AJVR

Computer-assisted surgical navigation opens new horizons in veterinary surgery

Andres F. Bonilla, DVM, PhD[1¶*]; Mathieu de Preux, DVM, DECVS[2,3¶]; Julien Guevar, DVM, DECVN[4,5]; Howard Seim, DVM, DACVS[1]; Brad B. Nelson, DVM, PhD, DACVS[1]; Christoph Koch, DVM, DECVS[2]; Jeremiah T. Easley, DVM, DACVS[1]

[1]Department of Clinical Sciences, Colorado State University, Fort Collins, CO
[2]Division of Equine Surgery, Department of Clinical Veterinary Science, Vetsuisse Faculty, Swiss Institute of Equine Medicine, University of Bern, Bern, Switzerland
[3]Graduate School for Health Sciences, University of Bern, Bern, Switzerland
[4]Section of Clinical and Comparative Neuropathology, Institute of Veterinary Pathology, Centre for Clinical Veterinary Medicine, Ludwig-Maximilians-Universität, Munich, Germany
[5]Clinique Vetelys, Geneva, Switzerland

¶Contributed equally to this work.

*Corresponding author: Dr. Bonilla (andres.bonilla@colostate.edu)

Abstract
Computer-assisted surgical navigation (CASN), encompassing preoperative imaging, real-time instrument tracking, and spatial registration, is an established standard of care in human orthopedic, spinal, oral and maxillofacial, and neurosurgical procedures. Although CT and MRI are now widely available at veterinary referral centers, CASN has only recently begun to gain traction in veterinary surgery. This narrative review synthesizes the current evidence on CASN across veterinary species, surgical disciplines, and study designs, identifying consistent benefits in implant placement accuracy, minimally invasive access to complex anatomical targets, and reduced reliance on fluoroscopy. The predominance of cadaveric and ex vivo studies reflects the early translational stage of this technology, yet the accuracy outcomes are favorable and broadly comparable to those reported in human surgical literature. Barriers to wider clinical adoption include the high cost of intraoperative imaging platforms, the paucity of veterinary-specific system configurations, limited standardized training, and a learning curve that discourages uptake among experienced surgeons. Emerging developments in augmented reality, AI-assisted registration, and robotic guidance are likely to accelerate the maturation and accessibility of CASN in veterinary practice. As these platforms evolve, CASN holds strong potential to improve surgical reproducibility, reduce radiation exposure, and strengthen the translational bridge between veterinary and human surgical innovation.

Keywords: image-guided surgery, computed tomography, optical tracking system, frameless stereotaxy, surgical navigation

Advancements in cross-sectional imaging, real-time data integration, computational modeling, and precision-driven surgical techniques have collectively propelled the evolution of computer-assisted surgery (CAS), a broad field encompassing surgical navigation, intraoperative imaging, robotics, augmented and virtual reality platforms, patient-specific planning, and data-guided decision-making systems.[1] Computer-assisted surgical navigation (CASN) is a component of CAS that uses preoperative and/or intraoperative imaging, real-time instrument tracking, and spatial registration algorithms to provide 3-D, image-guided feedback to the surgeon during a procedure.[2] By correlating the patient's anatomy with digital imaging datasets, CASN enables precise localization of instruments relative to critical anatomical structures, thereby improving accuracy, enhancing safety, reducing variability in complex surgical interventions, and supporting minimally invasive techniques.[3] It reduces the need for revision surgeries, minimizes postoperative complications, and enhances the overall efficiency of operating rooms.[4] In human medicine, CASN is now a fundamental component of advanced spinal and orthopedic procedures,[5] oral and maxillofacial surgery,[6] otolaryngology,[7] and neurosurgery.[8]

Although a strong body of evidence indicates the benefits of CASN for various indications in

Received April 24, 2026
Accepted June 25, 2026
Published online July 8, 2026

doi.org/10.2460/ajvr.26.04.0175

human medicine, and despite the increasing availability of CT and MRI units in veterinary referral centers, CASN has struggled to gain wide implementation in veterinary surgery. Although comprehensive, large-scale studies focusing on indications are still lacking, numerous reports describing the use of CASN in veterinary surgery are emerging. By integrating advanced 3-D imaging and CASN into the operating room, veterinarians are able to perform challenging procedures with greater precision and accuracy through less-invasive approaches, thus reducing complications and recovery times and ultimately improving patient outcomes.

This review evaluates the currently reported applications of CASN in veterinary medicine across species and surgical disciplines, aiming to provide veterinary surgeons with a comprehensive overview of the precision, accuracy, and clinical benefits of this technology. It further examines the limitations and challenges of its implementation in clinical practice and explores future directions, such as the integration of augmented and mixed reality as well as robotic assistance.

Methods—Literature Search Strategy

To identify relevant evidence, given the heterogeneous and emerging nature of this topic and rarity of veterinary publications in this area, a narrative rather than systematic approach was adopted, and findings are organized by surgical discipline to reflect the distinct translational contexts in which CASN has been applied across veterinary species. The narrative review format necessitated the selective inclusion of studies based on relevance, contribution to the field, and avoidance of redundancy. Literature was identified using Google Scholar, PubMed, and Web of Science with predefined search terms related to CASN using combinations of search terms, such as "computer-assisted surgery," "surgical navigation," "veterinary medicine," "animals," "large animals," "farm animals," "horses," "dogs," "small animals," and "cats," without restrictions on publication date, allowing the inclusion of both recent publications and milestone studies. Evidence was organized by surgical discipline to reflect translational and clinical applications across species.

Basic Principles and Instrumentation

This review does not aim to provide a comprehensive overview of all the systems available but will focus on frameless stereotactic systems, which are currently the most commonly employed in veterinary medicine. Stereotactic surgery encompasses techniques that facilitate surgical interventions on targets within the body by applying a 3-D Cartesian coordinate system for precise orientation.[9] As the name suggests, frameless stereotaxy does not require a frame to be rigidly fixed to the target structure to maintain the reference point of the Cartesian coordinate system and to ensure accurate intraoperative orientation.[9] The advantages of frameless stereotactic systems, including increased versatility, greater surgical flexibility, enhanced user friendliness, and reduced invasiveness, have made them the preferred approach for stereotactic surgery in human and veterinary medicine.

Computer-assisted surgical navigation systems enable real-time intraoperative spatial orientation and feedback on the surgical procedure based on a 3-D virtual model of the patient's anatomy generated from preoperative or intraoperative cross-sectional imaging modalities (ie, cone-beam CT [CBCT], fan-beam CT, MRI, or a combination).[10] Following image acquisition, the datasets are reviewed for quality and completeness, and a surgical plan is generated on the navigation workstation, typically including the definition of anatomical targets and implant trajectories in orthopedic applications **(Figure 1)**. In a subsequent step, registration

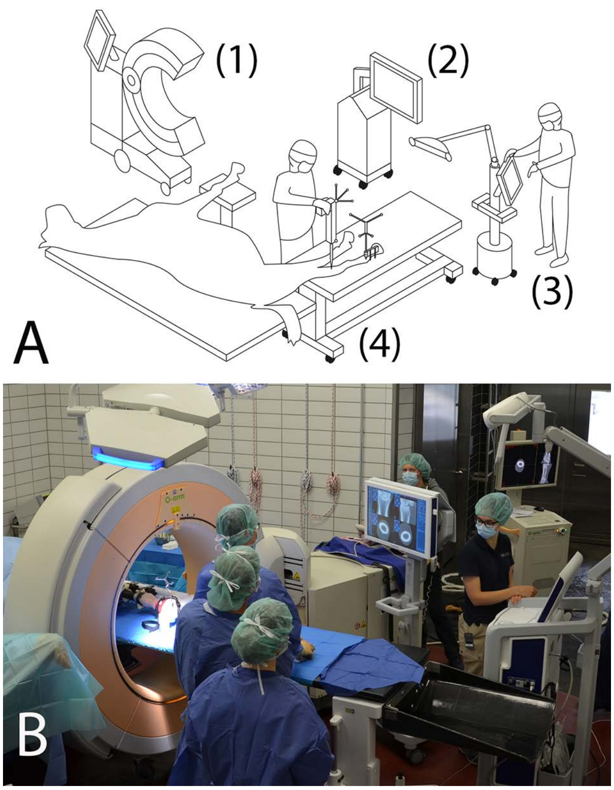

Figure 1—Overview of a computer-assisted surgery environment and workflow integrating intraoperative imaging and optical navigation technologies. A—Schematic representation of a computer-assisted surgery workflow using an optical tracking system, including (1) pre- or intraoperative image acquisition, (2) image review and quality assessment, (3) surgical planning, and (4) execution of the navigated procedure. B—Intraoperative overview of a computer-assisted surgical setup following preoperative imaging, showing the equipment required for imaging, planning, and navigation (ie, O-arm imaging unit coupled with the StealthStation navigation system [Medtronic]). The optical tracking camera is positioned to simultaneously detect both the patient and gantry trackers. Two teams are present in the operating room, one responsible for imaging and planning and the other for performing the navigated surgical procedure.

is performed to align the virtual imaging data with the patient's anatomy using techniques such as fiducial markers, surface matching, or landmark-based approaches, thereby establishing a shared spatial coordinate system between the patient and the navigation platform; in workflows relying on immediate pre- or intraoperative imaging with a patient tracker anchored to bone or an external frame, registration is commonly achieved by placing the tip of a navigated pointer (registration probe) into a predefined divot of the patient tracker. Throughout the navigated surgical procedure, referencing is maintained as a continuous process to ensure ongoing spatial consistency between the virtual model and the surgical field, with periodic verification and adjustment when required. To achieve this, it is critical that the navigation system is able to see the patient tracker (fixed reference point), which remains stable along with the spatial relationship to the patients' anatomy during all procedural steps, and the instrument trackers **(Figure 2)**.[11] A commonly used real-time tracking method relies on the emission and detection of near-infrared light by an array of cameras and on the reflection of this light by patient trackers and navigated instruments equipped with markers.[12] This optical tracking method is highly versatile as a wide variety of rigid surgical instruments can be equipped with specific markers and calibrated.[13] Furthermore, it provides reliable performance across a wide range of clinical environments, achieving target registration error and procedural accuracy that are typically within the submillimeter range.[14,15] One key feature of this tracking method is the need to maintain an unobstructed path between the cameras and the patient or instrument tracker, commonly referred to as the line-of-sight principle, which can be challenging in cluttered operating theaters.[12]

Figure 2—Photograph showing a procedure assisted by surgical navigation in a veterinary setting. This narrative review summarizes the current evidence on computer-assisted surgical navigation applications in veterinary surgery, with emphasis on reported applications, surgical accuracy outcomes, and translational potential. The navigation system (Imaginalis; visible on the right) uses optical tracking technology, with infrared cameras (top right) capturing the precise locations of specialized instruments and patient trackers in real time. The surgeon uses tracked instruments to navigate within the surgical field, guided by live imaging displayed on the screens. The images are published with permission of Dr Ilaria Grossi, the copyright holder, with all rights reserved. Anyone wishing to reproduce the images is directed to contact Dr. Ilaria Grossi (i.grossi@imaginalis.it) from Imaginalis, Via Rodolfo Morandi, 13–15 Sesto Fiorentino, FI, Italy.

