between open and minimally invasive approaches, yet this framing can obscure the distinct ways procedures succeed or fail. This article proposes a comparative surgical decision architecture based on failure modes rather than technique labels. The framework examines how exposure, visualization, access, fixation or repair control, tissue burden, patient characteristics, lesion characteristics, and procedural resources interact to influence the suitability of open surgery, arthroscopy, laparoscopy, and image-guided intervention. The article synthesizes comparative veterinary evidence to distinguish established observations from proposed decision logic. The central contribution is a failure-mode matching approach in which the preferred technique is determined by the dominant anticipated limitation and the consequences of alternative failure pathways. This framework does not establish a universally superior surgical method. Instead, it provides a structured basis for clinical reasoning, identifies boundaries requiring validation, and highlights the need for prospective comparative studies incorporating technical, functional, safety, and patient-centered outcomes.

Keywords: Veterinary surgery, Minimally invasive surgery, Arthroscopy, Laparoscopy, Image-guided intervention, Surgical decision-making

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Introduction

Veterinary surgical innovation has expanded the available options for approaching the same anatomical problem. Open surgery, arthroscopy, laparoscopy, and image-guided procedures increasingly coexist rather than compete as mutually exclusive alternatives. However, technique comparisons often focus on isolated outcomes such as incision size, operative duration, or technical completion, which may fail to represent the actual clinical decision faced by surgeons. Comparative studies of fracture fixation, adrenalectomy, intestinal foreign-body removal, and other procedures demonstrate that advantages are frequently endpoint dependent rather than universal. Minimally invasive techniques may reduce selected burdens while introducing limitations related to access, visualization, equipment, or conversion requirements [1–3].

A more useful question is therefore not whether one technique is superior, but which technique best addresses the anticipated failure mode for a particular patient, lesion, and procedural environment. This article proposes a comparative veterinary decision architecture that organizes surgical choice around clinically meaningful failure states rather than procedural categories alone. The framework integrates direct evidence with clearly identified proposed synthesis.

Why technique superiority is context dependent

Surgical technique superiority is conditional because procedures optimize different dimensions of performance. A technique that improves one outcome may provide no advantage, or create new limitations, in another domain. For example, minimally invasive fracture fixation has been associated with differences in operative duration and implant-related outcomes compared with open stabilization, while laparoscopic adrenalectomy has shown selected perioperative advantages without demonstrating universal superiority across all outcomes [1, 4].

The relevant comparison is therefore multidimensional. Access trauma, visualization quality, repair control, physiological tolerance, and rescue capability may not move in the same direction. In addition, technique selection is influenced by lesion characteristics, surgeon expertise, equipment availability, and institutional capability. The framework proposed here treats these variables as interacting modifiers rather than secondary considerations.

Defining clinically meaningful surgical failure modes

A surgical failure mode is defined here as a clinically relevant limitation that prevents a procedure from achieving its intended objective safely or reliably. This definition differs from failure defined only by complication occurrence or conversion. A procedure may be technically completed yet fail because visualization was inadequate, repair control was uncertain, or tissue injury exceeded acceptable expectations.

Evidence from canine stifle procedures illustrates this distinction. Arthroscopy improved visualization of intra-articular structures compared with mini-arthrotomy but was also associated with greater iatrogenic cartilage injury in a cadaveric model [5]. Similarly, laparoscopic access can introduce measurable physiological effects through pneumoperitoneum, demonstrating that access technology itself may create a separate burden requiring consideration [6].

The proposed architecture therefore separates failure into exposure, visualization, access, repair control, and tissue burden domains.

Failure of exposure

Exposure failure occurs when the surgical route does not provide sufficient working space, direct control, or rescue capability for the required intervention. Exposure is not equivalent to incision length; rather, it represents the ability to safely manipulate anatomy, identify relevant structures, and respond to unexpected findings.

Open surgery remains important because broad exposure can provide direct tissue handling and procedural flexibility. Open thoracic procedures, for example, continue to incorporate advanced devices such as stapling systems rather than representing a technologically outdated approach [7]. Conversely, reduced-access techniques may succeed when exposure demands are limited but become inadequate when anatomical complexity exceeds the available working corridor.

Exposure should therefore be considered a capability that may be necessary in some cases rather than a default indicator of inferior surgical design.

Failure of visualization

Visualization failure occurs when the surgeon cannot adequately identify, inspect, or manipulate the relevant target despite having procedural access. Visualization is highly dependent on anatomy, lesion location, instrument geometry, and the specific diagnostic or therapeutic goal.

