

Artificial Intelligence in Veterinary Medicine

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Artificial Intelligence (AI) technology is advancing at a rapid pace and is increasingly integrated into many areas of our life and work. It is crucial that we explore its potential impact on veterinary medicine, the veterinary workforce and animal welfare. From veterinary education to diagnostics, treatment, communications and workflows, AI impacts ever more in breadth and depth across the veterinary industry. This has important implications for animal health and welfare, and the working life and wellbeing of veterinary teams.

At VetCT, we strongly believe that the integration of AI tools into veterinary medicine has the potential to transform our industry and greatly benefit animal welfare. This white paper is designed to provide foundational understanding, explore current AI trends and developments across the sector, and encourage discussion and engagement with the many opportunities and challenges this technology presents.

Background:

Since its early development in the 1950s, AI has been successfully deployed across many global sectors, from data intelligence to automation tools. While many tools are already integrated into our daily lives, there is also enormous potential for AI to contribute to solving many of the present and future global challenges we face.

From research outputs and operational efficiencies and improving sustainability, to education, easing workforce strain and improving patient care, AI can provide time savings and insights wherever data exists to train, refine and query the AI models. With ever more complex 'deep learning', the non-human 'brain' provides an alternative, multi-layered neural network through which data can be analyzed and interpreted; AI thinks, but differently to us.

However, where there is opportunity there is also risk of misuse, misapplication and misinformation. A chasm exists between understanding and regulation of AI and development, deployment and commercialization of these technologies. As the pace of change accelerates, this gap is getting ever wider. Where technology icons such as Elon Musk and Geoffrey Hinton are respectively advising caution and even expressing regret for the way general AI is developing,¹ it sends a clear message that we need to ensure we are proactive in safeguarding against any negative impact on human and animal welfare.



What does all of this mean for the veterinary industry?

Unlike the highly regulated field of medical device development (including AI) in human medicine, there is currently no regulatory framework governing the development and implementation of AI tools in veterinary medicine. We need to recognize the importance of caution and responsibility when introducing such powerful technology that can impact both human and animal welfare. Therefore, it is our duty as veterinary professionals to hold ourselves accountable for ensuring the safety, accuracy, and reliability of any AI tools we develop or deploy.

In a field open to misinterpretation of data, even adversarially so, data transparency and use are key to successful outcomes. Deliberate manipulation of data can fool AI tools, such as a group from Massachusetts Institute of Technology demonstrating that image perturbations that the human eye perceives as minor alterations fooled an AI tool to misidentify an image of a tabby cat as having a higher probability of being guacamole.² While this is an amusing example, it begs the very serious question of what happens when the camera on a self-driving car becomes obscured leading to misinterpretation of blurred images of pedestrians?

There is a need to extend an evidence-based approach to AI development, coupled with transparency, ongoing quality assurance and risk:benefit analysis of use. We believe that AI tools should only be deployed in clinical practice once they have been fully validated, and that they should be continually monitored in clinical application following initial validation. In addition, it is vital that clear guidance and guardrails for optimal application of such tools is provided to veterinary professionals, decloaking the black box of AI mystery to ensure understanding and provide clear instruction of its data use, design, indications and limitations. This is vital to instill confidence and trust in AI technology, as only then will we realize its potential to solve more problems that it creates.





VetCT's position

As global leaders in veterinary radiology, a field of particularly rapid AI development, VetCT is committed to collaborating with stakeholders, both within and beyond the veterinary profession, to develop innovative and effective AI tools to improve workflows and for clinical applications. We also believe we have a responsibility to provide education on the safe and appropriate implementation of AI technology, while contributing to the discussion around proactive regulation to safeguard animal welfare. Further information can be found in the VetCT Position Statement on AI in Veterinary Radiology on the website.³

We are excited about the potential of AI in veterinary medicine, and committed to exploring this technology in a responsible and meaningful way. As we will discuss, the true power of AI lies in augmenting human intelligence, with the combination of natural and artificial intelligence being greater than the sum of its parts. We believe that the integration of AI tools in veterinary medicine will be a fundamental innovation in our industry, and we look forward to contributing to its development and implementation.

¹ <https://www.bbc.co.uk/news/technology-65110030>

² Athalye, A., Engstrom, L., Ilyas, A. and Kwok, K., 2018, July. Synthesizing robust adversarial examples. In International conference on machine learning (pp. 284-293). PMLR.

³ <https://www.vet-ct.com/gb/our-services/ai-veterinary-radiology/>

Artificial Intelligence (AI) has been a subject of intrigue, debate, and fascination for centuries. From ancient Greek myths of to Alan Turing's ground-breaking work in the 20th century, the idea of creating machines that can think and learn has captivated the human imagination.

Curiosity has often been balanced with uncertainty as we struggle to visualise how AI will impact our lives, both individually and socially. We may be ready to welcome AI empowered tools, yet anxious about how they impact our working and personal lives and how we might identify and mitigate the mistakes that are almost inevitable when introducing any new technology. How can we begin to fathom the impact of a technology that 'thinks', but not like us?

To foster trust in AI technology we must first lay the foundation of understanding.



AI terminology and methodology

Terminology in AI includes the types of algorithms such as machine learning, deep learning, natural language processing, and computer vision. Methodologies in the mechanisms used to train the AI models with large amounts of data to enable them to make decisions and predictions.

Terminology:

- **Artificial Intelligence (AI):** Refers to the simulation of human intelligence in machines designed to perform tasks that typically require human intelligence such as visual perception, speech recognition, decision-making, and language translation.
- **Machine Learning (ML):** A subfield of AI that involves building models that can learn from data, without being explicitly programmed. Machine learning algorithms can improve their accuracy over time with more data and feedback.
- **Deep Learning (DL):** A type of machine learning that uses artificial neural networks to model and solve complex problems, such as image and speech recognition.
- **Natural Language Processing (NLP):** A subfield of AI concerned with enabling computers to process, understand, and generate human language.
- **Natural Language Generation (NLG):** A subfield of NLP that involves generating human-like text from structured data. NLG is commonly used for tasks such as chatbots, automated writing, and content generation.
- **Computer Vision:** The field of AI that deals with enabling computers to interpret and understand visual information from the world, such as images and videos.

Methodologies:

- **Large Language Models (LLM):** A large language model (LLM) is a type of machine learning model that can perform a variety of natural language processing (NLP) tasks, including generating and classifying text, answering questions in a conversational manner and translating text from one language to another.
- **Artificial Neural Networks (ANN):** Machine learning models inspired by the structure and function of the human brain. ANN models consist of layers of interconnected nodes, or “neurons,” that process and transmit information between them.
- **Convolutional Neural Networks (CNN):** A type of ANN that is particularly well-suited for image and video recognition tasks. CNN models use convolutional layers to extract features from images and classify them.
- **Recurrent Neural Networks (RNN):** Another type of ANN that is designed to handle sequential data, such as text or time-series data. RNN models use feedback loops to enable the output of one time step to be fed back into the input of the next time step.
- **Long Short-Term Memory (LSTM):** A type of RNN that is designed to handle long-term dependencies in sequential data. LSTM models use memory cells and gating mechanisms to selectively store and forget information over time.
- **Support Vector Machines (SVM):** A supervised learning algorithm that is commonly used for classification and regression tasks. SVM models find the optimal hyperplane that separates data into different classes.
- **Decision Trees:** A type of supervised learning algorithm that is used for both classification and regression tasks. Decision tree models recursively partition data into subsets based on the values of input features, and make predictions based on these partitions.
- **Generative Adversarial Networks (GANs):** Deep learning algorithms that are used for generative tasks such as image and text synthesis. GANs consist of two neural networks, a generator network that creates fake data, and a discriminator network that distinguishes between real and fake data.
- **Transfer Learning:** Refers to a machine learning technique that involves using pre-trained models as a starting point for training new models. Transfer learning can save time and resources by leveraging the knowledge and expertise of existing models.
- **Reinforcement Learning:** This is a type of machine learning that involves training agents to interact with an environment and learn from feedback in the form of rewards or punishments. Reinforcement learning is commonly used for tasks such as game playing and robotics.
- **Bayesian Networks:** A probabilistic graphical model that represents the relationships between variables and their probabilities. Bayesian networks are commonly used for tasks such as prediction and decision-making.

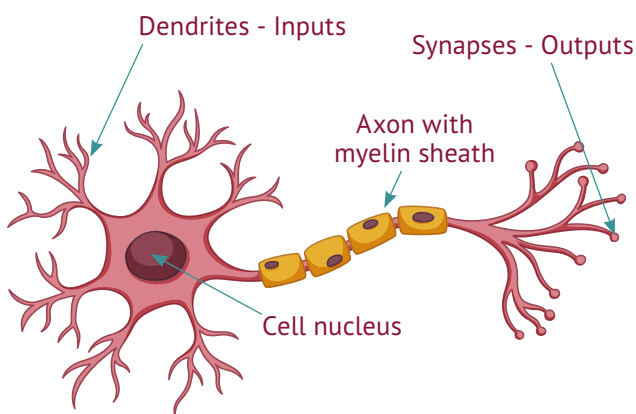
The history of AI

The history of AI can be traced back to ancient civilizations, where myths and legends about artificial beings and automatons were prevalent. The concept of intelligent machines was further explored by philosophers, mathematicians, and scientists over the centuries. In the 17th century, philosopher and mathematician René Descartes laid the foundations of the theory that complex cognitive function could be explained by mathematics and mechanics.¹

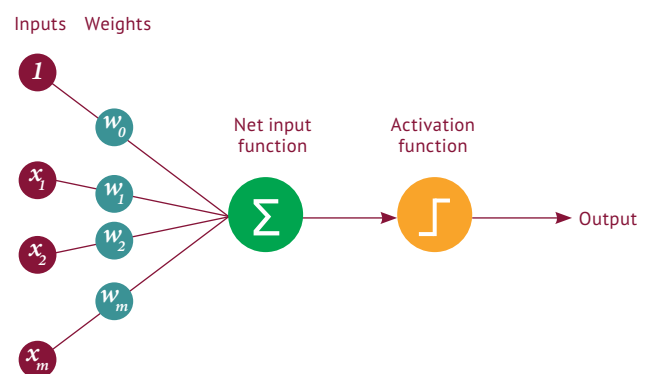
The 20th century witnessed the emergence of modern AI, with British mathematician and computer scientist Alan Turing leading the charge inspired by Descartes theories. Turing's 1950 paper, "Computing Machinery and Intelligence," introduced the Turing Test, a method to determine whether a machine could exhibit intelligent behavior indistinguishable from that of a human.²

The 1940s - 1960s saw work on the mathematical representation of a single neuron, known as a Perceptron, which was implemented algorithmically by Rosenblatt in 1958.

This is a key early step in the development of AI.³



NEURON



In the 1960s, researchers began to explore the idea of machine learning - the process by which computers can learn from data and improve over time. The concept of artificial neural networks gained traction during the 1980s, with back-propagation algorithms emerging as a crucial breakthrough for training multi-layered networks.

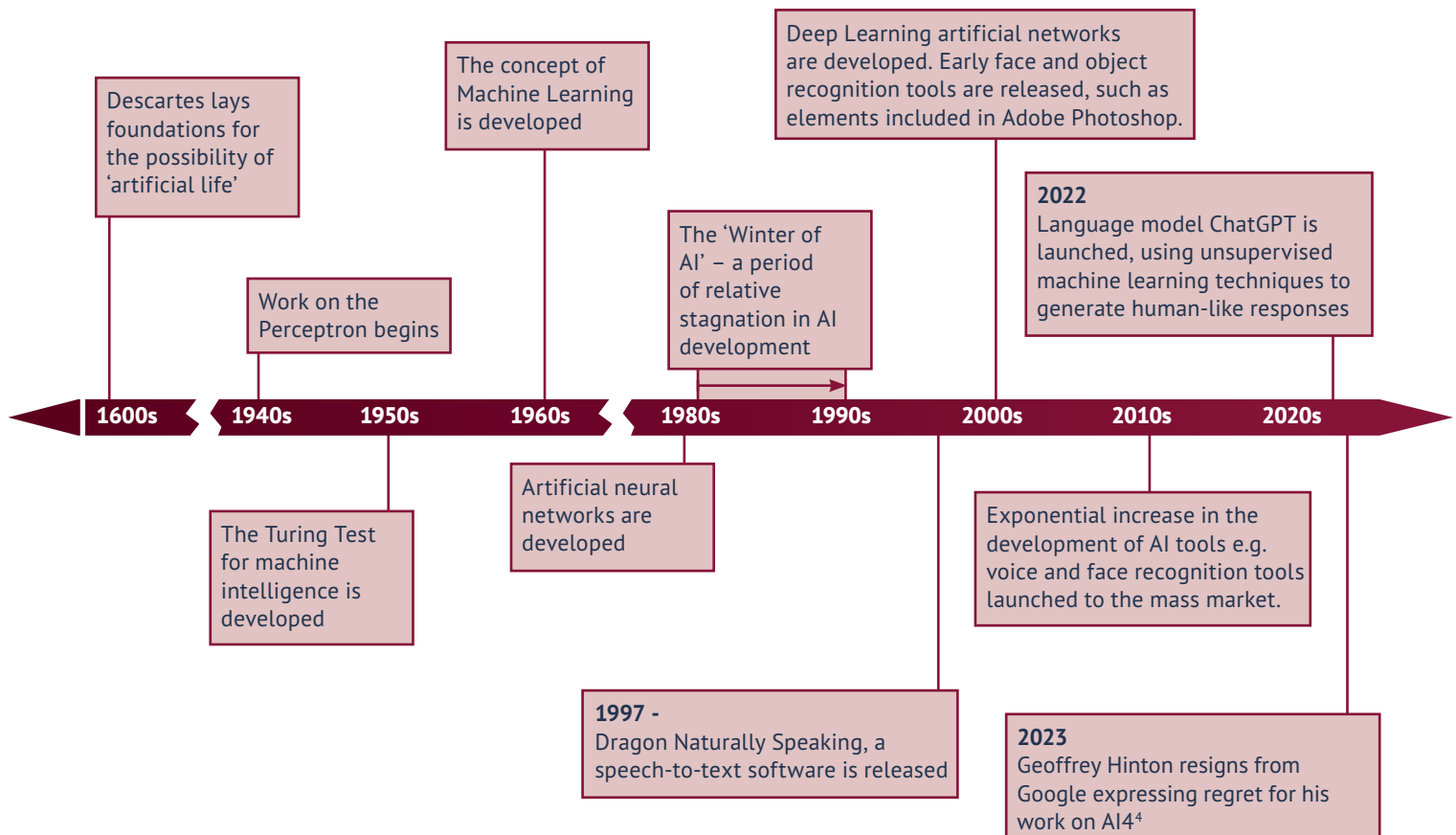
Following a couple of decades of relative stagnation as internet usage and capability developed, the 21st century is now seeing the rise of deep learning, a subset of machine learning that uses artificial neural networks with many layers to model complex data patterns. This work was led by three pioneers dubbed the "Godfathers of modern AI and Deep Learning" - Geoffrey Hinton, Yann LeCun and Joshua Bengio.