CASN Applications in Veterinary Medicine

Computer-assisted orthopedic surgery

Technological advancements are essential in orthopedic surgery to enable accurate implant placement via minimally invasive, soft tissue–sparing approaches, thereby reducing collateral tissue damage, infection risk, and morbidity while facilitating the development of patient-specific, biomechanically optimized implants with improved fixation stability. Early applications of CASN in veterinary medicine focused on improving screw placement accuracy in equine distal structures, with initial reports describing the coupling of surgical navigation systems with isocentric C-arm fluoroscopy for procedures involving the distal phalanx and distal sesamoid bone, both in experimental settings[16–19] and in clinical cases.[20,21] Following these initial reports, and in line with trends in human surgery, equine surgeons have now taken advantage of modern imaging units with higher spatial resolution, faster acquisition times, and larger fields of view for surgical navigation, such as CBCT scanners coupled with increasingly user friendly surgical navigation systems with optical tracking (eg, the StealthStation S8 by Medtronic or the DelphiVet by Imaginalis). Meanwhile, the use of CASN to facilitate orthopedic procedures in horses has been described across various anatomical locations and indications,[22] offering unmatched intraoperative control over instrument orientation and penetration depth during critical phases of the procedures. However, the direct application of navigation systems and instrumentation developed for human surgery to equine patients has inherent limitations, necessitating ongoing refinement of species-specific setups and rigorous evaluation of their surgical precision and accuracy. Notably, this includes the development of purpose-built frames (PBFs) to stabilize the equine extremity[23,24] during the navigated surgery, thereby allowing patient tracker fixation outside the surgical field, or simultaneously working across articular surfaces or on smaller target bones, for instance on the distal sesamoid bone **(Figure 3)**, without placing Schanz pins for patient tracker fixation.

In procedures involving navigated drilling of articulating bones, other (than PBFs) external stabilizing elements, such as a tube cast or a calf jack, can be integrated into the setup. Examples of published clinical applications are CASN fracture repair of minimally displaced accessory carpal bone fractures or the placement of toggle constructs to stabilize luxated coxofemoral joints following closed reduction.[25,26] Other innovations have focused on assessing how specific instruments influence surgical accuracy, such as a stereotactic aiming device

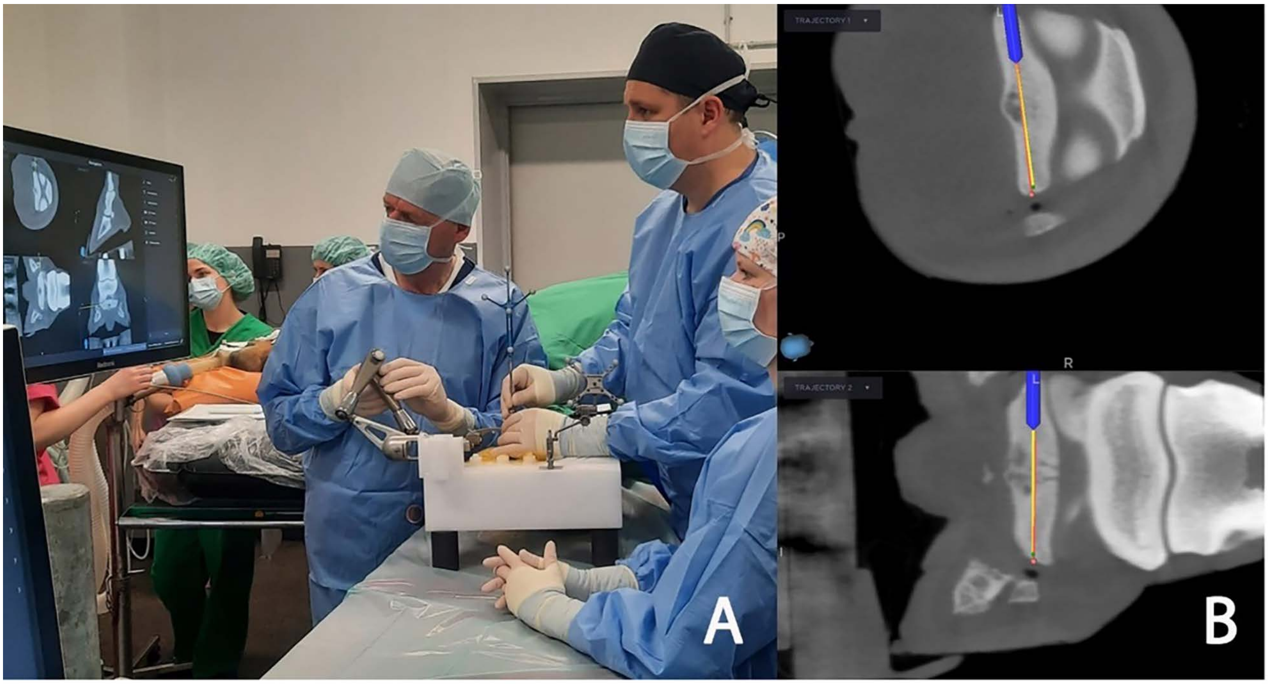

Figure 3—Navigated drilling of a cystic lesion in the distal sesamoid bone using an optical tracking system (Medtronic). A—The distal limb is stabilized in a purpose-built frame. A stereotactic aiming device is used to improve the accuracy of the procedure. The primary surgeon aligns the device with the preplanned trajectory using a navigated pointer. B—Close-up of a screenshot from the navigation system, showing drill bit (blue cylinder) orientation, the position of its tip, and its virtual projection (yellow line) aligned with the preplanned trajectory (red line).

for distal sesamoid bone fracture repair.[23] The principal studies reporting the use of CASN in veterinary orthopedic surgery, including the species evaluated, anatomical targets, navigation platforms, study design, and key accuracy outcomes, are summarized in **Supplementary Table S1**.

Interestingly, a comparable trend in the implementation of CASN into clinical practice has not yet been observed in small-animal orthopedic surgery. This is reflected in the limited number of published experimental or clinical studies in this field, with few reports on its use to improve the precision and accuracy of screw placement in the vertebral body in cats with sacroiliac joint luxation[27,28] or to enhance tibial component alignment in total knee replacement in dogs.[29] Nonetheless, small-animal orthopedic surgeons are increasingly using computer technologies to develop 3-D–printed models for surgical planning and patient-specific instrumentation (PSI), such as cutting guides, drill guides, and alignment jigs, to facilitate and improve the technical accuracy of complex corrective osteotomies,[30–35] fracture reduction,[36,37] minimally invasive plate osteosynthesis,[38–40] coxofemoral toggle pin placement,[41] total knee replacement,[42] and placement of bipolar coxofemoral osteochondral allograft[43] among others. This preference for 3-D printing and PSI over navigation systems is likely influenced by greater accessibility, lower costs, and the relatively recent introduction of navigation technologies into veterinary surgery.[44] However, 3-D printing and PSI require open approaches to the anatomy, whereas CASN allows for similar accuracy and precision without as much tissue exposure. These factors may represent key barriers to widespread clinical adoption, highlighting the need for further research, cost-effective system development, and training initiatives to facilitate broader integration of CASN into small-animal practice.

Reports on the use of surgical navigation in farm animals remain scarce in the literature. Recently, the use of CASN was reported for ventral bulla osteotomy in calves with otitis media.[45] However, authors of this review have performed numerous navigated orthopedic procedures in farm animals. These include treatment of coxofemoral joint luxation in a llama via navigated drilling of the femoral neck and head and acetabulum for toggle pin placement using a technique similar to that reported in small equids,[28] a slipped capital femoral epiphysis in a sheep treated with 2 cortical lag screws placed under surgical navigation guidance through a minimally invasive approach, a femoral neck fracture in a heifer treated with navigated lag screw fixation, and a combined Salter-Harris type III fracture of the fourth metacarpal bone and condylar fracture of the third metacarpal bone in another heifer **(Figure 4)** managed with navigated lag screw fixation and transfixation pin casting. Although these cases have not been formally reported, they illustrate the breadth of potential indications for CASN for farm animal surgery and underscore the need for prospective documentation of such cases. Beyond farm animals, exotic species may equally benefit from CASN, where limited anatomical references and restricted access to species-specific implants make

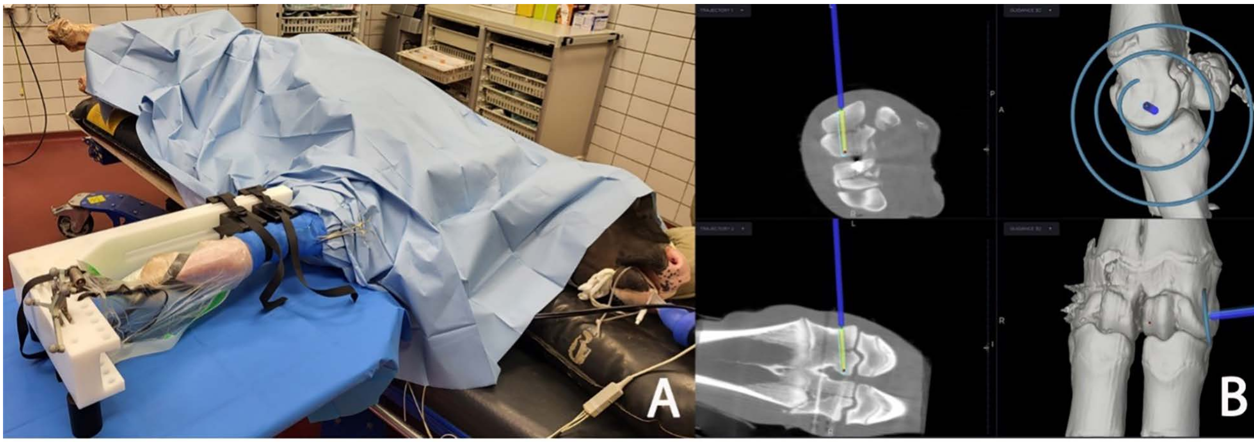

Figure 4—Navigated lag screw fixation of a fourth metacarpal fracture combined with a condylar fracture of the third metacarpal bone in a heifer. A—The distal limb is stabilized in a purpose-built frame, with the patient tracker attached to the side of the frame, providing unrestricted access to the surgical site. B—Screenshot from the navigation system (Medtronic) demonstrating planned screw trajectory (light blue cylinder) within the condyle on transverse, dorsal, and 3-D–reconstruction images. The real-time position and orientation of the drill bit are shown (dark blue cylinder), with its virtual projection (yellow cylinder) aligned with the planned trajectory. Note the metallic attenuation artifact caused by the cortical screw already inserted in the fourth metacarpal bone.

precise intraoperative guidance particularly valuable. This is illustrated by the authors' experience with navigation-assisted repair of a coxofemoral luxation in a 2-week-old camel. For all those procedures, the technical setup previously developed for computer-assisted orthopedic surgery in horses was applied given the comparable body sizes of sheep and llamas to ponies and of heifers to larger equine patients.