Needle arthroscopy in canine stifles demonstrates this principle. High diagnostic accuracy for medial meniscal tears was reported, but visualization and probing limitations remained for other regions of the joint [8]. Similarly, modified arthroscopic portal placement improved access to selected tarsocrural osteochondritis dissecans lesions while occasionally requiring limited open assistance [9].

Thus, visualization should not be evaluated as an inherent property of a technique alone. It represents the interaction between technology, target anatomy, and the information required for safe decision-making.

Failure of access

Access failure occurs when the planned pathway cannot safely reach, mobilize, exteriorize, or treat the target. Unlike exposure failure, access concerns whether the route itself is appropriate for the lesion and intended action. Laparoscopic-assisted intestinal foreign-body removal illustrates this distinction. Although minimally invasive access was feasible in selected dogs, conversion occurred when the planned approach could not adequately complete the procedure [3]. Lesion geometry and location are major contributors because the same access strategy may perform differently depending on the physical characteristics of the target.
Access should therefore be assessed before incision or portal placement by considering whether the intended route provides sufficient reach, manipulation, and rescue options.

Failure of fixation or repair

Fixation and repair introduce requirements that differ from diagnostic visualization. A procedure may provide excellent access yet fail if alignment, stability, reconstruction accuracy, or biological conditions for healing are compromised.
Recent orthopedic applications demonstrate how limited-exposure repair increasingly depends on supplementary technologies. Virtual planning and patient-specific systems have been used to facilitate minimally invasive fracture stabilization by providing additional alignment information when direct exposure is restricted [10]. Arthroscopic assistance has also been used during corrective procedures to improve intra-articular assessment, although evidence remains limited to selected clinical contexts [11].
Minimally invasive repair should therefore not be judged only by reduced access trauma. The central question is whether the chosen approach provides adequate control of the repair objective.

Failure through excessive tissue trauma

Tissue trauma represents a failure mode when the biological or physiological burden created by the procedure outweighs the intended advantage of the approach. This burden may involve direct injury, altered physiology, or delayed recovery consequences.
The relationship between invasiveness and trauma is not linear. Arthroscopy may improve visualization while creating focal cartilage injury, demonstrating that smaller access routes do not automatically eliminate tissue-related risks [5]. Likewise, laparoscopic insufflation produces measurable changes in portal pressure, indicating that minimally invasive procedures can introduce unique physiological demands [6].
The interpretation of tissue trauma therefore requires separating measured procedural effects from clinically meaningful outcomes. The following matrix summarizes the proposed adjudication approach for distinguishing tissue-related failure states and their implications. **Table 1** presents tissue-access trade-offs that determine when a less invasive route ceases to be biologically advantageous.

Table 1. Tissue-access trade-offs that determine when a less invasive route ceases to be biologically advantageous

Procedural burden	Biological cost or benefit	When technique comparison changes	Selection boundary and redesign question
Direct structural injury during access or instrumentation	**Meaning:** Technical completion may coexist with biological cost **Observed:** Tissue injury assessment or procedural observation	Target anatomy, instrument trajectory, operator experience	**Selection:** Compare benefit against injury burden **Limit:** Clinical importance may differ from experimental findings **Reconsider:** Reassess whether visualization or access gains justify injury risk
Physiological burden generated by access technology	**Meaning:** The access method itself becomes part of patient risk evaluation **Observed:** Physiological measurements during intervention	Patient tolerance, procedure duration, insufflation or positioning requirements	**Selection:** Modify technique, parameters, or patient selection **Limit:** Surrogate physiological changes may not equal clinical harm **Reconsider:** Validate patient-specific tolerance boundaries
Tissue preservation benefit with uncertain downstream advantage	**Meaning:** Reduced disruption may not automatically improve outcomes **Observed:** Comparative clinical outcomes where available	Disease process, healing environment, repair requirements	**Selection:** Avoid assuming smaller access is superior **Limit:** Long-term comparative evidence may be limited

			Reconsider: Include functional and recovery outcomes in future assessment
Trade-off between exposure and tissue preservation	**Meaning:** Greater exposure may improve control while increasing access burden **Observed:** Procedural requirements and complications	Lesion complexity, rescue needs, surgeon capability	**Selection:** Select the route matching the dominant failure risk **Limit:** No universal balance point exists **Reconsider:** Reconsider strategy when failure mode changes

Open surgical capability

Open surgery provides capabilities that remain difficult to replace in selected circumstances, particularly when direct exposure, broad manipulation, or rapid escalation is required. Its value lies not only in access size but in the range of actions available after unexpected findings occur.