The exponential increase in AI in the region of 2010 can be attributed to several factors, including:

- **Advancements in hardware:** The widespread availability of high-performance GPUs (graphics processing units) and other specialized hardware made it possible to train more complex AI models.
- **Increased data availability:** The massive amounts of data generated by the internet and other sources provided a wealth of information that AI models could use to learn.
- **Improved algorithms:** Researchers developed new algorithms and network architectures that were more effective at training AI models, such as deep learning and reinforcement learning.
- **Interdisciplinary research:** The growth of AI was driven by collaboration between researchers in a wide range of fields, including computer science, mathematics, physics, and psychology.
- **Industry investment:** Companies such as Google, Microsoft, Amazon, and others invested heavily in AI research and development, providing funding and resources to support the growth of the field.

This all led to significant advancements in AI capabilities, particularly in areas such as image and speech recognition, natural language processing, and reinforcement learning.

AI has evolved into a transformative force in modern society. As we continue to push the boundaries of AI research and applications, the potential for AI to revolutionize various aspects of human life becomes increasingly apparent.



History of AI in veterinary medicine

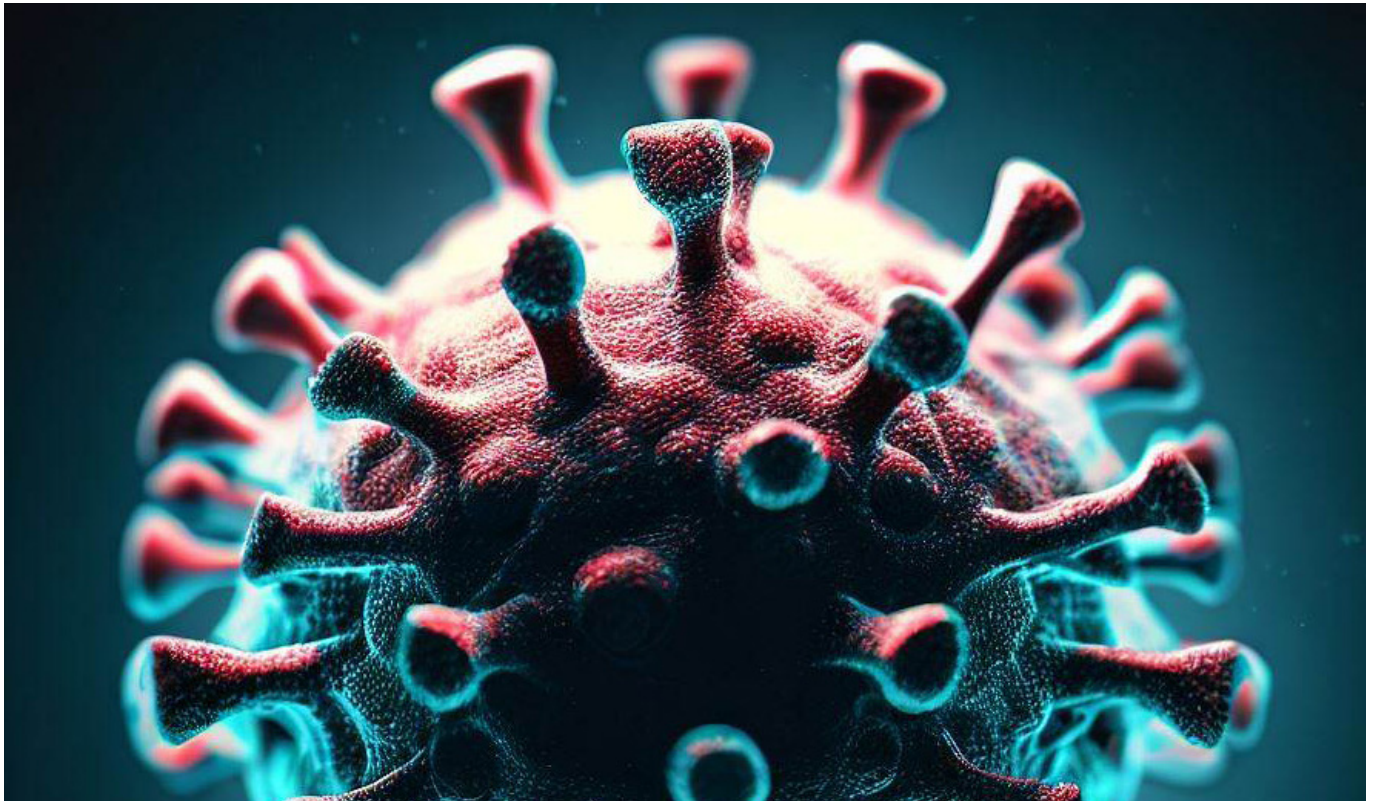
The history of AI in veterinary medicine is relatively short, however, there have been a number of notable developments and applications of AI in veterinary medicine in recent years.

There has been increasing interest and development of machine learning algorithms that can be trained on large sets of data to make predictions and diagnose diseases. These systems have been used in veterinary medicine to predict, diagnose and treat a variety of animal diseases, such as diagnosis of intestinal parasites.⁵

AI is also being applied in veterinary medicine in motion analysis. Examples include AI motion analysis to identify lameness straight from video with Sleip⁶, and the estimation of postural behaviors using remote 2D and 3D markers, such as DeepCutLab.⁷ Veterinary radiology is an interesting field of rapid AI development due to the availability of large digital data sources. We will discuss radiology in a later section.

At a population level, there is potential to apply AI to predictive epidemiology and the study of host-pathogen interactions in animal health. AI may be able to represent, model and predict outcomes in complex biological systems, speeding-up decisions and improving accuracy in risk analyses, informing better targeting of interventions.⁸





A timely example was highlighted in a systematic review of AI employed during the Covid pandemic highlighted its utility in achieving high performance in diagnosis, prognosis evaluation, epidemic prediction and drug discovery for COVID-19. The authors concluded that AI has the potential to enhance significantly existing medical and healthcare system efficiency during the COVID-19 pandemic.⁹

Overall, the use of AI in veterinary medicine is still in its early stages, but used wisely it has the potential to revolutionize the field, support veterinary teams and improve the health of animals, as we go on to discuss next.

¹ https://en.wikipedia.org/wiki/Ren%C3%A9_Descartes

² A. M. TURING, I.—COMPUTING MACHINERY AND INTELLIGENCE, *Mind*, Volume LIX, Issue 236, October 1950, Pages 433–460, <https://doi.org/10.1093/mind/LIX.236.433>

³ Ref: <https://en.wikipedia.org/wiki/Perceptron>

⁴ <https://www.bbc.co.uk/news/world-us-canada-65452940>

⁵ <https://www.vetscanimagyst.co.uk/HowItWorks.aspx#performance>

⁶ <https://sleip.com/>

⁷ <http://www.mackenziemathislab.org/deeplabcut>

⁸ Ezanno, P., Picault, S., Beaunée, G. et al. Research perspectives on animal health in the era of artificial intelligence. *Vet Res* 52, 40 (2021). <https://doi.org/10.1186/s13567-021-00902-4>

⁹ Wang, L., Zhang, Y., Wang, D., Tong, X., Liu, T., Zhang, S., Huang, J., Zhang, L., Chen, L., Fan, H., & Clarke, M. (2021). Artificial Intelligence for COVID-19: A Systematic Review. *Frontiers in Medicine*, 8. <https://doi.org/10.3389/fmed.2021.704256>

Artificial intelligence (AI) is being increasingly used in both human and veterinary medicine to improve patient outcomes and streamline healthcare delivery.

The first instances of AI in veterinary medicine emerged in the form of rule-based expert systems in the 1980s, which were designed to assist veterinarians in diagnosing specific diseases and conditions.

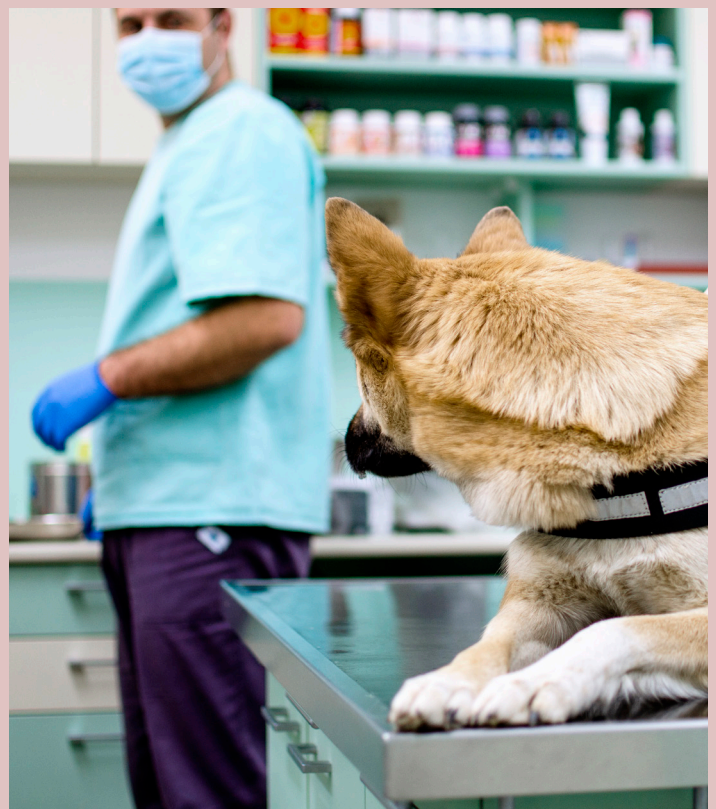
Following trends in human medicine, in recent years there has been an increase in the use of machine learning algorithms in veterinary medicine. These algorithms can be trained on large sets of data to generate models capable of making predictions and diagnosing diseases. AI can be employed where any data sets exist. In veterinary medicine, data sets include:

- **Visual and audio data** including vocalizations, diagnostic images, cytology and histology samples, and images of skin lesions etc.
- **Health data** e.g. heart rate, blood glucose, body weight, often collected through wearable devices.
- **Language data** written or audio information, including clinical notes, website copy, social media content, listening devices such as Apple's Siri or Amazon Alexa.
- **Animal data** number and type of species and breeds, genetic information, geographic and demographic distribution etc.
- **Pet owner data** such as demographics, trends and habits of pet ownership.

How data is used

AI tools are trained on data sets and directed to produce defined outputs. Image analysis has been utilized in monitoring the health and behaviour of livestock since the early 1990s. It has been employed to measure health, welfare and growth parameters of the animals including weight estimation,¹ and assessing the gait and lameness in broiler chickens.² Sound data has also been used to predict risk of respiratory disease in broiler chickens.^{3,4}

Since then, as data gathering and sharing has become more streamlined, advances in diagnostics and optimization of treatment through AI have been possible. At the population level, deep learning (DL) and Natural Language Processing (NLP) tools have been deployed in precision agriculture, and animal ecology as we shall discuss in a later section.



Opinions on AI in veterinary medicine - benefits and hopes

In a recent survey on AI in the veterinary profession conducted by VetCT, over one third of respondents felt they had only a little understanding of AI, with

Only 10% stating they felt they had a comprehensive understanding of AI.

Areas of AI development deemed to be most exciting included workflow efficiencies and educational applications, over and above clinical tools. For clinical tools specifically, disease risk, diagnosis and prognosis tools were deemed to be moderately or most exciting, whereas treatment tools were less exciting. **Individual responses to which areas of AI development respondents deemed most useful in practice varied greatly and included:**

“The only thing that really interests me is rotas, team management that type of thing. I see some scope in diagnostics. Clients don’t want chat bots!”

“Anesthetic dose calculations to reduce human error. Interpretation of radiographs and blood work to assist NOT REPLACE vet diagnostic skills.”

“Interactive diagnostics removing the need for a human clinician. This will happen and will be far better than most if not all veterinary clinicians.”

“A virtual AI vet that’s targeted to owners, offering first level triage as to whether a vet practice visit is necessary - and if it is, start to manage owner expectation on disease type, treatment and ultimately the potential cost they’re looking at.”

“Translation and that is it. I am not very excited about the use of AI in veterinary medicine at all.”

“Anything that will improve standard of care alongside a vet healthcare team.”

The last point is interesting, as standard of care means the recommendation of treatment that is accepted by medical experts as a proper treatment for a certain type of disease and that is widely used by healthcare professionals.⁵ Should standard of care be applied as a form of standardization to a non-human tool, or simply apply to the clinician that employs the tool?