Computer-assisted spine surgery

Spinal trauma, a frequent cause of acute spinal cord injury, includes vertebral fractures, luxation, subluxations, and traumatic disk extrusions. Stabilization of the spinal column can be achieved through dorsal fixation using plastic or metal plates, Steinmann pins, pedicle screws and rods, or vertebral body plating.[46] Pin and screw placement in small animals is challenging due to small vertebral bodies, breed-specific anatomical variations, and congenital or acquired instability, which require specialized surgical expertise. While general guidelines exist for insertion angles and landmarks in the thoracolumbar vertebrae,[47] these should be adjusted during surgery to account for challenges posed by soft tissue interference and to gain adequate bone purchase while avoiding inadvertent breach into the vertebral canal.

Surgical navigation with optical tracking has been tested for spine procedures in small animals in experimental cadaver studies,[14,27] but its use in clinical cases has not yet been reported. Implementing a navigation system designed for human surgery presents challenges, such as reduced accuracy due to alterations in patient posture during surgery[48] or, as experienced by the authors of this review, due to unstable patient tracker fixation. To address this, the use of a lighter, 3-D–printed, custom-made patient tracker has been reported in cadaveric studies[28,49] to reduce excessive lever-arm forces on the feline and canine lumbosacral spine, thereby minimizing the risk of dislodgment and the consequent loss of surgical system accuracy **(Figure 5)**. Further, a cadaveric study[50] evaluating CASN for thoracolumbar spinal instrumentation in large-breed dogs demonstrated 100% cortical safety during percutaneous polyaxial screw and rod placement as graded by a vertebral cortical breach scheme. Emerging results with CASN show it to be a valuable tool for enhancing precision, accuracy, and safety during vertebral implant placement in small spaces.

Potential applications of CASN using frameless stereotactic surgical navigation systems, coupled with a CBCT unit, have been described for the equine cervical spine.[22,51–54] These include navigated drilling of a fractured cervical articular process for internal fixation in a warmblood gelding[51] and navigated drilling of the cervical vertebral bodies in an experimental setting to facilitate ventral interbody fusion in horses with cervical vertebral compressive myelopathy (wobbler syndrome).[52] Specific challenges in this region include achieving stable fixation and positioning of the substantial equine neck as well as appropriate placement of the patient tracker, typically on the transverse process or ventral crest of the vertebrae. When a ventral approach is used, the latter challenge can be addressed by applying rigid external stabilization, analogously to the above described PBF, cast, or calf-jack setup described above for computer-assisted orthopedic surgery applications. For the equine cervical spine, a dedicated cervical frame has been developed in which the patient tracker is mounted on the side panels, providing simultaneous surgical access, CT gantry clearance, and ergonomic positioning for the surgeons and for pre- and intraoperative imaging.[52] Alternatively, when a lateral approach is used, the tracker can be rigidly fixed to the dorsal spinous process of C2.[55]

In other large-animal models, the efficacy of a stereotactic CASN system has been evaluated for discectomy in porcine and caprine spines, widely used

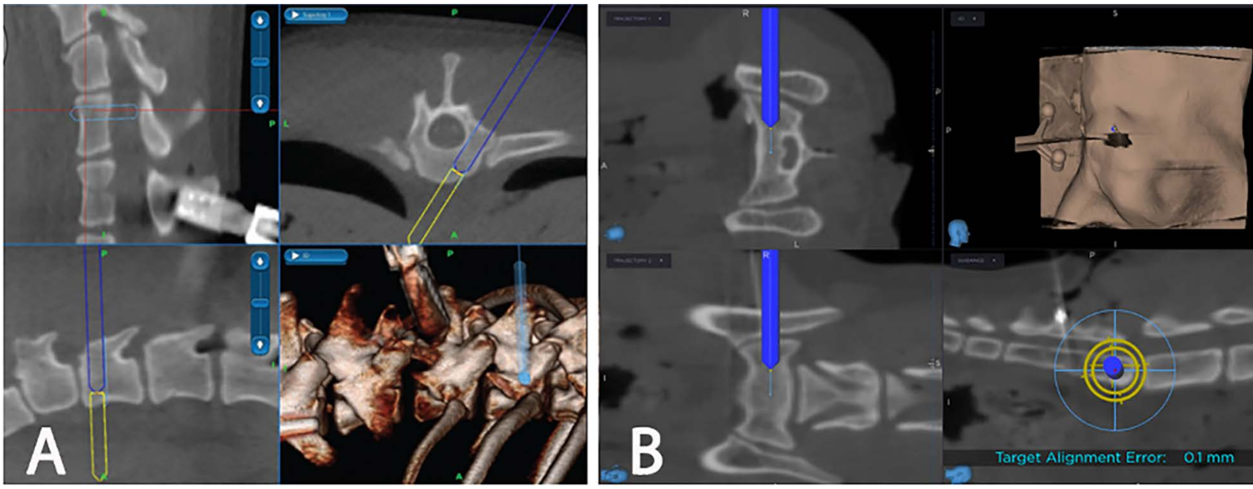

Figure 5—Close-up of screenshots from a navigation system (Medtronic) illustrating 2 computer-assisted spinal drilling procedures in small animals. A—Navigated drilling in a thoracic pedicle of a dog for the placement of a polyaxial screw for spinal stabilization. A clamp (metallic attenuation visible in the top left of the cone-beam CT reconstruction) was used to attach the tracker to a spinal process.[50] B—Navigated drilling across the sacroiliac joint of a cat for the placement of a screw to stabilize a luxation. A 3-D–printed patient tracker is anchored to the sacral spinous process using a single 1.4-mm pin, visible both on the 3-D reconstruction and as a metallic attenuation in the sagittal view.[27]

models for spine research.[56,57] Similarly, our group has employed CASN in preclinical settings for spinal stabilization and scoliosis growing rods in sheep, another widely used model for spine research.[58] The principal studies evaluating CASN for spinal instrumentation and stabilization across veterinary species are summarized in **Supplementary Table S2**.

Computer-assisted oral and maxillofacial surgery

Surgical orientation in the equine head presents significant challenges due to the complex anatomy of the nasal conchae and paranasal sinuses, the deeply embedded and long reserve crowns of the cheek teeth, the confined space, the proximity of critical vascular and neural structures, and the limitations of conventional intraoperative imaging caused by multiple anatomical superimpositions.[59] Similar challenges are encountered in small-animal surgery, where the diverse, often severe bony pathologies resulting from external trauma to delicate anatomical structures further complicate surgical planning and intervention.[60] Thus, accurate surgical orientation is critical for many interventions involving the head.

In equine surgery, CASN enables accurate and controlled interventions involving dental and conchosinusoidal structures. In clinical scenarios where conventional 2-D imaging or endoscopy is inadequate or fails, CASN allows for precise surgical access to targets that are otherwise inaccessible or obscured. For example, CASN enabled precise anatomical intraoperative orientation, ensuring accurate execution of a mandibular condylectomy and the removal of an ectopic tooth situated axially to the mandibular fossa, close to the base of the calvarium.[61] The use of CASN significantly facilitated the surgery, minimizing the risk of collateral damage to surrounding structures. Furthermore, CASN has proven helpful in accurately aligning a navigated dental punch with the long axis of the tooth, thereby facilitating cheek tooth repulsion and minimizing the risk of collateral damage.[62]

Computer-assisted surgical navigation has also facilitated intraoperative orientation during challenging dental extractions, drainage of empyema of the dorsal and ventral conchal bullae, mandibular fracture stabilization using locking compression plates as type 1 external fixators in horses, and revision surgery in a bovine patient following failed type 2 external fixator fixation. By improving intraoperative orientation, surgical navigation can enhance construct stability through optimized bone purchase, engaging a greater number of cortices while minimizing the risk of iatrogenic injury to dental roots. Although these cases have not been formally reported, they illustrate the breadth of potential indications for CASN in equine and bovine head surgery.

Computer-assisted surgical navigation enhances precision in oral and maxillofacial procedures in both small- and large-animal surgery, enabling accurate bone resections, implant placement, and complex reconstructions.[62–64] Its application in preclinical models provides a controlled and reproducible platform for evaluating surgical techniques, devices, and therapeutic interventions, thereby supporting the safe and effective translation of novel oral and maxillofacial procedures to human patients.[6] The principal studies describing the application of CASN in veterinary oral and maxillofacial surgery are summarized in **Supplementary Table S3.**

CAS for neuronavigation

The complex anatomy of the CNS, coupled with its dynamic pulsatile motion from blood flow and CSF circulation, presents major challenges for precise surgical localization. Consequently, neurosurgical procedures require exceptional precision to ensure both safety and efficacy.[48] These challenges have long justified the importance of frame-based stereotaxy and image-guided navigation in human neurosurgery and explain the growing adoption of similar technologies in veterinary medicine.[14,65–67]

The use of CT-guided, frame-based stereotaxy for brain biopsies in small animals has been well documented since the early 2000s.[68–72] As in human neurosurgery, a gradual transition occurred toward frameless neuronavigation systems, facilitated by advances in MRI technology and its growing availability as the gold standard for brain lesion diagnosis. Nevertheless, MRI has also been successfully employed for frame-based stereotactic procedures in small animals.[73,74]

Navigation technology has since been validated for brain biopsies in dogs and cats, demonstrating high diagnostic yield and spatial accuracy.[75–77] For instance, using MRI images, the Brainsight stereotactic system (Rogue Research Inc) demonstrated ease of use and high precision in cadaver studies[78] **(Figure 6)**, making it suitable for clinical use in dogs with brain lesions larger than 3.3 mm. Clinical applicability was further confirmed in a series of 10 dogs with forebrain lesions, in which neuronavigation-guided biopsies yielded successful diagnostic outcomes.[14,67] More recently, the technology has been extended beyond biopsy to ventriculoperitoneal shunt placement in dogs, further broadening the neurosurgical applications of neuronavigation in small-animal practice.[79]

Additionally, validation of CBCT-based automated image registration for frameless stereotactic biopsies in dogs and cats showed that diagnostic accuracy is independent of skull morphology and comparable to both frame-based and frameless