Comparative cystolithotomy data demonstrate why open procedures should not be judged by a single disadvantage category. Open surgery was associated with longer anesthesia time in one canine comparison, but other outcomes did not demonstrate a uniform difference favoring the alternative approach [12].

Open techniques should therefore be considered within a broader capability framework. A larger access route may represent a deliberate choice when exposure, repair control, or rescue capacity represents the dominant clinical requirement.

Arthroscopic capability

Arthroscopy provides specialized capability through magnified intra-articular visualization and targeted instrumentation. Its strongest applications occur when the clinical objective depends on detailed inspection of joint structures or minimally disruptive access to specific lesions.

However, arthroscopic capability is not unlimited. Visualization depends on portal placement, compartment anatomy, and the ability to manipulate instruments within restricted spaces. Evidence from canine stifle and tarsocrural applications demonstrates that improved visualization may coexist with limitations in access, probing, or tissue injury [5, 8, 9].

Arthroscopy should therefore be selected when its information and treatment advantages address the anticipated failure mode. It should not be selected solely because it represents a minimally invasive option.

Laparoscopic capability

Laparoscopy expands surgical options by providing access through limited abdominal entry points while maintaining visualization through optical systems. Its principal capability is not simply reduced incision size but the ability to perform selected procedures when the balance between access limitation and tissue preservation is favorable.

Comparative veterinary evidence demonstrates that laparoscopic procedures can achieve clinically useful outcomes in appropriately selected patients. Laparoscopic adrenalectomy has been evaluated against open approaches, while laparoscopic-assisted gastrointestinal surgery has been used for selected intestinal foreign bodies [2, 3]. However, these approaches depend strongly on lesion characteristics, operator experience, and the requirement for extracorporeal manipulation or conversion.

Advanced laparoscopic applications also illustrate increasing procedural specialization. Three-dimensional laparoscopy has been examined as a potential improvement in visualization, although the evidence remains insufficient to establish universal clinical superiority [13]. Therefore, laparoscopic capability should be interpreted as a conditional advantage requiring appropriate patient selection and procedural readiness.

Image-guided intervention

Image-guided intervention changes the relationship between anatomy and surgical access by allowing targeting through indirect visualization, navigation assistance, or procedural planning. Its primary contribution is not replacement of direct surgery but improved localization, trajectory control, or minimally disruptive intervention in selected situations.

Fluoroscopically guided procedures demonstrate this principle. Normograde pinning techniques have been used for metabone fractures, while patient-specific guides have been evaluated to facilitate fluoroscopic-assisted stabilization procedures [14, 15]. These approaches may reduce some technical uncertainties but remain dependent on imaging accuracy, equipment availability, and operator interpretation.

Image guidance may also extend to therapeutic targeting. Laparoscopic ultrasound-guided microwave ablation and fluorescence-guided lymph node procedures illustrate emerging applications where additional information modifies procedural decision-making [16, 17]. These techniques remain highly context dependent, and their role should be defined by the specific failure mode they address rather than by technological novelty.

Patient-level modifiers

Patient characteristics influence whether a technically appropriate procedure remains clinically appropriate. Age, body size, physiological reserve, concurrent disease, and tolerance for anesthesia or procedural duration can modify the balance between competing surgical options.

The importance of patient-level assessment is demonstrated by procedures requiring specialized access or prolonged manipulation. Laparoscopic techniques may introduce physiological effects related to insufflation, while fluoroscopic procedures introduce radiation considerations that require appropriate risk evaluation [6, 18].

Patient-level modifiers should not be interpreted as reasons to avoid advanced procedures automatically. Instead, they define boundaries within which a technique's expected benefits and limitations should be reassessed. The proposed architecture treats the patient as an active determinant of procedural suitability rather than a passive recipient of a selected technique.

Lesion-level modifiers

Lesion characteristics frequently determine whether a surgical technique can achieve its intended objective. Location, size, morphology, tissue involvement, accessibility, and reconstruction requirements influence whether exposure, visualization, or repair control becomes the dominant challenge.

For example, laparoscopic removal of pancreatic masses and minimally invasive management of selected hepatic or vascular abnormalities demonstrate that lesion-specific anatomy determines feasibility more than the availability of a particular technology [19, 20]. Similarly, ultrasonographic evaluation before laparoscopic gastrointestinal procedures highlights the importance of understanding lesion location before selecting an approach [21].

The table below organizes lesion-level states that alter interpretation and procedural choice. It intentionally separates observed evidence from proposed decision synthesis. **Table 2** presents lesion constraints and the procedural capabilities needed to control them.