Improved diagnostic accuracy and workflow efficiencies were ranked as most important to the individual, above improved patient outcomes, clinical insights and reduced human error. Additional responses included the use in communications, both across communities and for managing expectations:

“Less pressure on veterinary professional if the owner has already been through an expectation management process in terms of disease identification and treatment cost.”

“I have already used chat GPT in practice. I work with a socially disadvantaged portion of the community and have asked it to explain to someone with no medical knowledge things like pyometra, enucleation, post-op recovery etc. very successfully.”





Opinions on AI in veterinary medicine - risks and concerns

Survey respondents indicated clinical errors, lack of regulation and introduction of automation bias as the greatest potential risks posed by AI. Data bias, loss of human job roles and negative impact on patients were ranked as lower risks overall. Lack of scientific research and education around AI use were deemed to be of least concern, yet robust scientific research and education would, to some extent, mitigate the risks posed by lack of regulation and clinical errors.

Additional concerns raised included the potential skills loss:

“Deskilling of vet staff with over-reliance on AI.”

“Clients exhibiting automation bias of bypassing clinicians altogether if tools are made available to the public.”

“There’s always a risk that the owner trusts an AI solution over the vet themselves. Much like Dr Google today.”

“Clients using it to diagnose and then treat their own pets inappropriately. I’m all for clients researching but I am concerned if they use this instead of vets and they miss something resulting in inappropriately managed cases.”

One respondent highlighted the importance of human empathy in veterinary care:

“The risk of relying too much on technology and having a one size fits all approach. Isn’t the wonderful thing about human brains that we are able to assess a situation and treat every animal as an individual case. We can discuss with each other what potential causes and treatments could be AND allow the owner to make a decision. There are emotions involved in veterinary care, and I don’t think we should just be going by what computers advise.”

Another raised concerns over data used and ensuring the clinician takes the lead role,

“I think the danger is that we (and clients) come to rely on the AI... but this is only as smart as the algorithms and data input. The risk is that we stop looking at the patient in front of us and using our own skills. It should be an assistant not the leader.”

When asked if they would be happy deploying AI in veterinary practice, less than half of respondents said ‘Yes’, with a further third stating they were ‘Not sure’. Clearly, we have a huge mountain to climb to instil confidence in AI technology and encourage wide adoption of this technology. When asked what type of training and information would assist with AI adoption, education around specific tools; their indications, limitations, accuracy and how they were developed was ranked as most important. Over half also said a foundational understanding of AI was either essential or would help a great deal.





Further recommendations and food for thought included:

“Change is coming, AI cannot be stopped, now is the time to ensure it is harnessed to best advantage for veterinary medicine both in person and virtually.”

“Current AI applications are based on human expert opinion = mere automation of the human mind. What would be a game changer if this was not the case and the technology would be based on evidence-based outcomes (post mortem, biopsy, etc). Implementing this would potentially open new diagnostic avenues.”

“Scientific publication to accompany commercially available AI tools needs to be completely transparent - to be proper science needs to be repeatable by independent assessors not the commercial enterprise who benefits.”

Robust regulation could ensure that AI tools are validated, reliable and reproducible, as in human medicine where the medical use of AI tools need to pass FDA/EMA approval. Though a certain degree of insight into how AI tools work is needed to understand their use, we can't expect veterinarians to have the necessary expertise in data analysis and technology application on top of their qualifications. A regulatory body including such cross-sector expertise, could provide standards to prove the efficacy of AI tools and build the necessary trust for those tools that pass its scrutiny.



AI in diagnostics

One key area where AI is being used in veterinary medicine is in the diagnosis and prediction of diseases. For example, AI has been used to assist in the diagnosis of canine hypoadrenocorticism, which is a disease that can be fatal to the patient and challenging to diagnose, yet has an excellent prognosis with appropriate treatment.⁶

Such tools can improve cost efficiency of diagnosis, especially for conditions with non-specific presentation. One example is visceral Leishmaniasis, where AI algorithms applied to characteristics of physical examination are being explored for diagnostic accuracy.⁷ Machine learning algorithms have also been shown to be more accurate than serological testing in diagnosis of canine leptospirosis, which also has important zoonotic implications.⁸

Another area may be to reduce the complexity of diagnostic tests required. For example, chiari-like malformation (CM) and syringomyelia (SM) can be associated with pain and welfare impacts in Cavalier King Charles Spaniels, but historically MRI has been required to make a definitive diagnosis. By combining MRI data with facial image analysis, an AI tool can assist in predicting the likelihood of CM/SM from images of the dog's head obtained via an owner's smartphone.⁹

The beauty of AI is its ability to perform highly repetitive and time consuming tasks at great speed and without fatigue. In the field of pathology, analysis of entire sections of canine mast cell tumours submitted for histopathology is possible, whereas time constraints for the human pathologist have typically limited investigation to 10 high-power fields for deeper analysis of malignant characteristics, such as presence of mitoses¹⁰. This frees up human pathologists time to focus on more creative, interesting tasks such as complex cases and research projects.

Disease monitoring and prediction

The ultimate goal is of course to prevent disease rather than treat it or, failing that, to predict and intervene at the earliest opportunity to improve prognosis. With this in mind, artificial neural networks have been used to predict the likelihood of cats over the age of 7 years developing chronic kidney disease within a year.¹¹ AI tools have also been used to forecast seizures in dogs with epilepsy.¹² These diagnosis and detection tools open the door to prevention and early intervention, improving outcomes and welfare.

AI in treatments

Another area where AI is being used in veterinary medicine is in the treatment of diseases. A study published in the *Journal of Veterinary Emergency and Critical Care* found that an AI-based tool was able to accurately predict the outcomes of critically ill dogs with a high level of accuracy. Additionally, a study published in the *Journal of Feline Medicine and Surgery* used a machine learning algorithm to help determine which variables were most useful in predicting the outcomes of cats with acute-on-chronic kidney disease.¹⁶

AI in research and one health

AI has a huge potential role to play in development of novel diagnostics and treatments, especially at the level of genome and protein interrogation. Following developments in human medicine, AI has been used for early detection of cancer from cell-free DNA fragments in blood samples.¹³

Deep neural networks have been also developed to predict protein folding patterns, which can significantly accelerate the drug discovery process, helping to tackle problems from leishmaniasis to antibiotic resistance.¹⁴

The possibility of modelling drug targets and protein interactions and the complexities of genomics through AI algorithms may not only speed the drug discovery process, but also reduce the need for live animal testing. In the field of cancer research, mapping mutations in human cancers to canine cancers creates the opportunity to develop comparative species models for developing precision therapeutics, benefitting both dogs and their human counterparts.¹⁵



AI and the veterinary workforce crisis

AI can help address the shortage of veterinarians and veterinary specialists in several ways, improving the quality and accessibility of veterinary care, as well as supporting the professionals themselves. Here are some ways AI could help:

■ **Telemedicine:** AI-driven telemedicine platforms can enable pet owners to consult with veterinarians remotely, allowing professionals to reach more clients and reduce the burden on local clinics. AI can help analyze medical images and data, guiding veterinarians in their diagnoses and treatment recommendations.

■ **Triage and symptom analysis:** AI chatbots and voice assistants can help pet owners identify the urgency of their pets' symptoms and recommend appropriate next steps, such as seeking immediate care or waiting for a scheduled appointment. This can free up veterinary professionals' time to focus on more critical cases.

■ **Training and education:** AI-driven simulation and virtual reality can provide immersive and realistic training environments for aspiring veterinarians, helping them acquire critical skills and knowledge more efficiently. This can accelerate the process of training new professionals, helping to fill the shortage.

■ **Diagnostic support:** AI can be used to analyze complex medical data, such as lab results, imaging studies, and patient histories, to help veterinarians and specialists make more accurate diagnoses. This can reduce the need for additional tests, save time, and improve patient outcomes.

■ **Treatment planning and monitoring:** AI can help veterinarians develop personalized treatment plans based on an animal's unique needs and monitor their progress, providing alerts if there are deviations from expected outcomes. This can enhance the effectiveness of treatments and improve overall patient care.

■ **Research and drug discovery:** AI can support research by analyzing vast amounts of data, helping to identify new treatment options and refine existing ones. This can lead to more effective therapies and improved veterinary care.

■ **Workload optimization:** AI can help veterinary clinics optimize their workload by analyzing appointment data, predicting no-shows, assigning work according to interest area and skill set and adjusting schedules accordingly. This can help veterinarians manage their time more effectively and reduce the burden on individual practitioners.

■ **Collaboration and knowledge sharing:** AI-powered platforms can facilitate collaboration and knowledge sharing among veterinary professionals, enabling them to consult with specialists remotely and share best practices.

By integrating AI into the field of veterinary medicine, the industry can better address the shortage of veterinarians and specialists, enhance the quality of care provided, and improve overall efficiency.

Challenges

While AI technology is still in the early stages of development in veterinary medicine, it has the potential to revolutionize the way that animal patients are diagnosed and treated. One key challenge facing the use of AI in veterinary medicine is the limited availability of high-quality, large-scale data sets for training and evaluating AI-based systems.

Unlike human medicine, where there is a wealth of electronic health records and other data available for research, data on animal patients is often scattered in data silos and of lower and more variable quality. Additionally, the complex and diverse nature of veterinary medicine, with many different species of animals and a wide range of diseases, presents additional challenges for the development and validation of AI-based systems. Over-reliance on AI could also lead to loss of certain skills. For example, if we rely on AI for interpretation of cytology, our own cytology skills might deteriorate.

The future of AI in veterinary medicine

Despite these challenges, the field of veterinary medicine is well-positioned to benefit from the advancements in AI technology. The increased use of electronic health records and other digital tools in veterinary practice is making it easier to collect and analyze large-scale data sets, and many veterinary schools, private companies and research institutions are beginning to develop expertise in the use of AI.

Not only is there huge potential to improve the prevention, diagnosis and treatment of animal and zoonotic diseases, AI opens up the world of the genome and microbiome and impacts on animal health, welfare and production. Precision medicine is one of the areas of rapid development on the human side that will inevitably expand the potential for technology-based treatment protocols.

The potential to facilitate information transfer should improve communication among veterinary teams, with clients and even cross-sector and interdisciplinary collaboration with stakeholders involved with animal health, public health and environment sustainability. Traceability of food production animals, pharmacovigilance and epidemiological data should help to promote public health alongside animal welfare.



While AI technology has the potential to revolutionize many areas of veterinary medicine, the limited availability of high-quality data sets and the complex and diverse nature of veterinary medicine present significant challenges for the development and validation of AI-based systems. Despite these challenges, the field of veterinary medicine is well-positioned to benefit from the advancements in AI technology.



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⁶ Reagan KL, Reagan BA, Gilor C. Machine learning algorithm as a diagnostic tool for hypoadrenocorticism in dogs. *Domest Anim Endocrinol*. 2020 Jul;72:106396. doi: 10.1016/j.domaniend.2019.106396

⁷ Ferreira TS, Santana EEC, Jacob Junior AFL, Silva Junior PF, Bastos LS, Silva ALA, Melo SA, Cruz CAM, Aquino VS, Castro LSO, Lima GO, Freire RCS. Diagnostic Classification of Cases of Canine Leishmaniasis Using Machine Learning. *Sensors (Basel)*. 2022 Apr 20;22(9):3128. doi: 10.3390/s22093128

⁸ Reagan KL, Deng S, Sheng J, et al. Use of machine-learning algorithms to aid in the early detection of leptospirosis in dogs. *Journal of Veterinary Diagnostic Investigation*. 2022;34(4):612-621. doi:10.1177/10406387221096781

⁹ Spiteri, M, Knowler, SP, Rusbridge, C, Wells, K. Using machine learning to understand neuromorphological change and image-based biomarker identification in Cavalier King Charles Spaniels with Chiari-like malformation-associated pain and syringomyelia. *J Vet Intern Med*. 2019; 33: 2665– 2674. <https://doi.org/10.1111/jvim.15621>

¹⁰ Bertram, C.A., Aubreville, M., Marzahl, C. et al. A large-scale dataset for mitotic figure assessment on whole slide images of canine cutaneous mast cell tumor. *Sci Data* 6, 274 (2019). <https://doi.org/10.1038/s41597-019-0290-4>

¹¹ Biourge V, Delmotte S, Feugier A, Bradley R, McAllister M, Elliott J. An artificial neural network-based model to predict chronic kidney disease in aged cats. *J Vet Intern Med*. 2020 Sep;34(5):1920-1931. doi: 10.1111/jvim.15892

¹² Nejedly P, Kremen V, Sladky V, Nasser M, Guragain H, Klimes P, Cimbalnik J, Varatharajah Y, Brinkmann BH, Worrell GA. Deep-learning for seizure forecasting in canines with epilepsy. *J Neural Eng*. 2019 Jun;16(3):036031. doi: 10.1088/1741-2552/ab172d.

¹³ Flory, A. et al, Clinical validation of a next-generation sequencing-based multi-cancer early detection “liquid biopsy” blood test in over 1,000 dogs using an independent testing set: The CANcer Detection in Dogs (CANDiD) study, April 2022, *PLOS ONE*, 17(4), e0266623, <https://doi.org/10.1371/journal.pone.0266623>

¹⁴ <https://www.deepmind.com/research/highlighted-research/alphafold>

¹⁵ Rodrigues, F. et al, Shared hotspot mutations in spontaneously arising cancers position dog as an unparalleled comparative model for precision therapeutics, *bioRxiv* 2021.10.22.465469; doi: <https://doi.org/10.1101/2021.10.22.465469>

¹⁶ Renard J, Faucher MR, Combes A, Concordet D, Reynolds BS. Machine-learning algorithm as a prognostic tool in non-obstructive acute-on-chronic kidney disease in the cat. *Journal of Feline Medicine and Surgery*. 2021;23(12):1140-1148. doi:10.1177/1098612X211001273

AI has the potential to greatly influence education – and by extension veterinary education - in the future by providing more efficient and effective ways to teach and train students. It has the potential to revolutionize education by personalizing learning, increasing efficiency, and providing new opportunities for students and teachers. There is also potential to democratize learning and increase accessibility, both geographically and for neurodiverse individuals or those with disabilities.