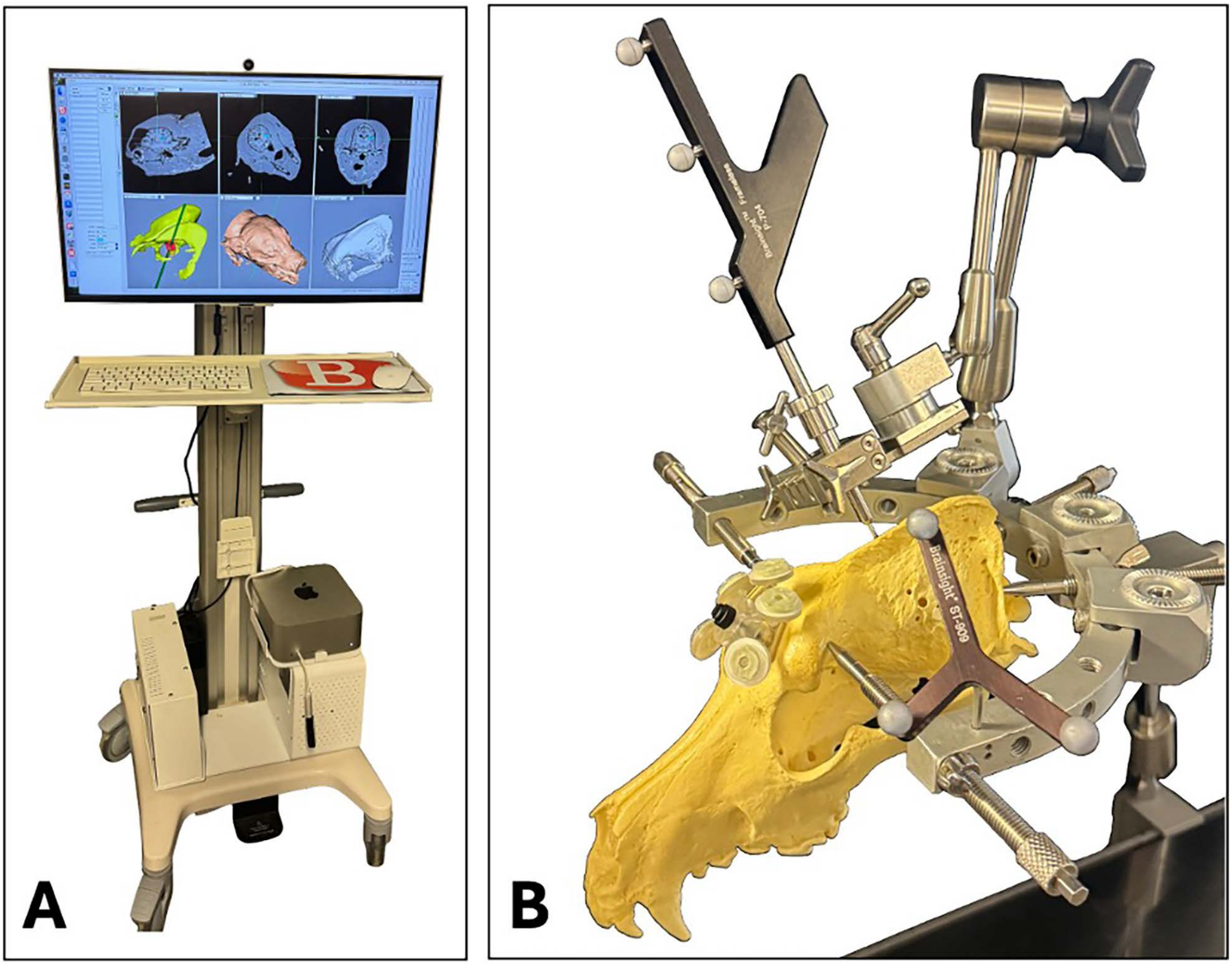

Figure 6—Optical navigation system and experimental setup for image-guided cranial instrumentation. A—Mobile optical neuronavigation workstation (Rogue Research Inc) displaying multiplanar CT reconstructions and 3-D models used for preoperative planning and intraoperative guidance. B—Experimental setup showing a skull specimen rigidly secured in a fixation frame. A reference patient tracker is attached to the specimen, and a tracked pointer is mounted on an adjustable mechanical arm to allow precise targeting and validation of planned trajectories under navigation guidance. The images are published with permission of Dr. Stephen Frey, the copyright holder, with all rights reserved. Anyone wishing to reproduce the images is directed to contact Dr. Stephen Frey (steve@rogue-research.com) from Rogue Research Inc, 300–6666 St-Urbain, Montreal, QC, Canada.

systems previously described in veterinary medicine.[80] The use of CAS has also been extended to large-animal models: optical neuronavigation-guided intracranial biopsy procedures were found feasible in horses,[65] and MRI-guided stereotactic techniques have been validated in sheep.[81]

To date, stereotactic brain biopsy remains the primary and most established indication for CASN in small-animal veterinary medicine. However, the clinical scope of CASN has progressively expanded beyond diagnostic purposes. For instance, frameless navigation systems have been employed for the implantation of electrodes for deep brain stimulation in dogs with refractory epilepsy, demonstrating high spatial precision and favorable clinical outcomes.[82] More recently, neuronavigation has also facilitated the placement of intracranial electrodes for electroencephalographic recording in experimental and clinical canine models, enabling improved localization of epileptogenic foci.[83] Similarly, CASN-guided targeting has supported the application of repetitive transcranial magnetic stimulation in behaviorally disordered dogs, enhancing the reproducibility and safety of coil positioning.[84] Beyond neurology, CASN has been integrated into radiation oncology to refine patient positioning and improve the geometric accuracy of treatment delivery[66] as well as into surgical oncology to improve the precision of forebrain mass resections,[85] and in general neurosurgical procedures CASN has supported accurate craniotomies and improved surgical planning.[14,67]

It is worth noting that all of the above-cited studies describe dorsal or dorsolateral approaches to the cranial cavity via the calvaria. Surgical approaches to the skull base present additional inherent challenges, primarily due to the narrow, deep surgical field surrounded by critical anatomical structures. In small animals, transsphenoidal hypophysectomy is well established for addressing pituitary, sellar, or parasellar masses that continue to cause clinical signs despite medical and radiation treatment.[86] The use of neuronavigation has been proposed to improve the accuracy of pituitary fossa localization and provide a safe ventral window for transsphenoidal hypophysectomy.[87] In horses, MRI- and CBCT-based navigation permits controlled access to the lateroventral aspect of the skull via a transmandibular approach. This approach enables transsphenoidal surgical manipulation of pituitary macroadenoma[88] and puncture of the trigeminal cave through the foramen lacerum,[89] potentially allowing for the development of a controlled rhizotomy procedure for horses suffering from trigeminal-mediated headshaking.

Collectively, these advances highlight the growing versatility of CASN in veterinary neurosurgery. The technology not only enhances diagnostic and therapeutic accuracy but also provides a robust preclinical platform for translational research. As CASN continues to evolve, its integration across neurological procedures will play a pivotal role in bridging experimental and clinical neurosurgery, ultimately improving outcomes for both animal and human patients.

Challenges and limitations of CASN in veterinary medicine

Despite the growing body of evidence supporting the potential advantages of CASN in veterinary medicine, including enhanced accuracy, precision, and safety, several challenges continue to limit its widespread adoption. Among the most significant barriers are the high costs associated with acquiring and maintaining the equipment. The most expensive component of a CASN setup is typically the imaging unit rather than the navigation platform itself. Fortunately, many advanced veterinary referral centers have already invested heavily in diagnostic imaging capabilities, which can partially mitigate this financial burden. However, integrating CASN requires dedicated space, appropriate infrastructure, and technical support, which can be difficult for smaller facilities to provide. The use of mobile intraoperative imaging systems represents a promising solution as these units can be integrated into most surgical suites without extensive renovations or architectural modifications.[90]

Beyond financial and infrastructural considerations, the successful implementation of surgical navigation is heavily dependent on the availability of adequately trained personnel. Effective use of this technology requires a multidisciplinary team with expertise spanning surgical planning, image acquisition and processing, system registration, and intraoperative troubleshooting. The learning curve associated with surgical navigation is well recognized in human medicine, where studies[91] have shown that procedural efficiency and accuracy improve significantly with experience. This applies equally in veterinary settings, where exposure to navigation systems remains limited and standardized training programs are largely absent. Unlike conventional surgical skills, navigation competency demands familiarity with both the software interface and the underlying imaging principles, representing a distinct and nontrivial skill set. The development of structured training curricula will therefore be essential to broaden the pool of veterinary professionals capable of applying this technology effectively and consistently in clinical practice.

An additional limitation stems from the fact that most commercial navigation systems were designed and calibrated for human anatomy. Tracking algorithms, reference arrays, and registration protocols are optimized for human skeletal geometry, tissue density, and instrument dimensions, which can create significant technical challenges when applied to species with markedly different anatomical proportions and biomechanics. Adapting these systems to veterinary patients, particularly those with small, delicate, or morphologically variable structures, often requires substantial customization, and acceptable accuracy is not always readily achievable.[92] This mismatch between system design and species-specific requirements not only limits the breadth of navigable procedures in veterinary surgery but also represents a fundamental barrier to broader dissemination of the technology across species and clinical settings.

The few CASN-related publications in veterinary medicine also highlight important sociological and technical barriers. Most reports originate from a small number of specialized referral or academic centers that possess both the infrastructure and motivation to explore these technologies. Beyond institutional limitations, the adoption of CASN is further constrained by surgeon-related factors, including a reluctance to invest time and effort in acquiring new technical skills associated with unfamiliar technology. The learning curve inherent to CAS systems, encompassing software interfaces, registration protocols, and intraoperative workflow adjustments, represents a significant psychological and practical deterrent, particularly for experienced clinicians who have developed confidence and efficiency with conventional techniques. Compounding this is the perceived burden of preoperative setup time, which, despite being offset by potential gains in intraoperative precision, is often viewed as disruptive to clinical throughput and scheduling.

Notably, there is a surprisingly low number of CASN reports in small-animal surgery and in farm animals. This may be explained by the high cost of systems relative to case volume and the limited perceived advantage for small bones that can be easily visualized with conventional radiography. In contrast, equine surgery has seen greater adoption, particularly in orthopedics, where CASN facilitates access to deeply embedded or distorted anatomical structures that are otherwise difficult to reach or image with conventional diagnostic modalities. In farm animals, the limited use of CASN may primarily be financial rather than clinical as the technology could provide substantial value for individuals of high genetic or economic worth.

A final consideration concerns the relative popularity of complementary technologies, such as 3-D–printed PSIs. In small-animal oral, maxillofacial, and spine surgery, 3-D–printed PSIs have gained wide acceptance due to their lower cost, ease of use, and lack of need for complex intraoperative imaging equipment.[93,94] However, PSI-guided surgery also has drawbacks, including the need for preoperative 3-D imaging to produce the guides, which leads to additional costs and anesthetic risks and a delay before surgical repair is performed. Furthermore, to apply 3-D–printed guides accurately and safely, larger surgical approaches are needed to adequately expose and clean bone surfaces for proper fit.[95] Thus, while PSI-based guidance offers an attractive alternative, real-time navigation remains uniquely valuable for minimally invasive procedures, complex anatomies, and deeply embedded targets. Together, these complementary modalities underscore that the true promise of CASN in veterinary surgery may lie not in replacing conventional methods but in augmenting them where precision and spatial awareness are most critical.

Future developments of CAS in veterinary medicine

The future of CASN in veterinary medicine, much like in human surgery, is likely to be driven by augmented reality (AR), AI, and robotic assistance. Augmented reality offers the possibility to overlay virtual anatomical models, planning data, or navigation cues directly onto the surgeon's field of view.[96] In small-animal research, AR has already been applied to craniofacial and surgical planning tasks. For instance, AR-based models of canine skulls have been used to visualize complex geometries and plan osteotomies.[97] More broadly, AR-assisted, robot-guided mandibular osteotomies in canine models have been demonstrated.[98] As AR headsets and display systems become lighter, more accurate, and better integrated with surgical navigation, they may transition from experimental tools to routine adjuncts in veterinary surgery.