Table 2. Lesion constraints and the procedural capabilities needed to control them

Lesion constraint	Capability the approach must supply	Patient or system conditions	Preoperative or intraoperative evidence	Technique consequence and contingency
Restricted anatomical location	Access route may determine procedural feasibility	Species, anatomy, available imaging	Preoperative imaging and operative findings	**Selection:** Select technique based on reach and control requirements **Limit:** Imaging may not fully predict intraoperative complexity **Escalation:** Update approach when anatomy differs from expectation
Complex geometry or reconstruction requirement	Repair demands may exceed minimally invasive capability	Surgeon expertise, instrumentation, implant needs	Alignment, reduction, repair assessment	**Selection:** Prioritize fixation or reconstruction reliability **Limit:** Comparative evidence may remain procedure specific **Escalation:** Consider escalation pathways
Multifocal or poorly defined target	Localization becomes central to success	Imaging quality and guidance availability	Diagnostic imaging and intraoperative localization	**Selection:** Increase planning or image-guidance support **Limit:** Detection does not guarantee treatability **Escalation:** Reassess whether intervention objective is achievable
Lesion requiring broad manipulation	Exposure may become the limiting factor	Rescue capability and operative environment	Intraoperative access requirements	**Selection:** Select approach allowing adequate control **Limit:** No single access threshold

applies universally **Escalation:** Maintain conversion readiness

Procedural and resource modifiers

Technique selection occurs within a procedural environment. Equipment availability, surgeon training, imaging resources, anesthesia support, and institutional experience influence whether a theoretically suitable approach can be delivered safely.

Survey evidence indicates that adoption of laparoscopic and thoracoscopic techniques among veterinary surgeons is associated with training exposure, resources, and practice environment [22]. Training effects are also reflected in orthopedic surgery, where resident experience influences procedure duration and structured training programs can improve assessment of technical skills [23, 24].

These factors do not imply that advanced procedures are inherently superior when resources are available. Rather, they define implementation boundaries. A technique that requires unavailable equipment or insufficient expertise may create a different failure pathway than the one it was designed to avoid.

A comparative procedure-selection architecture

The central proposal of this article is a failure-mode matching architecture in which surgical selection begins with identifying the dominant anticipated limitation rather than ranking procedures by invasiveness. The decision process moves from clinical objective to potential failure mode, then evaluates which technique provides the necessary capability.

This architecture is not a validated prediction model. It is a proposed reasoning structure integrating evidence-supported distinctions among exposure, visualization, access, repair control, tissue burden, patient modifiers, lesion modifiers, and procedural constraints.

The figure provides a visual representation of the proposed conditional decision logic, separating evidence-supported capabilities from proposed relationships and emphasizing reassessment when the initial assumption changes.