It will also help to prepare students for increasingly technology-enabled working environments as these developments are increasingly adopted in the practice setting and beyond. Indeed, training on AI terminology and the concepts behind development, data use, application and ethics should be included as a core element of modern veterinary training to equip students with the knowledge they need to apply these tools confidently and safely in practice, and communicate their use to owners..

Some examples of how AI could be used in veterinary education include:

For the student,

- **Virtual reality and simulation:** Virtual reality and simulation could provide students with hands-on experience in a safe and controlled environment, allowing them to practice procedures and techniques before working with live animals.
- **Predictive modeling:** Predictive modeling could help students to learn about the long-term outcomes of various treatments and procedures, and to make more informed decisions about how to care for animals.
- **Personalized learning:** AI-powered educational systems can analyze data on each student's learning progress, strengths, and weaknesses, and use this information to provide personalized feedback and guidance. These systems can be used in both online and offline environments and can adapt to the learning style and pace of each individual student. They could also adapt content for those with neurodiversity or disabilities.
- **Intelligent tutoring systems:** AI-powered intelligent tutoring systems can provide personalized instruction and feedback to students, helping them to learn at their own pace and in their own way.
- **Virtual tutors:** These tutors use natural language processing (NLP) and machine learning algorithms to understand and respond to student queries. They can provide immediate feedback, allowing students to quickly identify and correct their mistakes.
- **Assignments:** NLP systems are already being used by students to research and even write assignments. Tools have been developed to screen for AI-generated submissions, however, the students are now learning to 'trick' these tool by inserting random errors into assignments to make them more human-like.
- **Translation tools:** These could be used to translate learning content into different languages, increasing accessibility of both educational courses and CE.

For the educator

- **Automated assessment:** AI-powered assessment tools can grade student performance and provide feedback in real-time, allowing students to quickly identify areas where they need to improve.
- **Predictive analytics:** AI algorithms can analyze large amounts of data and provide insights that can help educators better understand student needs and tailor their teaching strategies accordingly.
- **Content creation:** AI is also being used to create digital content and educational tools. For example, AI-powered tools can be used to generate personalized lesson plans, quizzes and assessments for teachers. These tools can also be used to create interactive simulations, games, and virtual reality experiences for students.
- **Student performance feedback:** AI is also being used to analyze student data, such as test scores, assignment submissions, and participation in class discussions. This data can be used to identify patterns and trends, which can then be used to improve instruction and support student learning.

AI is being used in many different ways in education, but its impact is still being studied. Some researchers are concerned that AI could lead to a loss of human interaction and creativity in the classroom, while others argue that it has the potential to democratize learning and make education more accessible and effective for reduce some of the administrative workload for educators, improving their job satisfaction and wellbeing. A 2020 report by the European Coordinating Committee for Veterinary Training¹ concluded that digital technology and AI may also:

- facilitate the harmonization of the learning outcomes for any study programme, e.g. by evaluating teaching, learning and assessment processes;
- facilitate the feedback from students and stakeholders for further improvement of the curriculum;
- enhance the availability of innovative tools and facilitate their sharing between veterinary education establishments;
- increase accessibility of learning and widen participation;
- increase economic, social and green sustainability of learning and make it more affordable/cost effective while improving quality;
- provide updated tools and challenges, especially via AI auto-improvement processes;
- enhance interdisciplinary and 'one health' collaboration

¹ CREPORT OF THE ECCVT EXPERT WORKING GROUP ON THE IMPACT OF DIGITAL TECHNOLOGIES & ARTIFICIAL INTELLIGENCE IN VETERINARY EDUCATION AND PRACTICE, 2020, published online:https://www.intranet.eavee.org/fileadmin/downloads/eccvt/DTAI_WG_final_report_ECCVT_adopted.pdf

The need for regulation

It's important to note that regulations and guidelines for the use of AI in education are still evolving, and are likely to change as technology advances and its impact on education becomes better understood.

There are currently no specific regulations around the use of AI in schools and universities in most countries. However, there are a number of laws and guidelines that may apply to the use of AI in education, such as data protection and privacy laws, and laws related to discrimination and equal opportunities.

As AI technology is still developing it is hard to predict how its use in education will continue to evolve. It's important to consider the ethical and safety implications of using AI in veterinary education and ensure that the technology is used in a responsible manner to further learning, understanding and skills development, rather than detract from it.

Conclusion

Overall, AI has the potential to transform the way we think about education, providing new, cost-effective, personalized opportunities for students and teachers. As technology continues to advance, we can expect to see more innovative uses of AI within and beyond the classroom. Expanding learning opportunities across different abilities and language barriers and facilitating more flexible learning methods will increase the accessibility and affordability of education, and may in turn positively impact the veterinary workforce shortages, both within and beyond teaching institutions.



The equine industry is an essential part of the global economy and an important source of labor, entertainment, culture and sport. As technology advances, the potential of AI to modernize the industry is becoming increasingly apparent across breeding, racing, welfare and disease management.

■ Health monitoring and Diagnostics

Effective disease management is critical in maintaining the health and welfare of horses. AI can play a significant role in disease prevention, early detection, and treatment. By analyzing large amounts of data from various sources, such as veterinary records, weather patterns, and horse movement, AI can identify patterns and predict the likelihood of disease outbreaks, enabling proactive disease management strategies.

In addition, AI-powered imaging and diagnostic tools can assist veterinarians in detecting diseases and abnormalities at an early stage, facilitating timely treatment and potentially improving survival rates.

AI-powered tools and devices are used to monitor vital signs, analyze gait, and detect early signs of illness or injury. These tools can also help veterinarians make more accurate diagnoses and facilitate timely treatment plans and potentially improve outcomes. For example, body-mounted inertial sensors can collect movement data from several reference points, with analysis providing guidance for further lameness investigation in cases of poor performance.¹ AI can also be used to develop personalized treatment plans that take into account the individual horse's condition, history, and response to medications.

■ Nutrition and feeding

AI algorithms can analyze data on individual horses and provide customized feeding plans, considering factors such as age, activity level, and specific nutritional requirements.²

■ Breeding and genetics:

Through the use of advanced algorithms and machine learning, AI can process vast amounts of data on individual horses and their lineage to accurately predict their genetic potential. This information can be used to optimize breeding decisions and increase the chances of producing healthier, stronger and faster horses.

In addition, AI can be used to analyze and interpret genomic data, helping to identify specific genes associated with desirable traits such as athleticism, temperament, and disease resistance. With this information, breeders can make more informed decisions, leading to improvements in the overall quality of horses produced. AI-powered tools are employed to analyze pedigree, genetic, and performance data to predict the potential of offspring and improve breeding programs.³

■ **Training and performance optimization:** AI can help trainers create personalized training plans, monitor progress and identify areas for improvement. Biomechanics analysis and motion capture technology can also provide valuable insights into a horse's movement, helping to optimize performance and minimize injury risk.⁴

■ **Wearable technology:** Smart wearables, such as sensors and trackers, can collect real-time data on a horse's vital signs, activity levels, and behavior. AI algorithms can then analyze this data to provide insights and alerts to horse owners, trainers, breeders and veterinarians.

■ **Race prediction and betting:** AI can inform training methods, optimize race strategies, and enhance wagering systems. Machine learning algorithms can analyze vast amounts of data on an individual horse's performance, such as training times, racing history, and environmental factors, to develop individualized training programs and race strategies.⁵



Moreover, AI can be used to develop advanced simulations and predictive models, helping trainers and jockeys identify the most efficient ways to utilize a horse's strengths and weaknesses during a race. AI algorithms can be used to analyze historical race data, track conditions, and the impact of these factors on individual horse performance to predict race outcomes more accurately and optimize wagering strategies.

■ **Facilities management:** AI can be used to optimize farm and stable operations, such as monitoring and automating various tasks related to horse care, energy consumption, and waste management.

■ **Virtual assistants and chatbots:** AI-powered virtual assistants can be used to answer common questions, provide training and guidance, and offer support related to equine care and management. This could be hugely powerful when deployed in remote regions where working equids are vital to the survival and culture of rural communities, but access to veterinary knowledge and care is limited.

Benefits and challenges

The integration of AI into the equine industry offers numerous benefits, including more efficient breeding practices, improved training methods, enhanced disease management strategies and husbandry improvements. These advancements have the potential to increase the overall quality, health, and performance of horses, ultimately benefiting the entire industry and the communities and societies that rely on them.

However, the adoption of AI also presents challenges. There are concerns about the potential loss of jobs in the industry as AI systems become more capable of performing tasks currently carried out by humans. Additionally, ethical considerations must be taken into account when using AI genetic selection and breeding practices to ensure breeding is within regulations and that the welfare of the animals is not compromised. It may also fundamentally impact the way the betting industry operates.



The potential of AI to influence the equine industry is vast, and as technology continues to evolve, the benefits will likely become more apparent. By embracing AI and incorporating it into various aspects of the industry, stakeholders can optimize breeding, racing, and disease management practices, ultimately improving the quality, health, and performance of horses. However, we must ensure appropriate standards and regulations are developed and adhered to, providing transparency and safeguarding and prioritizing animal welfare.

¹ Reed, S. K., Kramer, J., Thombs, L., Pitts, J. B., Wilson, D. A., & Keegan, K. G. (2020). Comparison of results for body-mounted inertial sensor assessment with final lameness determination in 1,224 equids, *Journal of the American Veterinary Medical Association*, 256(5), 590-599. from <https://doi.org/10.2460/javma.256.5.590>

² Staniar, W. B. (2019). "Using technology to enhance equine nutrition." *Journal of Equine Veterinary Science* 76: 63-64.

³ Hill, E. W., et al. (2010). "A sequence polymorphism in MSTN predicts sprinting ability and racing stamina in thoroughbred horses." *PLoS One* 5.1: e8645. (<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0008645>)

⁴ Marlin, D. J., et al. (1999). "Physiological responses of horses during treadmill exercise and field training." *Equine veterinary journal. Supplement* 30: 493-497. (<https://onlinelibrary.wiley.com/doi/abs/10.1111/j.2042-3306.1999.tb05273.x>)

⁵ Benter, W. (1994). "Computer based horse race handicapping and wagering systems: a report." *Efficient Market Services*. (<https://pdfs.semanticscholar.org/1d36/53da4542a2e0ea2f71e3b3cc3e606c8f1e0.pdf>)

Agriculture is another industry that has undergone an AI revolution. Livestock farming in particular has been positively impacted by AI in a multitude of ways. This technology has the potential to enhance animal welfare, increase productivity, and promote sustainable farming practices.

Current applications of AI in livestock farming:

1. Precision livestock farming

Precision livestock farming (PLF) involves using AI and sensor technologies to monitor and manage individual animals. These technologies collect and analyze data related to animal growth, health, reproduction, and behavior, enabling farmers to make informed decisions and improve overall efficiency. The objective is to create management systems based on continuous automatic real-time monitoring and control of production, animal health and welfare, and the environmental impact of livestock production.¹

Examples include:

- Automated milking systems: These systems use AI and robotics to milk cows, reducing labor costs, and ensuring consistent milking routines.
- Wearable devices: These are attached to animals, collecting data such as body temperature, heart rate, and activity levels. This information is then analyzed to identify any anomalies, allowing for early detection of illness or stress and to predict oestrus in cattle.
- Computer vision systems: Cameras equipped with AI software can monitor livestock behavior, movement, and body condition, providing valuable insights into their well-being.

For example, lameness is a major welfare problem in modern dairy cows, where up to 25% may be badly affected. Image analysis of data from automatic camera footage of dairy cows approaching a milking robot enables detection of lameness problems and sends a warning to the farmer. This fully automatic monitoring of individual cows replaces a task the farmer can no longer carry out easily with increasing livestock numbers and admin tasks. This warning system has huge potential to enable early detection and treatment, improving the welfare of many cattle.²

2. Population disease detection and prevention

AI has enabled early detection of diseases in livestock, preventing their spread, and minimizing losses. Machine learning algorithms can analyze data from wearable devices, cameras, and other sensors, identifying patterns associated with specific diseases. This information allows farmers to take proactive measures to protect their animals, such as quarantine, vaccination, or treatment.

For example, AI-powered systems can detect and classify bird vocalizations to identify diseases and stress in poultry. Similarly, cough detection on pig farms enables ventilation problems to be identified and early treatment to be instigated for infectious respiratory disease.³

3. Genetic selection and breeding

AI is playing a crucial role in genetic selection and breeding in livestock farming. By analyzing vast amounts of data, AI algorithms can identify animals with desirable traits, such as higher milk production, disease resistance, or better growth rates. For example, the genomic selection method utilizes AI algorithms to predict the breeding values of animals based on their genomic information.⁴ Such information helps farmers make more informed breeding decisions, improving the overall genetic quality of their herds.

4. Nutritional optimization

Mathematical models can be used in the prediction of optimal livestock feed blend for animals, for example to find the most optimal percentage of price, nutrients and water.⁵



Future developments in AI for livestock farming:

1. AI-driven autonomous farming

As AI technology continues to advance, we could see the development of fully autonomous livestock farms. These farms would integrate various AI-driven systems, such as automated feeding, milking, and monitoring, to create a seamless, labor-free operation. This level of automation could significantly reduce labor costs, increase productivity, and enhance animal welfare. Automated milking systems already combine robotic milking with data analysis for improved herd management.⁶ It won't be long before end-to-end technological solutions are developed from breeding selection, to optimization of reproduction, feeding and activity, to health monitoring and selection for slaughter.