Artificial intelligence and robotics may further catalyze the maturation of veterinary CASN. Artificial intelligence algorithms hold promise for automating laborious steps, such as segmentation, registration, and trajectory planning, reducing setup time and user variability. In human and engineering systems, markerless AR registration frameworks have been developed to avoid reliance on fiducials.[99] In veterinary contexts, robotics is already being explored: veterinarians are training on systems such as the da Vinci robot (Intuitive Surgical Inc) to perform minimally invasive procedures in animals.[100] As AI-driven decision support and robotic instrument control mature, CASN may evolve into semiautonomous platforms capable of executing precise surgical steps under supervision.

Another key frontier lies in hardware adaptation for veterinary imaging constraints. Many navigation systems were designed for human-scale imaging geometry; interfacing CASN with large-bore, fan-beam CT scanners (or veterinary-specific scanner configurations) would expand access for equine and large-animal surgeons. Similarly, development of navigation systems engineered from the ground up for veterinary anatomy, such as those with customizable trackers, software tailored for multiple species, or modular configurations, may accelerate adoption across institutions.

As CASN becomes more cost-effective and refined methodology improves precision, we expect it to further transform veterinary surgery by enabling highly accurate implant positioning and reducing dependency on conventional intraoperative imaging, thereby decreasing radiation exposure. Over time, CASN may support broader use of minimally invasive techniques, combined AR/AI guidance, and novel surgical workflows across species. Ultimately, the convergence of these technologies will help translate experimental innovations into routine veterinary surgical care, elevating both safety and outcomes for animal patients.

As technological advancements continue, reductions in cost are anticipated as surgical navigation systems become more efficient, widely accepted, and accessible in veterinary medicine. Innovations such as robotic assistance and AR are expected to become more affordable as competition and development of cost-effective solutions increase. These technologies will further enhance CASN by reducing intraoperative disruptions, streamlining system registration, and improving procedural precision.

Looking forward, efforts should focus on increasing CASN accessibility by lowering costs,expanding training and educational opportunities for veterinary surgeons, and refining hardware and software to better accommodate diverse species and anatomical challenges. Integration with robotics; 3-D–printed, patient-specific instruments; and AI-supported planning holds promise for improving reproducibility and efficiency.

Overall, as CASN technologies continue to mature, their adoption in veterinary medicine is poised to expand, supporting minimally invasive procedures, reducing radiation exposure for veterinary staff and personnel, and enabling translational research that bridges veterinary and human surgical innovations. By combining precision, reproducibility, and safety, CASN is set to redefine the standard of care across multiple veterinary surgical disciplines.

Acknowledgments

The authors would like to thank Leonardo Manetti and Ilaria Grossi from Imaginalis for providing the images for Figure 2 and Stephen Frey from Rogue Research for providing the images for Figure 6.

Disclosures

The authors have nothing to disclose. No AI-assisted technologies were used in the composition of this manuscript.

Publisher's Note

The American Veterinary Medical Association (AVMA), the Editor, and the Editorial Board are not responsible for the content, claims, opinions, or conclusions published in the Journal. These are solely those of the author(s), and publication does not imply endorsement by the AVMA, the Editor, or the Editorial Board. The Journal's content is provided for educational purposes only.

Funding

The authors acknowledge financial support from the Faculty Clinical Research Platform, Vetsuisse Faculty, University of Bern, which partially funds the employment of Dr. de Preux.

ORCID

Andres F. Bonilla https://orcid.org/0000-0003-4593-3173

Mathieu de Preux https://orcid.org/0000-0003-4357-6096

Julien Guevar https://orcid.org/0000-0001-9868-5703

Howard Seim https://orcid.org/0009-0008-2629-1164

Brad B. Nelson https://orcid.org/0000-0002-0205-418X

Christoph Koch https://orcid.org/0000-0002-4574-6952

Jeremiah T. Easley https://orcid.org/0000-0002-7294-6407

References

1. Giménez M, Gallix B, Costamagna G, et al. Definitions of computer-assisted surgery and intervention, image-guided surgery and intervention, hybrid operating room, and guidance systems. *Ann Surg Open.* 2020;1(2):e021. doi:10.1097/AS9.0000000000000021
2. Mezger U, Jendrewski C, Bartels M. Navigation in surgery. *Langenbecks Arch Surg.* 2013;398(4):501–514. doi:10.1007/s00423-013-1059-4
3. Fan X, Liu X, Xia Q, et al. Advanced image-guidance and surgical-navigation techniques for real-time visualized surgery. *Adv Sci.* 2025;12(41):e09294. doi:10.1002/advs.202509294
4. Wilson JP, Fontenot L, Stewart C, Kumbhare D, Guthikonda B, Hoang S. Image-guided navigation in spine surgery: from historical developments to future perspectives. *J Clin Med.* 2024;13(7):2036. doi:10.3390/jcm13072036
5. Zheng G, Nolte LP. Computer-assisted orthopedic surgery: current state and future perspective. *Front Surg.* 2015;2:66. doi:10.3389/fsurg.2015.00066
6. Nilsson J, Hindocha N, Thor A. Time matters – differences between computer-assisted surgery and conventional planning in cranio-maxillofacial surgery: a systematic review and meta-analysis. *J Craniomaxillofac Surg.* 2020;48(2):132–140. doi:10.1016/j.jcms.2019.11.024
7. Rosvall BR, Choby GW. Navigating the nose—the future of endoscopic endonasal surgical navigation. *JAMA Otolaryngol Head Neck Surg.* 2024;150(4):326–327. doi:10.1001/jamaoto.2024.0025
8. Tzelnick S, Rampinelli V, Sahovaler A, et al. Skull-base surgery—a narrative review on current approaches and future developments in surgical navigation. *J Clin Med.* 2023;12(7):2706. doi:10.3390/jcm12072706
9. Jensen MA, Neimat JS, Kerezoudis P, et al. Principles of stereotactic surgery. *Oper Neurosurg.* 2025;28(3):303–321. doi:10.1227/ons.0000000000001422
10. Ahmadian A, Farnia P, Najafzadeh E, Lavasani SN, Aziz MJ, Ahmadian A. Fundamentals of navigation surgery. In: Parhiz SA, James JN, Ghasemi S, Amirzade-Iranaq MH, eds. *Navigation in Oral and Maxillofacial Surgery.* Springer International Publishing; 2022:1–50. doi:10.1007/978-3-031-06223-0_1
11. Grunert P, Müller-forell W, Darabi K, et al. Basic principles and clinical applications of neuronavigation and intraoperative computed tomography. *Comput Aided Surg.* 1998;3(4):166–173. doi:10.3109/10929089809148141
12. Yang R, Wang Z, Liu S, Wu X. Design of an accurate near infrared optical tracking system in surgical navigation. *J Lightwave Technol.* 2013;31(2):223–231. doi:10.1109/JLT.2012.2227943
13. Mekuria K, Kim Y, Cho H, et al. The effect of optical marker configuration on tracking accuracy in image guided surgery. *Stud Health Technol Inform.* 2016;220:227–232.
14. Gutmann S, Heiderhoff M, Möbius R, Siegel T, Flegel T. Application accuracy of a frameless optical neuronavigation system as a guide for craniotomies in dogs. *Acta Vet Scand.* 2023;65(1):54. doi:10.1186/s13028-023-00720-y
15. Schneider D, Hermann J, Gerber KA, et al. Noninvasive registration strategies and advanced image guidance technology for submillimeter surgical navigation accuracy in the lateral skull base. *Otol Neurotol.* 2018;39(10):1326–1335. doi:10.1097/MAO.0000000000001993
16. Rossol M, Gygax D, Andritzky-Waas J, et al. Comparison of computer assisted surgery with conventional technique for treatment of abaxial distal phalanx fractures in horses: an in vitro study. *Vet Surg.* 2008;37(1):32–42. doi:10.1111/j.1532-950X.2007.00346.x
17. Schwarz CS, Rudolph T, Kowal JH, Auer JA. Introduction of 3.5mm and 4.5mm cortex screws into the equine distal sesamoid bone with the help of the VetGate computer assisted surgery systems and comparison of the results with the previously reported ones, acquired with the SurgiGATE 1.0 system – an in vitro study. *Pferdeheilkd Equine Med.* 2017;33(3):223–230. doi:10.21836/PEM20170302
18. Schwarz CS, Rudolph T, Kowal JH, Auer JA. Comparison of the VetGate and SurgiGATE 1.0 computer assisted surgery systems for insertion of cortex screws across the distal phalanx in horses – an in vitro study. *Pferdeheilkd Equine Med.* 2017;33(2):120–126. doi:10.21836/PEM20170202