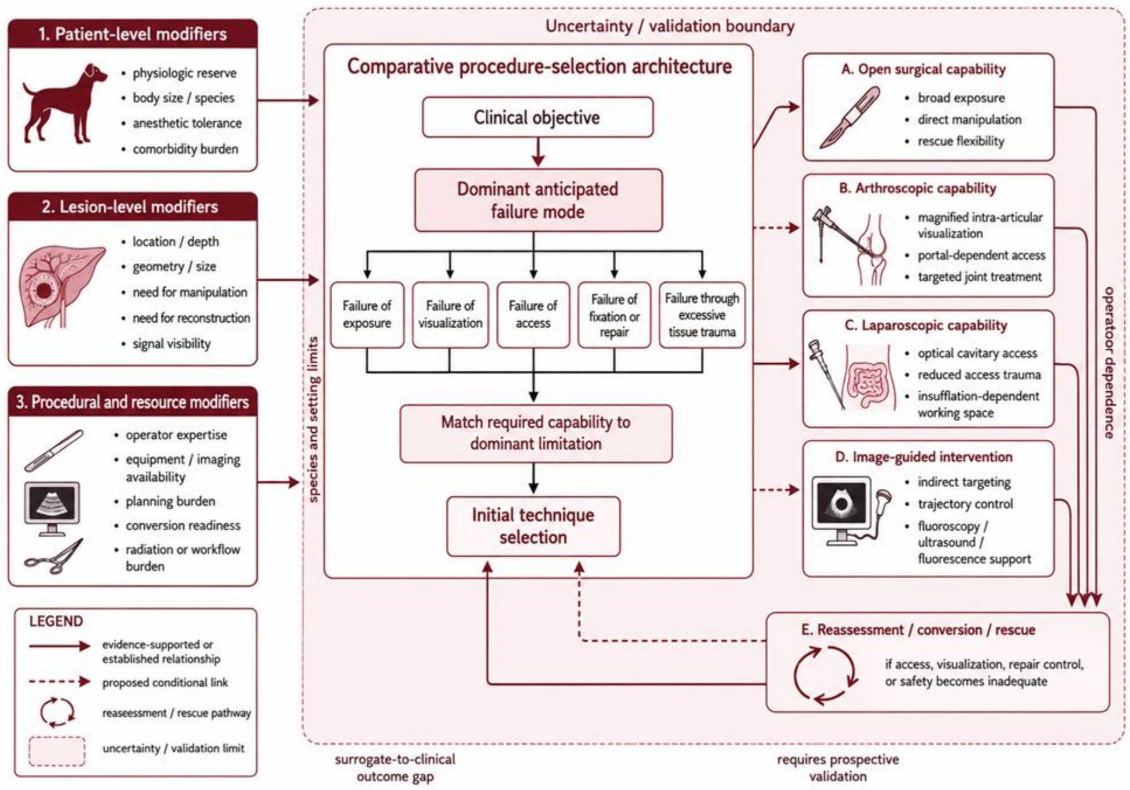

Figure 1. Conditional alignment of surgical capability with the dominant failure mode in veterinary intervention selection

Conversion and rescue strategies

Conversion should not be interpreted only as procedural failure. In a failure-mode framework, conversion represents a controlled response when the selected approach no longer provides adequate capability.

Examples from minimally invasive procedures demonstrate that successful outcomes depend partly on recognizing when access, visualization, or repair requirements exceed the available approach. Laparoscopic-assisted procedures and minimally invasive fracture techniques require judgement regarding whether continuation preserves safety or whether escalation improves control [3, 10].

A conversion strategy should therefore be planned before surgery begins. The decision to escalate should depend on the dominant unmet requirement rather than on preservation of the original technique. This interpretation shifts conversion from an undesirable endpoint to a component of adaptive surgical planning.

Training and equipment constraints

Technical capability depends on both technology and human performance. Procedures requiring specialized visualization systems, imaging equipment, or advanced instrumentation create learning requirements that influence reliability and availability.

Structured training programs have been evaluated as methods for assessing surgical skill development, while resident experience has been associated with procedural duration differences [23, 24]. These findings support the importance of competency development but do not establish that training alone guarantees clinical superiority.

Equipment constraints also influence procedural selection. Radiation exposure during fluoroscopic procedures represents one example of a resource-related consideration requiring balance between procedural benefit and occupational or patient considerations [18].

Training and equipment should therefore be incorporated as modifiers of suitability rather than treated as administrative concerns separate from surgical decision-making.

Clinical applications

The proposed architecture is applicable across diverse veterinary surgical contexts where multiple techniques compete for the same clinical objective. Orthopedic repair, joint intervention, abdominal procedures, thoracic procedures, and image-guided treatments each demonstrate different dominant failure risks.

For example, minimally invasive fixation may be advantageous when exposure reduction is important but may require additional planning when repair accuracy is difficult to achieve. Arthroscopy may provide diagnostic and therapeutic benefits when intra-articular visualization is central, whereas open approaches may remain preferable when broad manipulation is required [7, 10, 11].

These examples do not establish universal procedural hierarchies. Instead, they illustrate how the same technique can represent an optimal solution in one context and an inadequate solution in another.

Validation priorities

The proposed architecture requires empirical evaluation before clinical performance claims can be made. Future studies should compare procedures using outcomes that capture more than technical completion, including functional recovery, complication patterns, patient-centered outcomes, and long-term results.

Outcome measurement is particularly important because veterinary surgery increasingly incorporates owner-reported outcomes and surveillance approaches [25, 26]. Such measures may complement traditional surgical endpoints by identifying differences meaningful to patients and caregivers.

Validation should also examine external applicability across species, institutions, surgeon experience levels, and procedural environments. The framework should be tested, refined, or rejected according to whether it improves decision consistency without introducing unsupported assumptions.

Conclusion

The best veterinary surgical technique is not determined by invasiveness alone. Open, arthroscopic, laparoscopic, and image-guided procedures represent different capability profiles that become valuable under different clinical constraints. A failure-mode approach reframes surgical selection as a conditional decision problem involving exposure, visualization, access, repair control, tissue burden, patient factors, lesion characteristics, and procedural resources. The proposed architecture organizes these relationships while maintaining clear boundaries between established evidence and future validation needs. Its purpose is not to identify a universally superior technique, but to support more explicit reasoning about when and why a surgical approach is appropriate.

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