China recently hit the news with its high-rise pig farms, with the potential to process over one million pigs per year, all monitored and fed by automated systems. For a country struggling to produce enough food for its population this is being hailed as a huge step forward to increase livestock production. However, inevitably welfare concerns have been raised about this new level of intensification.⁷



2. Integration of AI with IoT and big data

As the Internet of Things (IoT) and big data technologies mature, their integration with AI could revolutionize livestock farming. The combined power of these technologies could provide farmers with real-time insights into their animals' health, well-being, and productivity, creating the smart farms of the future.⁸ This information could help farmers make better decisions, improving overall farm efficiency and sustainability. For Example, the SmartCow project already combines IoT, big data, and AI to improve animal welfare, farm productivity, and environmental sustainability.⁹

3. Personalized nutrition and health management

Future AI systems could provide individualized nutrition and health management for each animal in a herd. By analyzing data from various sources, AI algorithms could determine the optimal diet, vaccination schedule, and other health interventions for each animal, based on its specific needs. This approach could lead to improved animal welfare, reduced disease incidence, and increased productivity. There are already facial recognition systems being developed for cows to monitor their health and nutrition.¹⁰ This could be extended to improve reliable and continuous animal welfare, e.g. through animal surveillance during transport. There are also opportunities to promote consumer protection and public health by improving traceability.

4. Environmental impact reduction

AI could help livestock farmers reduce the environmental impact of their operations. By optimizing feed formulations AI could minimize the amount of waste produced and the use of natural resources. AI-powered feed optimization software is already being used to help reduce methane emissions and environmental impacts. AI-driven farm management systems could also optimize the use of water, energy, and land, promoting more sustainable farming practices. AI can also be applied to modeling interactions between animals and the environment.¹¹



However, this must be balanced by the potential deepening of intensification, reducing the attention and value given to the individual animal and further pressuring small producers to keep up with high production units. Local farming communities also have deep cultural and land management value that we must be cognizant of when advising the adoption of technology at scale. The potential for real, significant positive impact by improving health, welfare, productivity and environmental impact is enormous, but as ever we must ensure human intelligence considers the 'big picture' and social sustainability alongside environmental.

¹ Berckmans, D. (2017). Precision livestock farming technologies for welfare management in intensive livestock systems. *Revue scientifique et technique (International Office of Epizootics)*, 36(1), 97-105.

² Viazzi S., Bahr C., Schlageter-Tello A., Van Hertem T., Romanini C.E.B., Pluk A., Halachmi I., Lokhorst C. & Berckmans D. (2013). – Analysis of individual classification of lameness using automatic measurement of back posture in dairy cattle. *J. Dairy Sci.*, 96 (1), 257–266

³ Pourdarbani, R., Yarahmadi, P., & Maleki, S. (2021). FowlGuard: An IoT-based smart system for early detection of poultry diseases. *Computers and Electronics in Agriculture*, 182, 105983

⁴ Hayes, B. J., Bowman, P. J., Chamberlain, A. J., & Goddard, M. E. (2009). Invited review: Genomic selection in dairy cattle: progress and challenges. *Journal of Dairy Science*, 92(2), 433-443

⁵ Saxena, Pratiksha & Parasher, Yaman. (2019). Application of Artificial Neural Network (ANN) for Animal Diet Formulation Modeling. *Procedia Computer Science*. 152. 261-266. 10.1016/j.procs.2019.05.018.

⁶ Munksgaard, L., & Ingvarsten, K. L. (1993). Behavioral and pituitary adrenal-axis responses of dairy cows to social isolation and deprivation of lying down. *Journal of Dairy Science*, 76(6), 1746-1753

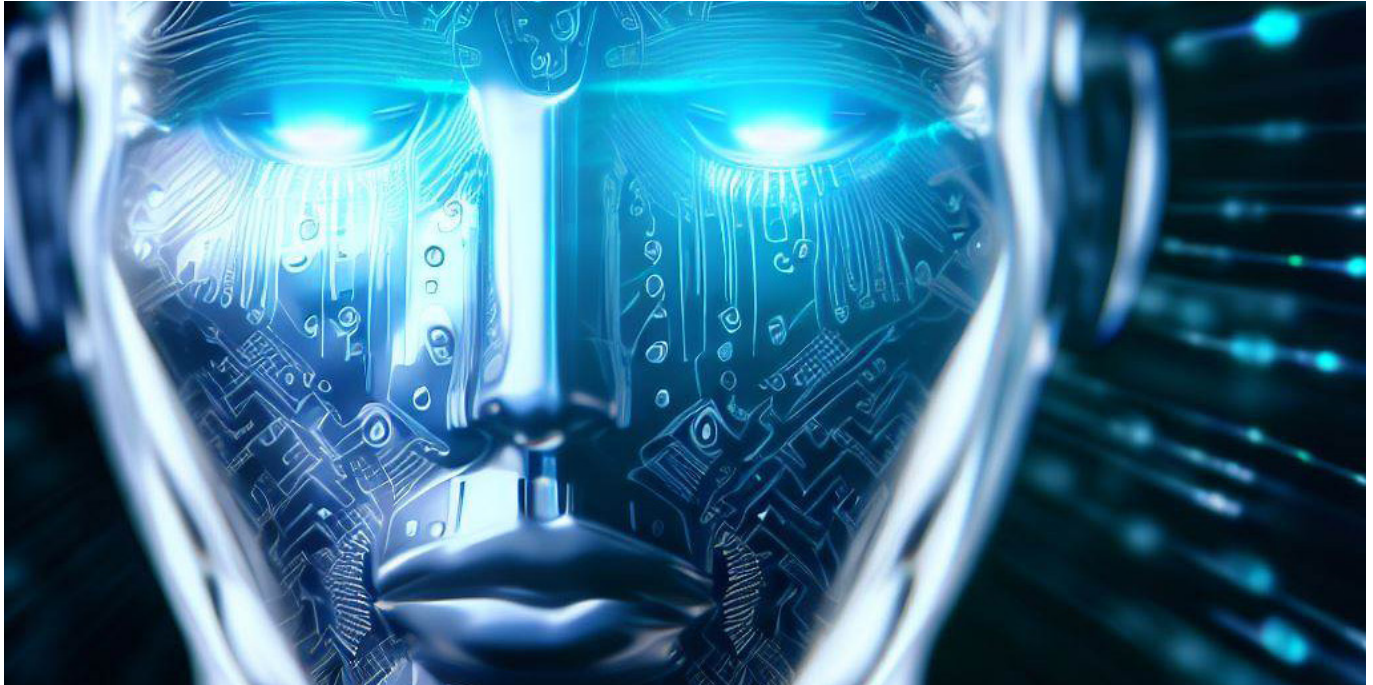
⁷ China's Bid to Improve Food Production? Giant Towers of Pigs. (2023). <https://www.nytimes.com/2023/02/08/business/china-pork-farms.html>

⁸ Wang S, Jiang H, Qiao Y, Jiang S, Lin H, Sun Q. The Research Progress of Vision-Based Artificial Intelligence in Smart Pig Farming. *Sensors (Basel)*. 2022 Aug 30;22(17):6541. doi: 10.3390/s22176541

⁹ SmartCow. (2018). SmartCow: An integrated infrastructure for the European cattle sector. Retrieved from <https://www.smartcow.eu>

¹⁰ Gomes, R. A., Kerssen, R. P., Dórea, J. R. R., Moraes, L. E., & Carvalho, P. H. A. (2019). Predicting efficiency of individual dairy cows using precision technologies. *Journal of Dairy Science*, 102(5), 4496-4507

¹¹ H. Saarenmaa et al., An artificial intelligence modelling approach to simulating animal/habitat interactions, (1988), *Ecol. Model.*



The ethics of AI is a complex and rapidly evolving field that raises many questions about the impact of artificial intelligence on society and the individuals within it. It is essential to consider the ethical implications of AI technology as it becomes increasingly integrated into our lives and the world of work.

Bias and discrimination

One of the biggest ethical concerns with AI is the potential for algorithms to perpetuate and amplify existing biases and discrimination. This can result in decisions that are unjust or unfair, particularly when it comes to applications in areas such as employment, housing, and criminal justice. For example, Amazon's AI-powered recruitment tool was found to discriminate against women, as it had been trained on resumes submitted to the company over a 10-year period, the majority of which were from men.¹

In addition, automation bias is the human tendency to believe the machine over and above our own or another human opinion.² We must be mindful of this when there is disagreement, seeking additional clarification rather than assuming the AI is right. This can be a particular problem when AI draws erroneous conclusions, or 'hallucinates'.

Hallucination

In the context of artificial intelligence (AI), the term "hallucination" is often used to describe a situation where an AI model sees something that is not there, or misinterprets the data it is processing. This is a frequent issue with complex AI systems like neural networks, which can overfit or underfit their training data, leading to incorrect inferences or conclusions.

AI hallucination is a common issue in image processing systems. For example, AI image recognition algorithms have been known to “hallucinate” nonexistent features in images or interpret random noise patterns as recognizable objects. This is often due to biases or flaws in the model’s training data, or the overemphasis of certain features during the learning process.

Deep learning models, which are a type of AI that use neural networks with many layers, are especially prone to hallucinations. These models are extremely powerful and can identify complex patterns, but they also have a tendency to “see” patterns where none exist - a remarkably human trait - if not properly trained or regulated. This can lead to unexpected and sometimes bizarre outcomes.

In machine learning models, AI can also hallucinate - or fabricate - scientific references and papers. Extreme caution and thorough fact-checking should be applied to any scientific writing generated by these tools, which present a mix of both accurate and fabricated data as equally credible within a body of text.³

AI hallucination can be a serious issue, especially in critical applications like self-driving cars or medical imaging, where misinterpretation can have serious consequences. Researchers are working on various strategies to mitigate the problem, including better methods for training AI, such as techniques that make the model’s decision-making processes more transparent and interpretable.

Hallucination is certainly an emerging issue with contemporary AI. Not only the degree of error, but how it is matched with significant degree of certainty from the AI.

Interestingly, as Large Language Models (LLMs) have emerged as conversational AI, it’s outputs are often difficult to discriminate as truth, prediction or speculation, and can all be presented with the same degree of confidence. Prior to LLMs, where AI outputs/predictions were a single number or binary prediction, there was less opportunity for this confident hallucination.



Data privacy and security

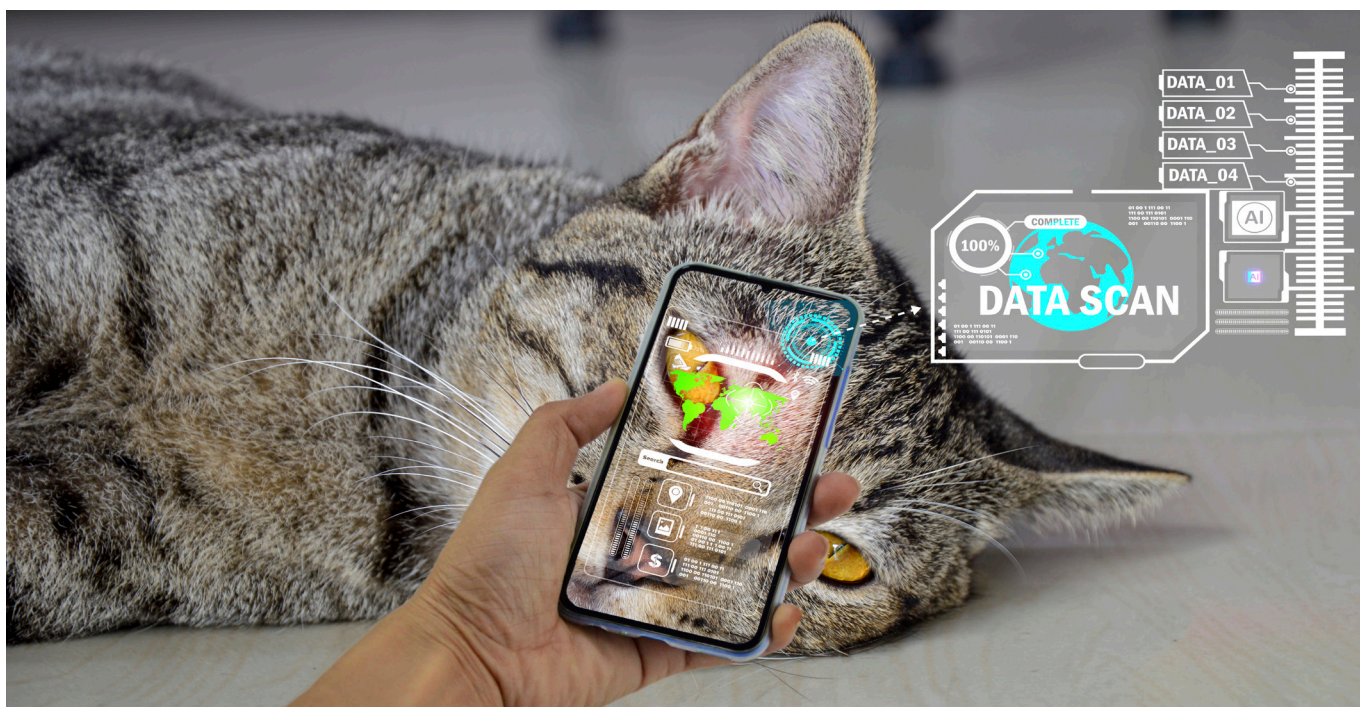
As AI systems collect and process large amounts of personal data, privacy and security become major ethical concerns. The mishandling of personal information could result in significant harm to individuals, such as identity theft or financial fraud. Think back to 2018, when Cambridge Analytica, a political consulting firm, used personal data collected from Facebook to try and influence the outcomes of the U.S. presidential election and the UK's EU exit referendum.⁴ The impact of data misuse can have major, far-reaching and long-lasting impacts around the globe.