19. Gygax D, Lischer C, Nitzel D, Rossol M, Auer JA. Computer-Assisted surgery for screw insertion into the distal sesamoid bone in horses: an in vitro study. *Vet Surg.* 2006;35(7):626–633. doi:10.1111/j.1532-950X.2006.00200.x
20. Heer C, Fürst AE, Del Chicca F, Jackson MA. Comparison of 3D-assisted surgery and conservative methods for treatment of type III fractures of the distal phalanx in horses. *Equine Vet Educ.* 2020;32(suppl 10):42–51. doi:10.1111/eve.13232
21. Stucki G, Fürst AE, Jackson MA. Navicular bone fractures in horses: prognosis after conservative and surgical treatment. *Schweiz Arch Tierheilkd.* 2024;166(6):309–320. doi:10.17236/sat00425
22. de Preux M, Klopfenstein Bregger MD, Brünisholz HP, Van der Vekens E, Schweizer-Gorgas D, Koch C. Clinical use of computer-assisted orthopedic surgery in horses. *Vet Surg.* 2020;49(6):1075–1087. doi:10.1111/vsu.13486
23. de Preux M, Precht C, Travaglini AT, et al. Influence of the Vertek aiming device on the surgical accuracy of computer-assisted drilling of the equine distal sesamoid bone—an experimental cadaveric study. *Vet Surg.* 2025;54(1):118–128. doi:10.1111/vsu.14176
24. de Preux M, Vidondo B, Koch C. Influence of a purpose-built frame on the accuracy of computer-assisted orthopedic surgery of equine extremities. *Vet Surg.* 2020;49(7):1367–1377. doi:10.1111/vsu.13484
25. de Preux M, van der Vekens E, Racine J, et al. Accessory carpal bone fracture repair by means of computer-assisted orthopaedic surgery in a warmblood stallion. *Equine Vet Educ.* 2022;34(11):e478–e484. doi:10.1111/eve.13594
26. Claeys I, Van der Vekens E, Kümmerle J, de Preux M, Koch C. Computer-assisted surgery for placing toggle constructs across the coxofemoral joints of small equids using a minimally invasive approach–a proof-of-concept cadaveric study. *Vet Surg.* 2023;52(7):994–1008. doi:10.1111/vsu.14004
27. Wolf ND, Kleiner L, Precht C, et al. Minimally invasive computer-assisted repair of feline sacroiliac luxation—a cadaveric study. *Front Vet Sci.* 2025;12:1528345. doi:10.3389/fvets.2025.1528345
28. Kleiner L, Wolf N, Precht C, Haenssgen K, Forterre F, Düver P. Feline sacroiliac luxation: comparison of fluoroscopy-controlled freehand vs. computer-navigated drilling in the sacrum—a cadaveric study. *Front Vet Sci.* 2025;11:1510253. doi:10.3389/fvets.2024.1510253
29. Peters KM, Hutter E, Siston RA, Bertran J, Allen MJ. Surgical navigation improves the precision and accuracy of tibial component alignment in canine total knee replacement. *Vet Surg.* 2016;45(1):52–59. doi:10.1111/vsu.12429
30. Townsend A, Guevar J, Oxley B, Hetzel S, Bleedorn J. Comparison of three-dimensional printed patient-specific guides versus freehand approach for radial osteotomies in normal dogs: ex vivo model. *Vet Surg.* 2024;53(2):234–242. doi:10.1111/vsu.13968
31. De Armond CC, Lewis DD, Kim SE, Biedrzycki AH. Accuracy of virtual surgical planning and custom three-dimensionally printed osteotomy and reduction guides for acute uni- and biapical correction of antebrachial deformities in dogs. *J Am Vet Med Assoc.* 2022;260(13):1–9. doi:10.2460/javma.21.09.0419
32. Carwardine DR, Gosling MJ, Burton NJ, O'Malley FL, Parsons KJ. Three-dimensional-printed patient-specific osteotomy guides, repositioning guides and titanium plates for acute correction of antebrachial limb deformities in dogs. *Vet Comp Orthop Traumatol.* 2021;34(1):43–52. doi:10.1055/s-0040-1709702
33. Hall EL, Baines S, Bilmont A, Oxley B. Accuracy of patient-specific three-dimensional-printed osteotomy and reduction guides for distal femoral osteotomy in dogs with medial patella luxation. *Vet Surg.* 2019;48(4):584–591. doi:10.1111/vsu.13126
34. Longo F, Penelas A, Gutbrod A, Pozzi A. Three-dimensional computer-assisted corrective osteotomy with a patient-specific surgical guide for an antebrachial limb deformity in two dogs. *Schweiz Arch Tierheilkd.* 2019;161(7):473–479. doi:10.17236/sat00216
35. Crosse KR, Worth AJ. Computer-assisted surgical correction of an antebrachial deformity in a dog. *Vet Comp Orthop Traumatol.* 2010;23(5):354–361. doi:10.3415/VCOT-10-01-0010
36. Johnson MD, Lewis DD, Sutton WA, et al. Efficacy of two reduction methods in conjunction with 3-D–printed patient-specific pin guides for aligning simulated comminuted tibial fractures in cadaveric dogs. *Am J Vet Res.* 2022;83(9):ajvr.21.12.0215. doi:10.2460/ajvr.21.12.0215
37. Lynch A, Davies J. Percutaneous tibial fracture reduction using computed tomography imaging, computer modelling and 3D printed alignment constructs: a cadaveric study. *Vet Comp Orthop Traumatol.* 2019;32(2):139–148. doi:10.1055/s-0039-1677751
38. Scheuermann LM, Lewis DD, Johnson MD, Biedrzycki AH, Kim SE. Efficacy of virtual surgical planning and a three-dimensional-printed, patient-specific reduction system to facilitate alignment of diaphyseal tibial fractures stabilized by minimally invasive plate osteosynthesis in dogs: a prospective clinical study. *Vet Surg.* 2024;53(6):1039–1051. doi:10.1111/vsu.14118
39. Dalton CL, Kim SE, Biedrzycki AH, Mullen KM. Minimally invasive repair of acetabular fractures in dogs: ex vivo feasibility study and case report. *Vet Surg.* 2023;52(6):836–845. doi:10.1111/vsu.13937
40. Oxley B. A 3-dimensional-printed patient-specific guide system for minimally invasive plate osteosynthesis of a comminuted mid-diaphyseal humeral fracture in a cat. *Vet Surg.* 2018;47(3):445–453. doi:10.1111/vsu.12776
41. Darrow BG, Snowdon KA, Hespel A. Accuracy of patient-specific 3D printed drill guides in the placement of a canine coxofemoral toggle pin through a minimally invasive approach. *Vet Comp Orthop Traumatol.* 2021;34(1):1–8. doi:10.1055/s-0040-1719169
42. Fracka AB, Oxley B, Allen MJ. 3D-printed, patient-specific cutting guides improve femoral and tibial cut alignment in canine total knee replacement. *Vet Surg.* 2023;52(5):674–685. doi:10.1111/vsu.13963
43. De Armond CC, Kim SE, Lewis DD, et al. Three-dimensional-printed custom guides for bipolar coxofemoral osteochondral allograft in dogs. *PLoS One.* 2021;16(2):e0244208. doi:10.1371/journal.pone.0244208
44. Gauci MO. Patient-specific guides in orthopedic surgery. *Orthop Traumatol Surg Res.* 2022;108(1S):103154. doi:10.1016/j.otsr.2021.103154
45. Tsuka T, Yamahita M, Okamoto Y, et al. Utility of a free-hand frameless navigation system in computed tomography-assisted ventral bulla osteotomy for otitis media in calves. *PLoS One.* 2026;21(2):e0342569. doi:10.1371/journal.pone.0342569
46. Orgonikova I, Brocal J, Cherubini GB, Palus V. Vertebral fractures and luxations in dogs and cats, part 1: evaluation of diagnosis and prognosis. *Companion Anim.* 2021;26(2):1–10. doi:10.12968/coan.2020.0027
47. Watine S, Cabassu JP, Catheland S, Brochier L, Ivanoff S. Computed tomography study of implantation corridors in canine vertebrae. *J Small Anim Pract.* 2006;47(11):651–657. doi:10.1111/j.1748-5827.2006.00070.x
48. Wininger F. Neuronavigation in small animals. *Vet Clin North Am Small Anim Pract.* 2014;44(6):1235–1248. doi:10.1016/j.cvsm.2014.07.015
49. Papacella-Beugger A, Forterre F, Samer E, et al. Spinal neuronavigation for lumbar plate fixation in miniature breed dogs. *Vet Comp Orthop Traumatol.* 2024;37(06):279–285. doi:10.1055/s-0044-1787707
50. Guevar J, Samer ES, Precht C, Rathmann JMK, Forterre F. Accuracy and safety of neuronavigation for minimally invasive stabilization in the thoracolumbar spine using polyaxial screws-rod: a canine cadaveric proof of concept. *Vet Comp Orthop Traumatol.* 2022;35(6):370–380. doi:10.1055/s-0042-1750056

51. Käfer-Karrer MJ, de Preux M, Van der Vekens E, et al. Internal fixation of a fractured cranial articular process of the sixth cervical vertebra by means of computer-assisted surgery in a warmblood gelding. *Vet Surg.* 2025; 54(5):920–929. doi:10.1111/vsu.14273
52. Maurer T, de Preux M, Precht C, Vidondo B, Koch C. Accuracy of computer-assisted drilling of equine cervical vertebral bodies using a purpose-built cervical frame—an experimental cadaveric study. *Vet Surg.* 2025;54(5): 898–908. doi:10.1111/vsu.14271
53. Nelson BB, Easley JT. Current and future central nervous system surgery—part 1. *Vet Clin North Am Equine Pract.* 2026;42(1):171–183. doi:10.1016/j.cveq.2025.12.006
54. Nelson BB, Easley JT. Current and future central nervous system surgery—part 2. *Vet Clin North Am Equine Pract.* 2026;42(1):185–197. doi:10.1016/j.cveq.2025.12.007
55. Masca SA, Easley JT, Koch DW, Aragon JM, Winston SE, Bonilla AF. A pilot study to assess feasibility of a computer-assisted surgery system for navigation in the equine cervical spine. *Am J Vet Res.* 2026;87(6):ajvr.25.12.0441. doi:10.2460/ajvr.25.12.0441
56. von Jako RA, Cselik Z. Percutaneous laser discectomy guided with stereotactic computer-assisted surgical navigation. *Lasers Surg Med.* 2009;41(1):42–51. doi:10.1002/lsm.20728
57. Chai BNW, Chen Y, Sheng L, Huang Y. An animal model study of simplified optical navigation system-assisted percutaneous lumbar transforaminal puncture. *J Orthop Surg Res.* 2025;20(1):757. doi:10.1186/s13018-025-06191-3
58. Bonilla AF, Seim HB III, Gadomski B, Patel VV, Easley JT. Ovine models of intervertebral disc degeneration. *Ann Transl Med.* 2025;13(6):79–79. doi:10.21037/atm-25-136
59. Liuti T, Reardon R, Dixon PM. Computed tomographic assessment of equine maxillary cheek teeth anatomical relationships, and paranasal sinus volumes. *Vet Rec.* 2017;181(17):452–452. doi:10.1136/vr.104185
60. Bar-Am Y, Pollard RE, Kass PH, Verstraete FJM. The diagnostic yield of conventional radiographs and computed tomography in dogs and cats with maxillofacial trauma. *Vet Surg.* 2008;37(3):294–299. doi:10.1111/j.1532-950X.2008.00380.x
61. Greim E, de Preux M, Koch C, et al. Computer-assisted removal of an ectopic tooth from the mandibular fossa through a mandibular condylectomy approach in a Comptois gelding. *Equine Vet Educ.* 2023;35(5): e364–e371. doi:10.1111/eve.13742
62. Klopfenstein Bregger MD, de Preux M, Brünisholz HP, Van der Vekens E, Schweizer D, Koch C. Cheek tooth repulsion aided by computer-assisted surgery in 16 equids. *Front Vet Sci.* 2025;12. doi:10.3389/fvets.2025.1571539
63. Jiang T, Zhu M, Chai G, Li Q. Precision of a novel craniofacial surgical navigation system based on augmented reality using an occlusal splint as a registration strategy. *Sci Rep.* 2019;9(1):501. doi:10.1038/s41598-018-36457-2
64. Feng Z, Zhao J, Zhou L, Dong Y, Zhao Y. Modified animal model and computer-assisted approach for dentoalveolar distraction osteogenesis to reconstruct unilateral maxillectomy defect. *J Oral Maxillofac Surg.* 2009;67(10): 2266–2274. doi:10.1016/j.joms.2009.04.070
65. Santistevan L, Easley J, Ruple A, et al. A pilot study of optical neuronavigation-guided brain biopsy in the horse using anatomic landmarks and fiducial arrays for patient registration. *J Vet Intern Med.* 2020;34(4):1642–1649. doi:10.1111/jvim.15813
66. Vanhaezebrouck IF, Ballegeer EA, Frey S, Sieffert R. Accuracy and precision of a veterinary neuronavigation system for radiation oncology positioning. *J Vet Med.* 2018;2018:6431749. doi:10.1155/2018/6431749
67. Gutmann S, Tästensen C, Böttcher IC, et al. Clinical use of a new frameless optical neuronavigation system for brain biopsies: 10 cases (2013–2020). *J Small Anim Pract.* 2022;63(6):468–481. doi:10.1111/jsap.13482
68. Troxel MT, Vite CH. CT-guided stereotactic brain biopsy using the Kopf stereotactic system. *Vet Radiol Ultrasound.* 2008;49(5):438–443. doi:10.1111/j.1740-8261.2008.00403.x
69. Flegel T, Podell M, March PA, Chakeres DW. Use of a disposable real-time CT stereotactic navigator device for minimally invasive dog brain biopsy through a mini-burr hole. *AJNR Am J Neuroradiol.* 2002;23(7):1160–1163.
70. Giroux A, Jones JC, Bohn JH, Duncan RB, Waldron DR, Inzana KR. A new device for stereotactic CT-guided biopsy of the canine brain: design, construction, and needle placement accuracy. *Vet Radiol Ultrasound.* 2002; 43(3):229–236. doi:10.1111/j.1740-8261.2002.tb00995.x
71. Añor S, Sturges BK, Lafranco L, et al. Systemic phaeohyphomycosis (*Cladophialophora bantiana*) in a dog—clinical diagnosis with stereotactic computed tomographic-guided brain biopsy. *J Vet Intern Med.* 2001; 15(3):257. doi:10.1892/0891-6640(2001)015<0257:SPBIAD>2.3.CO;2
72. Moissonier P, Bordeau W, Delisle F, Devauchelle P. Accuracy testing of a new stereotactic -guided brain biopsy device in the dog. *Res Vet Sci.* 2000;68(3): 243–247. doi:10.1053/rvsc.1999.0370
73. Rossmeisl JH, Andriani RT, Cecere TE, et al. Frame-based stereotactic biopsy of canine brain masses: technique and clinical results in 26 cases. *Front Vet Sci.* 2015;2:20. doi:10.3389/fvets.2015.00020
74. Squires AD, Gao Y, Taylor SF, Kent M, Tse ZTH. A simple and inexpensive stereotactic guidance frame for MRI-guided brain biopsy in canines. *J Med Eng.* 2014;2014:139535. doi:10.1155/2014/139535
75. Yang CC, Huang WH, Chang YP. Accuracy of a frameless optical stereotactic neuronavigation system for brain biopsy in cats: a cadaveric study. *Taiwan Vet J.* 2024;49(1):31–38. doi:10.1142/S1682648524500021
76. Kim T, Jeon Y, Kim Y, et al. Comparison of accuracy of brain biopsy simulation between 3-dimensional–printed guides and neuronavigation in skull-brain tumor models of dogs and cats. *Am J Vet Res.* Published online December 5, 2024. doi:10.2460/ajvr.24.10.0301
77. Dockx R, Peremans K, Duprat R, et al. Accurate external localization of the left frontal cortex in dogs by using pointer based frameless neuronavigation. *PeerJ.* 2017;5:e3425. doi:10.7717/peerj.3425
78. Chen AV, Wininger FA, Frey S, et al. Description and validation of a magnetic resonance imaging-guided stereotactic brain biopsy device in the dog. *Vet Radiol Ultrasound.* 2012;53(2):150–156. doi:10.1111/j.1740-8261.2011.01889.x
79. Jeon Y, Cho C, Jeong J, Meij B, Lee H. Comparative accuracy evaluation of patient-specific 3D-printed guide and neuronavigation for ventriculoperitoneal shunt in dogs: a dual-phase ex vivo and in vivo study. *Front Vet Sci.* 2025;12:1665844. doi:10.3389/fvets.2025.1665844
80. Meneses F, Maiolini A, Forterre F, Oevermann A, Schweizer-Gorgas D. Feasability of a frameless brain biopsy system for companion animals using cone-beam CT-based automated registration. *Front Vet Sci.* 2022; 8:779845. doi:10.3389/fvets.2021.779845
81. Staudacher A, Oevermann A, Stoffel MH, Gorgas D. Validation of a magnetic resonance imaging guided stereotactic access to the ovine brainstem. *BMC Vet Res.* 2014;10(1):216. doi:10.1186/s12917-014-0216-5
82. Long S, Frey S, Freestone DR, et al. Placement of deep brain electrodes in the dog using the Brainsight frameless stereotactic system: a pilot feasibility study. *J Vet Intern Med.* 2014;28(1):189–197. doi:10.1111/jvim.12235
83. Rogers CB, Meller S, Meyerhoff N, Volk HA. Comparative subcutaneous and submuscular implantation of an electroencephalography device for long term electroencephalographic monitoring in dogs. *Front Vet Sci.* 2024;11:1419792. doi:10.3389/fvets.2024.1419792
84. Dockx R, Peremans K, Vlerick L, et al. Anaesthesia, not number of sessions, influences the magnitude and duration of an aHF-rTMS in dogs. *PLoS One.* 2017;12(9):e0185362. doi:10.1371/journal.pone.0185362

85. Doran CE, Frank CB, McGrath S, Packer RA. Use of handheld Raman spectroscopy for intraoperative differentiation of normal brain tissue from intracranial neoplasms in dogs. *Front Vet Sci.* 2022;8:819200. doi:10.3389/fvets.2021.819200
86. van Rijn SJ, Galac S, Tryfonidou MA, et al. The influence of pituitary size on outcome after transsphenoidal hypophysectomy in a large cohort of dogs with pituitary-dependent hypercortisolism. *J Vet Intern Med.* 2016;30(4):989–995. doi:10.1111/jvim.14367
87. Owen TJ, Chen AV, Frey S, Martin LG, Kalebaugh T. Transsphenoidal surgery: accuracy of an image-guided neuronavigation system to approach the pituitary fossa (sella turcica). *Vet Surg.* 2018;47(5):664–671. doi:10.1111/vsu.12906
88. de Preux M, Precht C, Guevar J, et al. A transmandibular lateral transsphenoidal navigated surgical approach to access a pituitary macroadenoma in a warmblood mare. *Vet Q.* 2024;44(1):1–10. doi:10.1080/01652176.2023.2300947
89. de Preux M, Precht C, Becker R, Stieglitz L, Easley J, Koch C. Navigated minimally invasive puncture of the trigeminal cistern in horses—a cadaveric study in preparation for a controlled rhizotomy. *Front Vet Sci.* 2025;12:1562404. doi:10.3389/fvets.2025.1562404
90. Koch C, Pauwels F, Schweizer-Gorgas D. Technical set-up and case illustrations of orthopaedic cone beam computed tomography in the standing horse. *Equine Vet Educ.* 2021;33(5):255–262. doi:10.1111/eve.13290
91. Bai YS, Zhang Y, Chen ZQ, et al. Learning curve of computer-assisted navigation system in spine surgery. *Chin Med J (Engl).* 2010;123(21):2989–2994.
92. Rigo M, Cinti F, Menchetti M, Ventura L, Pratesi A. Feasibility and accuracy of pedicle screws in the feline thoracolumbar spine. *Vet Comp Orthop Traumatol.* 2025;39(2):81–88. doi:10.1055/a-2653-2592
93. Hobert M, Sharma N, Benzimra C, et al. Case report: one-stage craniectomy and cranioplasty digital workflow for three-dimensional printed polyetheretherketone implant for an extensive skull multilobular osteochondosarcoma in a dog. *Front Vet Sci.* 2024;11:1459272. doi:10.3389/fvets.2024.1459272
94. Scheuermann LM, Lewis DD, Johnson MD, Biedrzycki AH, Kim SE. Virtual surgical planning and use of a 3D-printed, patient-specific reduction system for minimally invasive plate osteosynthesis of diaphyseal tibial fractures in dogs: a historic case control study. *Vet Surg.* 2024;53(6):1052–1061. doi:10.1111/vsu.14112
95. Baraza N, Chapman C, Zakani S, Mulpuri K. 3D - printed patient specific instrumentation in corrective osteotomy of the femur and pelvis: a review of the literature. *3D Print Med.* 2020;6(1):34. doi:10.1186/s41205-020-00087-0
96. Aghapour M, Bockstahler B. State of the art and future prospects of virtual and augmented reality in veterinary medicine: a systematic review. *Animals.* 2022;12(24):3517. doi:10.3390/ani12243517
97. Jiang N, Jiang Z, Huang Y, et al. Application of augmented reality models of canine skull in veterinary anatomical education. *Anat Sci Educ.* 2024;17(3):546–557. doi:10.1002/ase.2372
98. Zhou C, Zhu M, Shi Y, et al. Robot-assisted surgery for mandibular angle split osteotomy using augmented reality: preliminary results on clinical animal experiment. *Aesthetic Plast Surg.* 2017;41(5):1228–1236. doi:10.1007/s00266-017-0900-5
99. Chen Z, Cruciani L, Fan K, et al. Towards safer robot-assisted surgery: a markerless augmented reality framework. *Neural Netw.* 2024;178:106469. doi:10.1016/j.neunet.2024.106469
100. Buote NJ. Looking to the future; veterinary robotic surgery. *Vet Clin North Am Small Anim Pract.* 2024;54(4):735–751. doi:10.1016/j.cvsm.2024.02.008

Supplementary Materials

Supplementary materials are posted online at the journal website: avmajournals.avma.org.

Supplementary Table S1. Summary of computer-assisted orthopedic surgery studies in veterinary medicine. This narrative review summarizes the current evidence on computer-assisted surgical navigation across veterinary species and surgical disciplines, highlighting reported applications, accuracy outcomes, and translational potential.

Species	Anatomical Region	Navigation Technology	Study Type	Key Accuracy / Outcome Metric	Reference
Horse	Distal phalanx	fluoroscopy + optical tracking	Cadaveric	Improved angular accuracy of lag screw placement vs. conventional technique	[1,2]
Horse	Distal sesamoid bone	fluoroscopy + optical tracking	Cadaveric	Accurate screw insertion; submillimeter angular error	[3–6]
Horse	Distal phalanx	fluoroscopy + optical tracking	Clinical	Successful fracture fixation; comparable to conventional technique	[7]
Horse	Various orthopedic indications	CBCT + optical tracking	Clinical	Feasibility across multiple anatomical sites; reliable intraoperative guidance	[8]
Horse	Distal extremities	CBCT + optical tracking + PBF	Cadaveric	PBF significantly improved navigation accuracy	[9]
Horse	Distal sesamoid bone	CBCT + optical tracking + Vertek aiming device + PBF	Cadaveric	Aiming device significantly improved angular drilling accuracy	[10]
Horse	Accessory carpal bone	CBCT + optical tracking + tube cast stabilization	Clinical	Minimally invasive screw placement, accurate implant positioning confirmed	[11]
Horse	Coxofemoral joint	CBCT + optical tracking + calf jack stabilization	Cadaveric	Toggle construct placement; accurate minimally invasive approach	[12]
Dog	Tibia —Knee replacement	Image-free navigation + optical tracking	Cadaveric	Significantly improved tibial component alignment vs. conventional freehand	[13]
Cat	Sacroiliac joint	CBCT + optical tracking	Cadaveric	Accurate minimally invasive screw placement, feasibility confirmed	[14]

Species	Anatomical Region	Navigation Technology	Study Type	Key Accuracy / Outcome Metric	Reference
Bovine	Tympanic bulla	CT + optical tracking	Clinical	Successful ventral bulla osteotomy for otitis media; feasibility confirmed	15

CASN: Computer-assisted surgical navigation; CBCT: Cone-beam computed tomography; CT: Computed tomography; PBF: Purpose-built frame.