The AVMA's progressive code of veterinary medical ethical conduct advises careful safeguarding of animal and owner data, in addition to laws on data privacy and security. The key principles are summarised below.⁵

■ Veterinarians shall safeguard medical information within the confines of the law:

- The information within veterinary medical records is confidential. It must not be released except as required or allowed by law, or by consent of the owner of the patient.
- Without the express permission of the practice owner, it is unethical for a veterinarian to remove, copy, or use the medical records or any part of any record for personal or professional gain.
- Medical records are the property of the practice and the practice owner. Information within veterinary medical records is confidential. It must not be released except as required or allowed by law, or by consent of the owner of the patient.

■ A veterinarian shall be influenced only by the welfare of the patient, the needs of the client, the safety of the public, and the need to uphold the public trust vested in the veterinary profession, and shall avoid conflicts of interest or the appearance thereof.



In an age where AI algorithms are gleaning data from across the internet, we need to exercise caution when sharing patient and client data. It is not impossible to imagine a scenario where an algorithm can match patient data labelled in an image from a training dataset to the owners data accessible on the internet, with unknown consequences.

In addition, as practice management systems (PMSs) are increasingly integrating with varied software technologies, it is important to have transparency around data gathering and use and robust safeguards established to ensure that the animal and owner data is protected, and that it is used only for the purpose of improving patient care.

Data privacy presents a dilemma: the more representative data an algorithm has access for training and refinement, the more likely it is to be accurate and unbiased, and consequently the more likely it is to support good outcomes and foster trust in technology. However, where informed consent is required from pet owners to share patient data, we need to understand the way the data will be shared and used by an algorithm that assimilates that data in a way we cannot always predict and where the outcomes are unknown. AI developers need to work closely with veterinary teams to ensure transparency, validation and use of data sets to enable informed consent to be obtained to create accurate, useful tools.

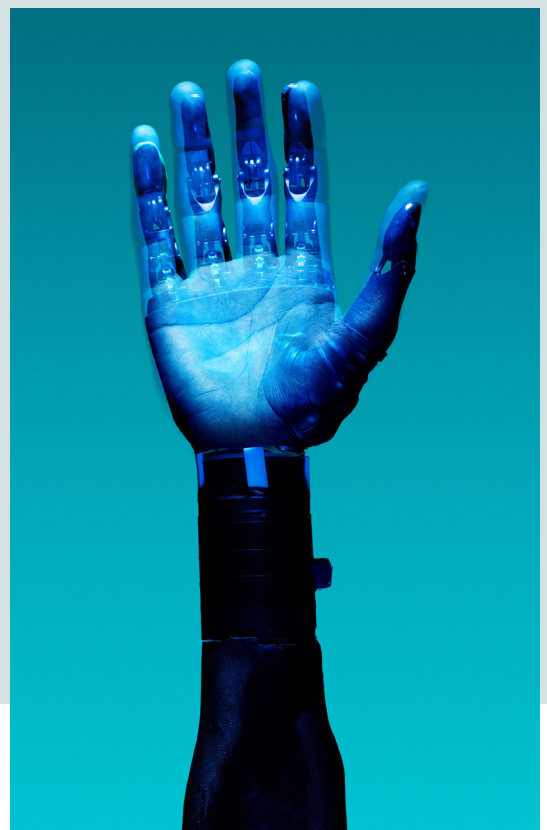
There is also an issue around the monetary value of data and the subsequent intellectual property generated from that data. Who should benefit from the profits generated by an AI tool trained on data from veterinary practices and how is an agreement reached and policed?

Responsibility and liability

Another ethical challenge with AI is determining who is responsible and liable in the event of an error or harmful outcome. This becomes especially problematic in scenarios where AI systems make decisions that have significant consequences, such as autonomous vehicles causing accidents. In these cases, it may be difficult to determine whether the fault lies with the AI system, the human operator, or the manufacturer.

One of the main ethical considerations is animal welfare. AI-powered diagnostic tools and treatment plans should be tested and validated to ensure that they do not compromise the welfare of the animals being treated. This means ensuring that any procedures or treatments recommended by the AI are in line with veterinary standards of care, and that the AI is not recommending procedures that are unnecessary or harmful to the animal.

This can be challenging when the veterinarian may not necessarily understand why the algorithm has reached a certain conclusion.

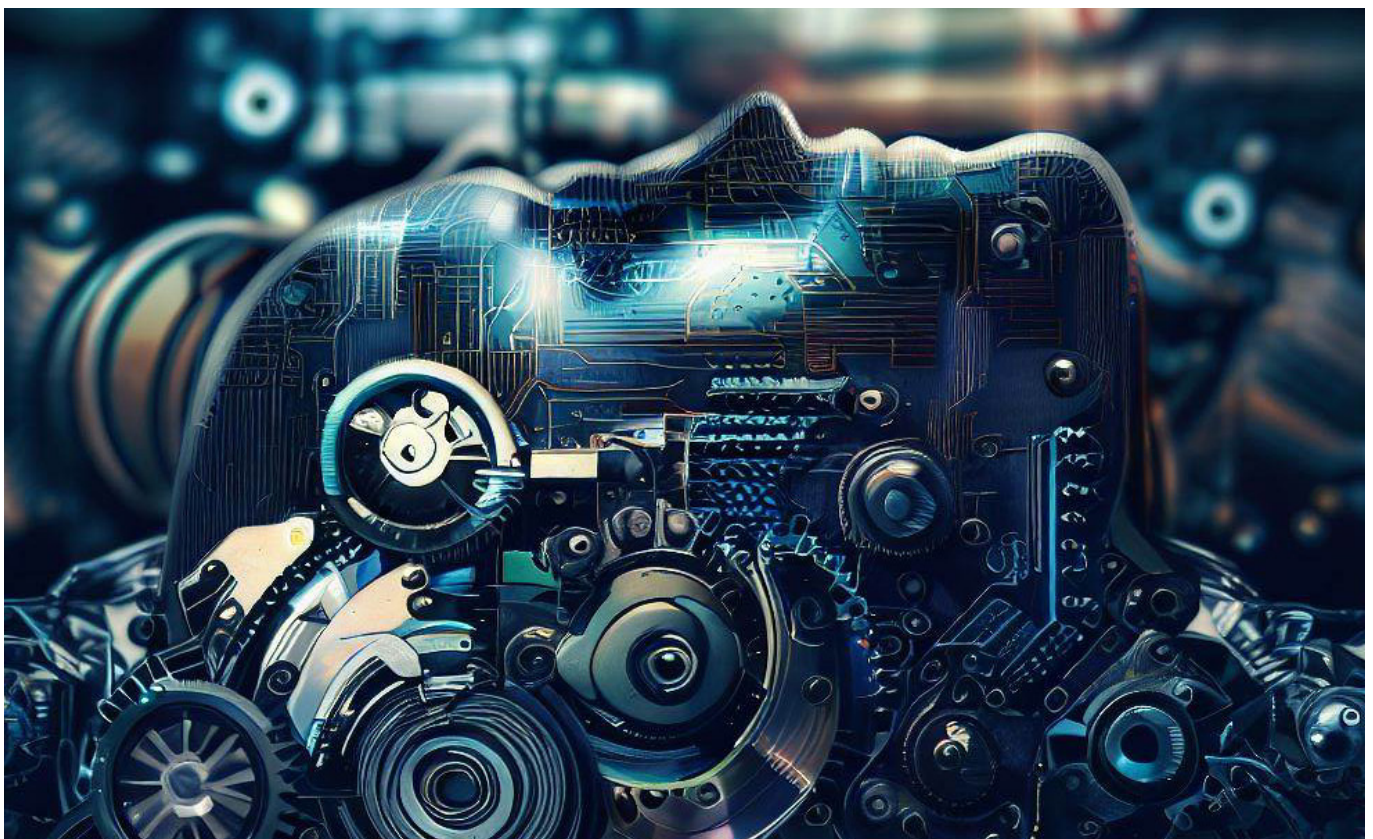


Machine learning algorithms are also constantly learning and evolving, leading to varying outputs over time. In theory, these outputs should be improving, but this again relies on non-biased data and appropriate training model protocols. There is potential for exacerbation of error if data sets are not representative of the patient population, for example in a different geographical region. In human medicine, the Food and Drug Agency has advised that “...the software developer should describe the underlying data used to develop the algorithm and should include plain language descriptions of the logic or rationale used by an algorithm to render a recommendation.”⁶

In the field of veterinary medicine, where the only regulated entity is the veterinarian holding the VCPR (Vet-client-pet-relationship), the fault when applying errant AI technology in the clinical situation currently lies solely at the veterinarian’s door. Is there a case for establishing a virtual VCPR with an AI tool - provided informed owner consent has been obtained for ‘referral’ of the case to AI - if the technology is providing a diagnosis and case management advice? This would shift liability for errors away from the veterinarian and onto the AI developer/commercial entity.

Unless we provide standards and regulations for the development and licencing of veterinary medical tools, we must provide the veterinarian with clear and transparent guidelines for best-practice use and thorough understanding of the limitations and potential for error to enable them to apply these tools appropriately and with confidence, and indeed to explain their use to owners to obtain informed consent.

However, as the excellent paper by Cohen and Gordon on ethics in radiology AI cautions: “Veterinary products do not fall under the same regulatory guidelines as human products... and companies bringing veterinary AI products to market are not required to report validity and performance data.”⁷



There is a very real possibility that veterinarians could be presented with a suite of AI tools with unproven accuracy and quality assurance. They go on to give recommendations for ethical use of AI in veterinary radiology, paraphrased here to encompass all areas of veterinary medicine:

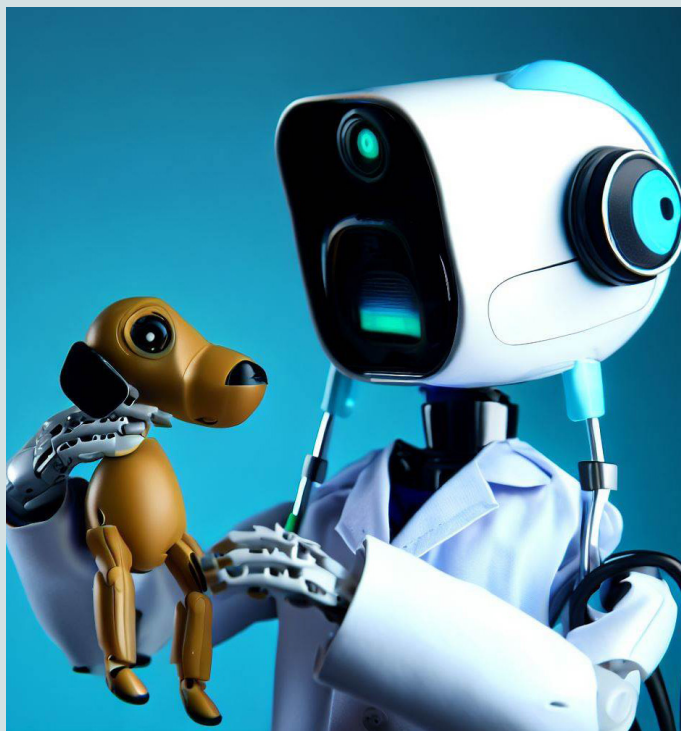
- AI technology should do no harm.
- Domain experts (e.g. board-certified specialists) should be “in the loop” from start to finish of development, deployment, and supervision of AI products.
- AI companies and their products should be transparent, and provide/disclose information relating to data use, validation and training, calibration, outcomes, and errors.
- AI products should be subject to peer review (ideally prior to entry into the market for clinical use) and guided by position/white papers by domain experts when possible.
- When medical errors occur, a root-cause analysis should be performed to identify points at which decision making was faulty. Ideally this would be shared on a national database. Companies should be transparent when errors occur. This is part of Post-Market Surveillance (PMS) in human medical devices and is very stringently regulated.
- Until further progress is made, the profession should strive to have domain experts involved in final recommendations in conjunction with AI, rather than by AI alone.

Job loss and economic disruption

In 2023, a report by the World Economic Forum estimated that one fifth of companies expected to see job displacement, yet half expected technological advancement to see job growth.⁸ Key to successful expansion of the labor market will be reskilling to adapt to changing work environments.

As AI systems become more advanced, there is a growing concern that they will automate many jobs, leading to widespread job losses and economic disruption. This raises ethical questions about how society should address the potential displacement of workers and how to ensure that everyone has access to meaningful employment and a decent standard of living.

In an industry facing a global workforce crisis at all levels – from veterinary technicians to specialists – AI tools that ease workforce pressure and improve efficiencies in practice are vital to forming part of the solution. We must ensure, however, that alongside technology we are investing in healthy pipelines of skilled and well supported human resource across the veterinary ecosystem.