References

1. Rossol M, Gygax D, Andritzky-Waas J, et al. Comparison of Computer Assisted Surgery with Conventional Technique for Treatment of Abaxial Distal Phalanx Fractures in Horses: An In Vitro Study. *Veterinary Surgery*. 2008;37(1):32-42. doi:10.1111/j.1532-950X.2007.00346.x

2. Andritzky J, Rossol M, Lischer C, Auer JA. Comparison of Computer-Assisted Surgery with Conventional Technique for the Treatment of Axial Distal Phalanx Fractures in Horses: An In Vitro Study. *Veterinary Surgery*. 2005;34(2):120-127. doi:10.1111/j.1532-950X.2005.00019.x

3. Schwarz CS, Rudolph T, Kowal JH, Auer JA. Comparison of the VetGate and SurgiGATE 1.0 computer assisted surgery systems for insertion of cortex screws
across the distal phalanx in horses – an in vitro study. *Pferdeheilkunde Equine Medicine*. 2017;33(2):120-126. doi:10.21836/PEM20170202

4. Schwarz CS, Rudolph T, Kowal JH, Auer JA. Introduction of 3.5mm and 4.5mm cortex screws into the equine distal sesamoid bone with the help of the VetGate Computer Assisted Surgery Systems and comparison of the results with the previously reported ones, acquired with the SurgiGATE 1.0 System – an in vitro study. *Pferdeheilkunde Equine Medicine*. 2017;33(3):223-230. doi:10.21836/PEM20170302

5. Stucki G, Fürst AE, Jackson MA. Navicular bone fractures in horses: Prognosis after conservative and surgical treatment. *Schweiz Arch Tierheilkd*. 2024;166(6):309-320. doi:10.17236/sat00425

6. Gygax D, Lischer C, Nitzel D, Rossol M, Auer JA. Computer-Assisted Surgery for Screw Insertion into the Distal Sesamoid Bone in Horses: An In Vitro Study. *Veterinary Surgery*. 2006;35(7):626-633. doi:10.1111/j.1532-950X.2006.00200.x

7. Heer C, Fürst AE, Del Chicca F, Jackson MA. Comparison of 3D-assisted surgery and conservative methods for treatment of type III fractures of the distal phalanx in horses. *Equine Vet Educ*. 2020;32(S10):42-51. doi:10.1111/eve.13232

8. de Preux M, Klopfenstein Bregger MD, Brünisholz HP, Van der Vekens E, Schweizer-Gorgas D, Koch C. Clinical use of computer-assisted orthopedic surgery in horses. *Veterinary Surgery*. 2020;49(6):1075-1087. doi:10.1111/vsu.13486

9. de Preux M, Vidondo B, Koch C. Influence of a purpose-built frame on the accuracy of computer-assisted orthopedic surgery of equine extremities. *Veterinary Surgery*. 2020;49(7):1367-1377. doi:10.1111/vsu.13484

10. de Preux M, Precht C, Travaglini AT, et al. Influence of the Vertek aiming device on the surgical accuracy of computer-assisted drilling of the equine distal sesamoid bone—An experimental cadaveric study. *Veterinary Surgery*. 2025;54(1):118-128. doi:10.1111/vsu.14176

11. de Preux M, van der Vekens E, Racine J, et al. Accessory carpal bone fracture repair by means of computer-assisted orthopaedic surgery in a Warmblood stallion. *Equine Vet Educ*. 2022;34(11). doi:10.1111/eve.13594

12. Claeys I, Van der Vekens E, Kümmerle J, de Preux M, Koch C. Computer-assisted surgery for placing toggle constructs across the coxofemoral joints of small equids using a minimally invasive approach–A proof-of-concept cadaveric study. *Veterinary Surgery*. 2023;52(7):994-1008. doi:10.1111/vsu.14004

13. Peters KM, Hutter E, Siston RA, Bertran J, Allen MJ. Surgical Navigation Improves the Precision and Accuracy of Tibial Component Alignment in Canine Total Knee Replacement. *Veterinary Surgery*. 2016;45(1):52-59. doi:10.1111/vsu.12429

14. Wolf ND, Kleiner L, Precht C, et al. Minimally invasive computer-assisted repair of feline sacroiliac luxation—a cadaveric study. *Front Vet Sci*. 2025;12. doi:10.3389/fvets.2025.1528345

15. Tsuka T, Yamahita M, Okamoto Y, et al. Utility of a freehand frameless navigation system in computed tomography-assisted ventral bulla osteotomy for otitis media in calves. *PLoS One*. 2026;21(2):e0342569. doi:10.1371/journal.pone.0342569

Supplementary Table S2. Summary of computer-assisted spine surgery studies in veterinary medicine

Species	Anatomical Region	Navigation Technology	Study Type	Key Accuracy / Outcome Metric	Reference
Dog	Thoracolumbar spine	CBCT + optical tracking	Cadaveric	Polyaxial pedicle / locking head screws - cortical safety	1,2
Cat	Thoracolumbar spine	CBCT + optical tracking	Cadaveric	Feasibility and accuracy of screw placement confirmed	2
Horse	Cervical Spine	CBCT + optical tracking + cervical frame	Cadaveric	Ventral interbody approach Drilling accuracy within acceptable clinical range for ventral approach	3
Horse	Cervical spine	CBCT + optical tracking	Clinical	Successful navigated internal fixation	4
Horse	Cervical spine	CBCT + optical tracking	Cadaveric	Feasibility of C2 tracker fixation for lateral cervical navigation confirmed	5
Pig	Lumbar Spine	Stereotactic CASN + laser guidance	Cadaveric	Accurate percutaneous laser discectomy feasible; spine research model validated	6
Sheep	Thoracolumbar spine	CBCT + optical tracking	Preclinical in vivo	Accurate screw and rod placement for growing rod constructs in ovine model	7
Goat	Lumbar spine	Simplified optical navigation system	Cadaveric	Submillimeter accuracy	8

CASN: Computer-assisted surgical navigation; CBCT: Cone-beam computed tomography.

References

1. Guevar J, Samer ES, Precht C, Rathmann JMK, Forterre F. Accuracy and Safety of Neuronavigation for Minimally Invasive Stabilization in the Thoracolumbar Spine Using Polyaxial Screws-Rod: A Canine Cadaveric Proof of Concept. *Veterinary and Comparative Orthopaedics and Traumatology*. 2022;35(06):370-380. doi:10.1055/s-0042-1750056

2. Rigo M, Cinti F, Menchetti M, Ventura L, Pratesi A. Feasibility and Accuracy of Pedicle Screws in the Feline Thoracolumbar Spine. *Veterinary and Comparative Orthopaedics and Traumatology*. Published online July 22, 2025. doi:10.1055/a-2653-2592

3. Maurer T, de Preux M, Precht C, Vidondo B, Koch C. Accuracy of computer-assisted drilling of equine cervical vertebral bodies using a purpose-built cervical frame—An experimental cadaveric study. *Veterinary Surgery*. 2025;54(5):898-908. doi:10.1111/vsu.14271

4. Käfer-Karrer MJ, de Preux M, Van der Vekens E, et al. Internal fixation of a fractured cranial articular process of the sixth cervical vertebra by means of computer-assisted surgery in a Warmblood gelding. *Veterinary Surgery*. 2025;54(5):920-929. doi:10.1111/vsu.14273

5. Masca SA, Easley JT, Koch DW, Aragon JM, Winston SE, Bonilla AF. A pilot study to assess feasibility of a computer-assisted surgery system for navigation in the equine cervical spine. *Am J Vet Res*. Published online February 18, 2026:1-6. doi:10.2460/ajvr.25.12.0441

6. von Jako RA, Cselik Z. Percutaneous laser discectomy guided with stereotactic computer-assisted surgical navigation. *Lasers Surg Med*. 2009;41(1):42-51. doi:10.1002/lsm.20728

7. Bonilla AF, Seim III HB, Gadomski B, Patel V V., Easley JT. Ovine models of intervertebral disc degeneration. *Ann Transl Med*. 2025;13(6):79-79. doi:10.21037/atm-25-136

8. Chai BNW, Chen Y, Sheng L, Huang Y. An animal model study of simplified optical navigation system-assisted percutaneous lumbar transforaminal puncture. *J Orthop Surg Res*. 2025;20(1):757. doi:10.1186/s13018-025-06191-3

Supplementary Table S3. Summary of computer-assisted surgery in oral and maxillofacial studies in veterinary medicine

Species	Anatomical Region	Navigation Technology	Study Type	Key Accuracy / Outcome Metric	Reference
Horse	Mandibular fossa	CBCT + optical tracking	Clinical	Successful condylectomy and ectopic tooth removal; collateral damage avoided	1
Horse	Cheek teeth	CBCT + optical tracking	Clinical	Accurate dental punch alignment with tooth long axis	2
Horse	Skull base / pituitary	CBCT optical navigation	Clinical	Successful controlled access to pituitary macroadenoma via novel navigated approach	3
Horse	Trigeminal cistern	CBCT + optical navigation	Cadaveric	Accurate puncture of trigeminal cave; feasibility for controlled rhizotomy confirmed	4
Dog	Maxilla	PSI	Cadaveric	Custom guide improved resection accuracy vs. freehand approach	5
Dog	Mandible	PSI	Clinical	Successful mandibular reconstruction	6

CBCT: Cone-beam computed tomography, PSI: Patient Specific Instrumentation.

References

1. Greim E, de Preux M, Koch C, et al. Computer-assisted removal of an ectopic tooth from the mandibular fossa through a mandibular condylectomy approach in a Comptois gelding. *Equine Vet Educ*. 2023;35(5). doi:10.1111/eve.13742
2. Klopfenstein Bregger MD, de Preux M, Brünisholz HP, Van der Vekens E, Schweizer D, Koch C. Cheek tooth repulsion aided by computer-assisted surgery in 16 equids. *Front Vet Sci*. 2025;12. doi:10.3389/fvets.2025.1571539

3. de Preux M, Precht C, Guevar J, et al. A transmandibular lateral transsphenoidal navigated surgical approach to access a pituitary macroadenoma in a warmblood mare. *Veterinary Quarterly*. 2024;44(1):1-10. doi:10.1080/01652176.2023.2300947

4. de Preux M, Precht C, Becker R, Stieglitz L, Easley J, Koch C. Navigated minimally invasive puncture of the trigeminal cistern in horses—a cadaveric study in preparation for a controlled rhizotomy. *Front Vet Sci*. 2025;12. doi:10.3389/fvets.2025.1562404

5. Chambers A, Traverson M, Neal S, Konala S, Harrysson O. Performances of novel custom 3D-printed cutting guide in canine caudal maxillectomy: a cadaveric study. *Front Vet Sci*. 2023;10. doi:10.3389/fvets.2023.1127025

6. Sampaio E, Perry A, Freeman A. Mandibular Reconstruction With a Patient-Specific Implant Following Surgical Excision of an Acanthomatous Ameloblastoma in a Dog. *J Vet Dent*. 2025;42(5):382-396. doi:10.1177/08987564241306935