Human relations

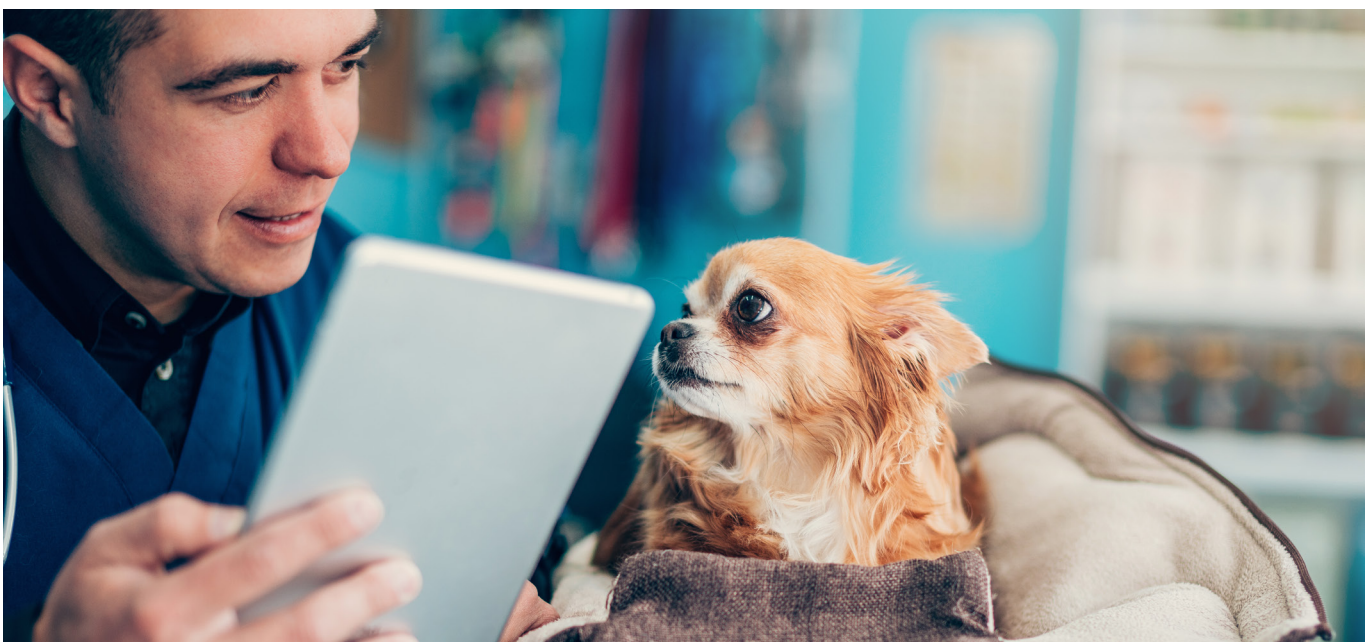
There is a concern that automation and AI will lead to a loss of the nuance of human connection and empathy, so important in building relationships and successful working partnerships. For example, if AI chatbots lead to a reduction in the number of interactions by veterinarians with pet owners in the clinic, or on the farm, there is less opportunity to build the trust that is so vital for a strong, healthy VCPR.

Conversely, time-savings afforded by AI could be released for important tasks such as building social capital, community building and working on the foundations and development of trust. AI also offers scalability beyond the limitations of physical resources. It's about deploying tools that offer the best balance to foster trust and enable timely delivery of care.

Control and transparency

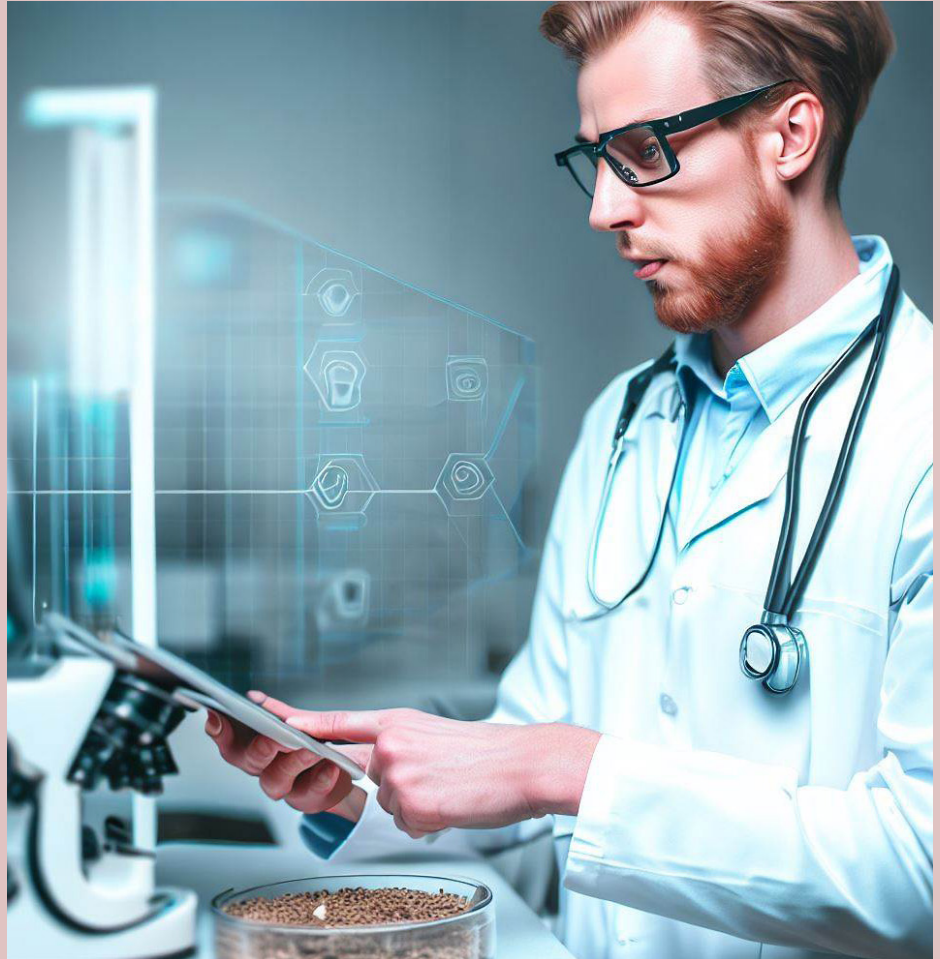
There is a need for education, transparency and control in the decision-making processes of AI systems. It is crucial to ensure that AI systems are transparent and developers are accountable so that users can understand how decisions are made, and have the confidence to challenge or appeal them if necessary. This becomes vitally important in applications where AI systems are used to inform decisions that can literally have a life and death impact through the potential for euthanasia.

Another consideration is the impact of AI on pet owners and their relationships with their veterinarians and their animals. Pet owners may have concerns about the use of AI in veterinary medicine, such as whether it will replace the expertise of veterinary professionals or whether it will lead to overdiagnosis or overtreatment. Clear communication and transparency around the use of AI in veterinary medicine is crucial to address these concerns and to ensure that pet owners understand the role of AI in the diagnostic process, any limitations or potential errors, and can give their informed consent.



Summary

In conclusion, the ethics of AI is a complex and multifaceted field that raises many important questions about the impact of AI on society, individuals, animal welfare, and the interplay between them. It is essential to consider these ethical concerns and to address them proactively and ensure that AI is developed and used in a responsible and ethical manner. While it would be rational to expect or even demand that these dilemmas are solved by veterinary medical regulatory bodies, but the reality is that regulators and governments are struggling to keep up with the pace of technology, let alone reach quorum across sectors as diverse as social media platforms to self-driving cars to automated weapons. To this end, it is important to engage widely across the veterinary profession to debate and discuss the ethical implication of AI in our own industry, and to invest in ongoing research and development in the field of AI ethics.



¹Dastin J, (2018) Amazon scraps secret AI recruiting tool that showed bias against women, Reuters <https://www.reuters.com/article/us-amazon-com-jobs-automation-insight-idUSKCN1MK08G>

² https://en.wikipedia.org/wiki/Automation_bias

³Alkaissi H, McFarlane SI. Artificial Hallucinations in ChatGPT: Implications in Scientific Writing. *Cureus*. 2023 Feb 19;15(2):e35179. doi: 10.7759/cureus.35179.

⁴Confessore N, (2018) Cambridge Analytica and Facebook: The Scandal and the Fallout So Far <https://www.nytimes.com/2018/04/04/us/politics/cambridge-analytica-scandal-fallout.html>

⁵American Veterinary Medical Association. AVMA Policies- Principles of veterinary medical ethics of the AVMA. 2019. Accessed May 19, 2023; <https://www.avma.org/resources-tools/avma-policies/principles-veterinary-medical-ethics-avma>

⁶U.S Food & Drug Administration. Proposed Regulatory Framework for Modifications to Artificial Intelligence/Machine Learning (AI/ML)- Based Software as a Medical Device (SaMD) . 2020. <https://www.fda.gov/media/122535/download>

⁷Cohen, EB, Gordon, IK. First, do no harm. Ethical and legal issues of artificial intelligence and machine learning in veterinary radiology and radiation oncology. *Vet Radiol Ultrasound*. 2022; 63(Suppl. 1): 840– 850. <https://doi.org/10.1111/vru.13171>

⁸World Economic Forum 'Future of Jobs Report 2023' https://www3.weforum.org/docs/WEF_Future_of_Jobs_2023.pdf

As AI is fundamentally transforming our world and bringing about significant changes in various domains, including healthcare, education, and employment. As such, it has profound implications for human mental, physical, and social well-being, presenting both opportunities and challenges.

Mental well-being

AI has a broad range of applications in mental health, with potential for substantial benefits.

In terms of work, AI can perform repetitive tasks and assist with analysing large data sets without getting tired, thereby increasing productivity and allowing humans to focus on more complex and interesting tasks that require creative and critical thinking.

AI algorithms can analyze behavior patterns, social media interactions, or even speech and text for early signs of mental health issues, such as depression or anxiety, thus facilitating early intervention. This could be particularly beneficial for individuals who may not recognize their own symptoms or for those in situations where a human observer isn't available.



According to the World Health Organization, there is a global shortage of mental health-trained health workers. Many mental health initiatives do not reach those in need, with nearly 70% having no access to these services.¹ AI-powered chatbots or digital therapists can deliver cognitive-behavioral therapy (CBT) techniques or mindfulness exercises to help individuals cope with their anxiety. These tools can provide support to individuals who might not have access to mental health care due to geographical, financial, or stigma-related barriers. Digital platforms can provide 24/7 support, responding immediately to individuals in need and AI's ability to analyze large amounts of data can facilitate personalized treatment plans, tailored to the individual's specific needs and circumstances. It can potentially predict how an individual might respond to different treatments, which could potentially increase the effectiveness of recommended treatment.

However, while AI-based interventions can provide immediate and accessible support, the lack of human contact may not fully replace the empathetic understanding that comes from human therapists. This depersonalization might be less effective for some individuals and could potentially exacerbate feelings of isolation.

Concerns also arise with the potential for AI to automate certain jobs, leading to unemployment in some sectors. While AI may also create new jobs, there's a risk these may require skills that the displaced workers don't possess. Fears may also arise due to potential lack of human contact, or even fear of the AI itself (for example, fears about AI becoming too powerful).

In areas like privacy, with AI often needing extensive personal data to operate effectively, concerns about how this data might be used can create anxiety. Technologies that involve constant tracking and monitoring could also exacerbate symptoms in certain individuals. The potential depersonalization of care, increased dependency on technology, and AI-related fears could also contribute to anxiety and depression.

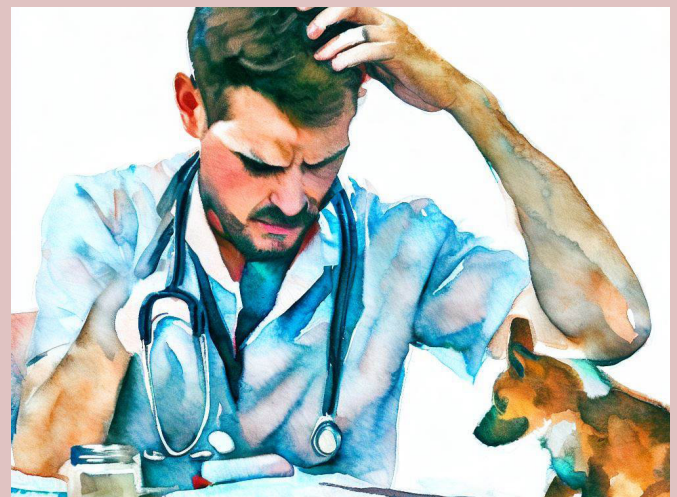
Like any technology, AI can be misused. For instance, deepfakes (AI-generated synthetic media) can be used to spread misinformation, leading to stress. Furthermore, over-reliance on technology and the "always-on" culture can contribute to increased stress and anxiety. AI advancements might exacerbate this by pushing for more automation and constant connectivity. As AI often involves digital interfaces, increased screen time is a concern as large amounts of screen time has been linked to increased risk for depression. Excessive use of AI technologies

Physical well-being

AI can improve fitness and wellness, providing personalized recommendations to improve physical health. AI can also be used in public health initiatives, predicting disease outbreaks, or analyzing the impact of different health policies.

It can help differently-abled people by enhancing their abilities to interact with the world and drive inclusive equality across a broad range of fields such as employment, education and independent living. Examples include AI-powered prosthetics, voice recognition technology for people with motor impairments, and AI-driven text-to-speech technologies for people with visual impairments.

Nevertheless, increased use of AI technologies could contribute to a more sedentary lifestyle. While AI can improve healthcare access, disparities might be exacerbated if certain groups lack access to these technologies due to financial or other barriers. If the data used to train an AI system includes biases, the system can also exhibit those biases, leading to unrepresentative, unjust or discriminatory outcomes. For example, a report for United Nations Human Rights Council highlights that steps must be taken to ensure the algorithms are not biased through training on ableist data.²



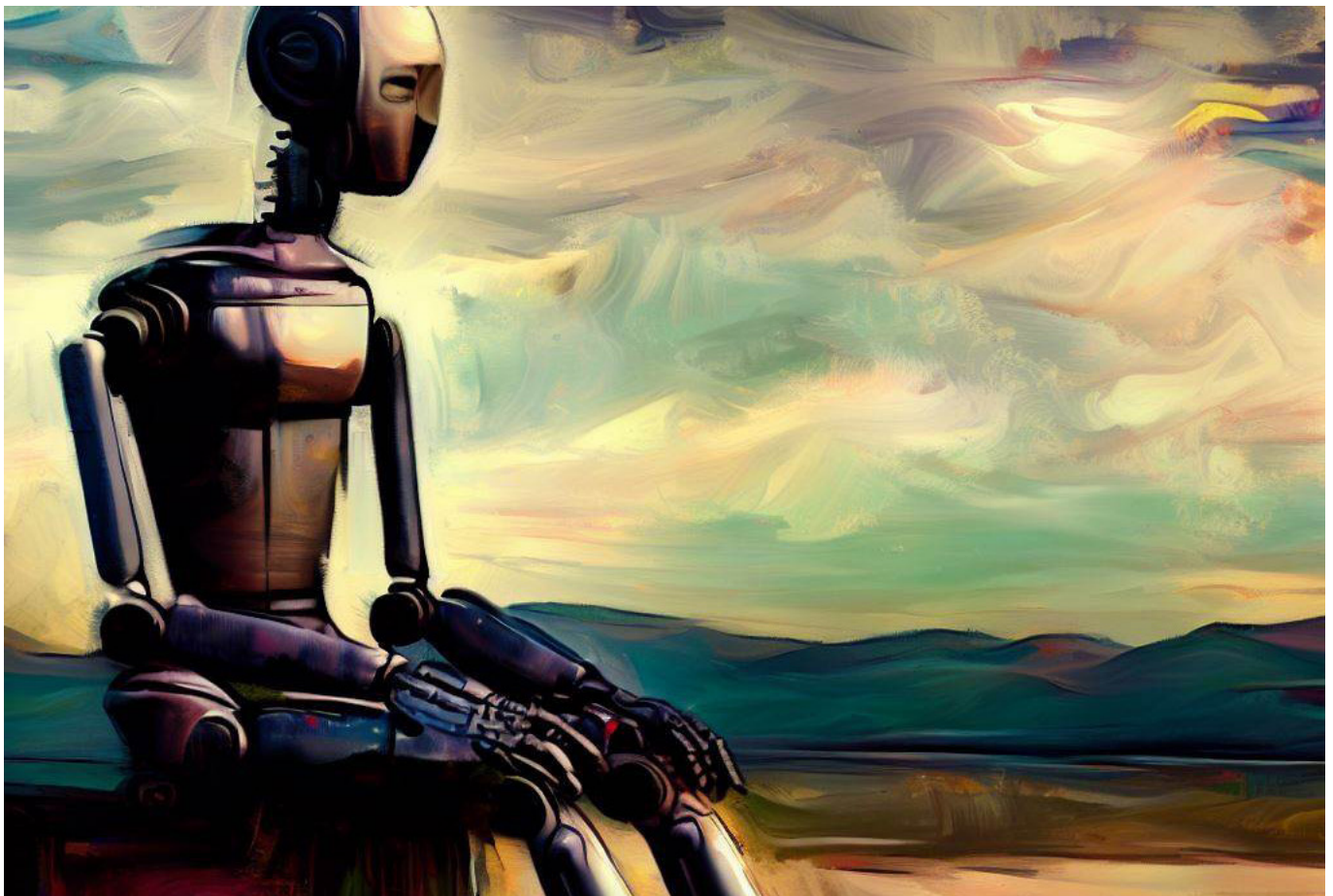
Social well-being

AI has the potential to enhance social cohesion by improving communication, promoting social inclusion and increasing public safety. It can help people connect and communicate more effectively. For example, real-time translation tools can break down language barriers, and social media algorithms can connect individuals with similar interests.

The social model of disability proposes that people are disabled by barriers in society, not by their impairment. AI can assist differently-abled people in various ways, such as voice recognition for those with mobility issues. This can help them to participate more fully in society, thereby promoting social inclusion.

Conversely, AI could contribute to social division by perpetuating existing social inequalities. For example, personalized news feeds can create echo chambers that reinforce pre-existing beliefs, polarize opinions and disconnect people from differing perspectives.³

The automation of jobs through AI could lead to unemployment, exacerbating social inequality, and potentially undermining social cohesion. The gathering and analyzing of extensive data can cause privacy and trust issues, which may lead to societal stress and mistrust and further erode social cohesion. These concerns are eloquently narrated through the 2013 film, 'Her', and the 2020 documentary, 'The Social Dilemma'.





Mitigation strategies

As with any technology, the key to leveraging AI in a beneficial way is to use it thoughtfully and ethically, keeping the well-being of the individual at the forefront. Measures to ensure data privacy, limit excessive screen time, and provide human support in conjunction with AI-based interventions can help mitigate potential negative impacts. Additional areas of focus include:

1. **Ethical and responsible AI:** AI systems should be designed and deployed ethically, considering implications for mental, physical, and social well-being. This includes addressing algorithmic bias, protecting privacy, and ensuring transparency.
2. **Education and skill development:** As AI transforms the job market, educational institutions should prepare individuals with the necessary skills for new roles. Lifelong learning and reskilling initiatives can help workers adapt to change. This could also include measures support workers affected by automation, and promote the responsible use of AI.
3. **Policy and regulation:** To maximize the positive impacts of AI on social cohesion and well-being, and to mitigate the negative impacts, it's crucial to have appropriate policies and regulations. Policymakers should create regulations that protect individuals while encouraging innovation. This includes policies to protect privacy, prevent discrimination, and manage the impact of AI on employment.
4. **Accessible AI:** Efforts should be made to ensure AI technologies are accessible to all, preventing disparities in healthcare and other areas.
5. **Promote healthy behaviours:** Encourage a balanced approach to technology use, promoting healthy behaviors to mitigate potential negative impacts on physical and mental health.
6. **Support change management:** The pace of AI development is extremely rapid, and the consequence rate of change is difficult to predict. It's important to use AI technologies mindfully and to consider potential sources of stress when designing and implementing AI systems.

In conclusion, AI presents a wealth of opportunities to enhance human mental, physical, and social well-being. However, there are risks around perpetuation of unhealthy habits, fear and inclusiveness. The associated challenges must be addressed to ensure overall benefits are realized. By implementing thoughtful and proactive strategies, we can harness the power of AI to improve human well-being while mitigating potential negative impacts.



¹ Ellis D. (2022) Artificial Intelligence in CBT, News-Medical.net <https://www.news-medical.net/health/Artificial-Intelligence-in-CBT.aspx>

² Quinn, G. (2021), Artificial intelligence and the rights of persons with disabilities - Report of the Special Rapporteur on the rights of persons with disabilities, <https://www.ohchr.org/en/documents/thematic-reports/ahrc4952-artificial-intelligence-and-rights-persons-disabilities-report>

³ Calice, M. N., Bao, L., Freiling, I., Howell, E., Xenos, M. A., Yang, S., Brossard, D., Newman, T. P., & Scheufele, D. A. (2021). Polarized platforms? How partisanship shapes perceptions of “algorithmic news bias.” *New Media & Society*, 0(0). <https://doi.org/10.1177/14614448211034159>

The field of both human and veterinary medicine where AI is perhaps most advanced in terms of wide deployment of clinical tools is radiology. This both presents an opportunity and places a burden on veterinary radiology to lead the way with ethically responsible innovation in AI development and application.

The use of AI tools in human radiology has rapidly gained popularity in recent years. These tools have been developed to assist radiologists in the analysis of medical images, with the aim of making the process faster, more efficient, and more accurate. There is no doubt that tools such as these applied to veterinary radiology will go a significant way to easing the pressure on radiologists due to growing demand for radiology services and a shortage of diploma-holding specialists.



Examples of the application of AI in radiology:

- **AI-based triage systems:** Help radiologists prioritize cases and manage workflow by identifying high-priority cases and flagging them for immediate attention. This can help to reduce delays and improve the overall efficiency of the radiology department.
- **Computer-aided detection (CAD):** Used to analyse images and identify suspicious radiological signs, helping radiologists to quickly locate areas that require further attention.
- **Image segmentation:** The process of identifying and outlining specific structures in an image, such as organs or tumors. This is an important step in many image analysis tasks, such as image registration, image-guided surgery, and radiation therapy planning. AI algorithms can be used to automate this process, making it faster and more accurate.
- **Image enhancement:** The process of improving the visibility of structures in an image. This can be done by adjusting the brightness and contrast of the image, or by applying filters that can highlight certain structures. AI algorithms can be used to automate this process, making it more efficient and consistent.
- **Image classification:** AI algorithms can be used to classify medical images into different categories, such as healthy vs diseased, benign vs malignant, etc. This helps radiologists make more informed decisions about treatment and management options.
- **Image registration:** Used to align and register multiple images of the same body part, allowing radiologists to better understand the evolution of a condition over time.
- **Quantitative imaging:** This can be used to extract quantitative information from medical images, such as measurement of tissue density or volume, which can help radiologists make more informed decisions about recommendations.
- **Autonomous imaging:** The use of AI algorithms to control the imaging process and make decisions about image acquisition. This can include things like adjusting the radiation dose, selecting the most appropriate imaging modality, or optimizing the imaging parameters for a specific clinical task.
- **Radiomics:** The extraction of quantitative features from medical images and use of these features to predict patient outcomes, such as survival, tumor progression, and treatment response. This is done by using AI algorithms to analyze the images and extract meaningful information that is not visible to the human eye, such as individual pixel/voxel intensity values within a region of interest.
- **Imaging workflow optimization:** This refers to the application of AI to improve the efficiency and effectiveness of the workflow in a radiology department, such as workforce scheduling, case assignment and report generation.

As we can see from the above examples, artificial intelligence (AI) has enormous potential to revolutionize veterinary radiology, just as it has in human radiology. However, there are some key differences around data between the two fields that should be taken into consideration.

Data

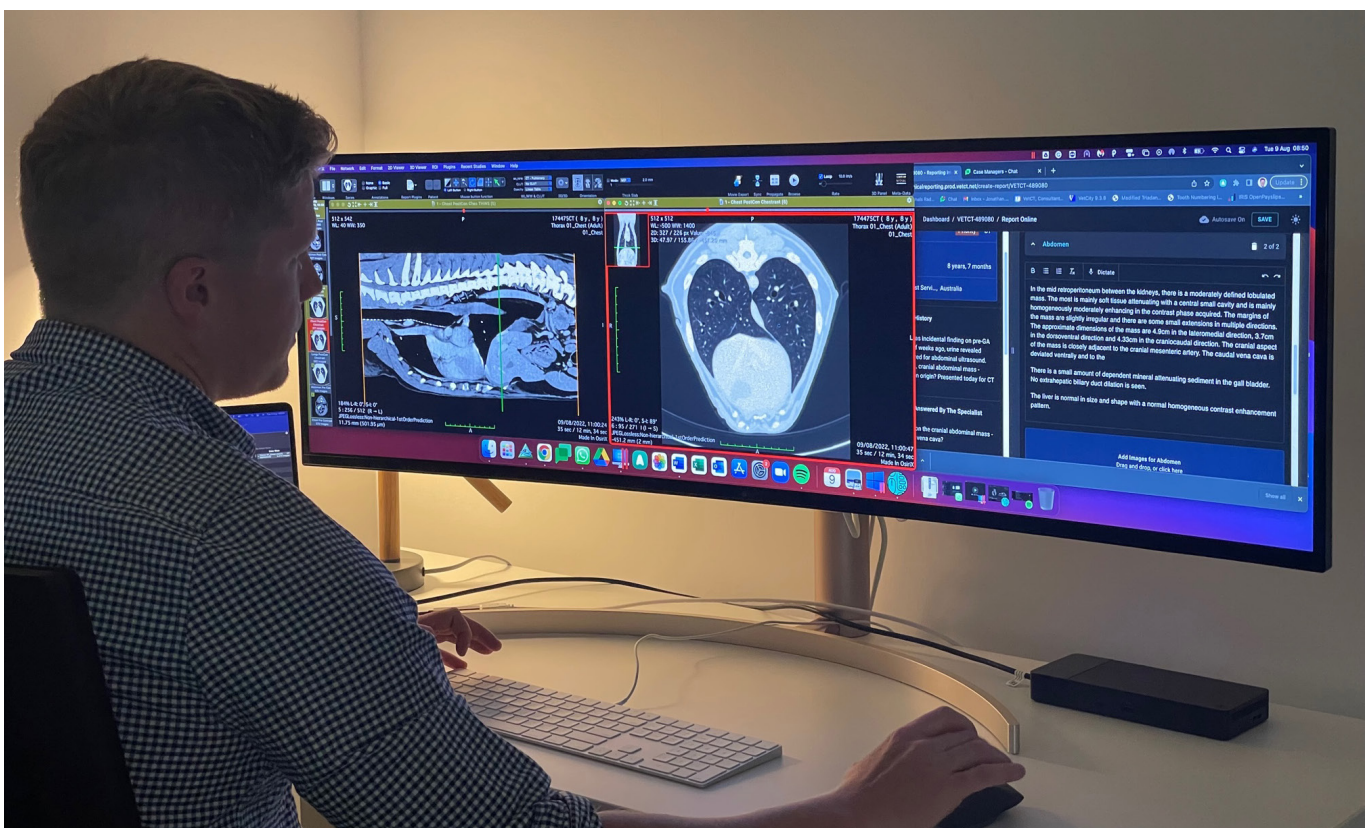
Major differences exist in the availability, quality and quantity of data between human and veterinary fields.

■ **Quantity:** In human radiology, there is a vast amount of standardized data available, including millions of images and associated clinical information. In veterinary radiology, the volume of data is much more limited, with increased anatomical variation due to the variety of breeds and species. This makes it more difficult to train AI algorithms and achieve the same level of accuracy as in human radiology.

■ **Quality:** Quality control of both image acquisition and processing, including positioning, exposure and labeling, is much more variable in veterinary compared to human radiology.

■ **Availability:** Human medical data is subject to stricter regulations and privacy concerns, such as HIPAA (Health Insurance Portability and Accountability Act) in the United States. These regulations aim to protect patient privacy and require explicit consent for data sharing and research purposes. In contrast, veterinary data typically has fewer regulatory hurdles, making it more readily available for research and AI projects. This places the veterinary industry as an ideal candidate to develop effective AI tools in diagnostic imaging where a sufficient data pool exists.

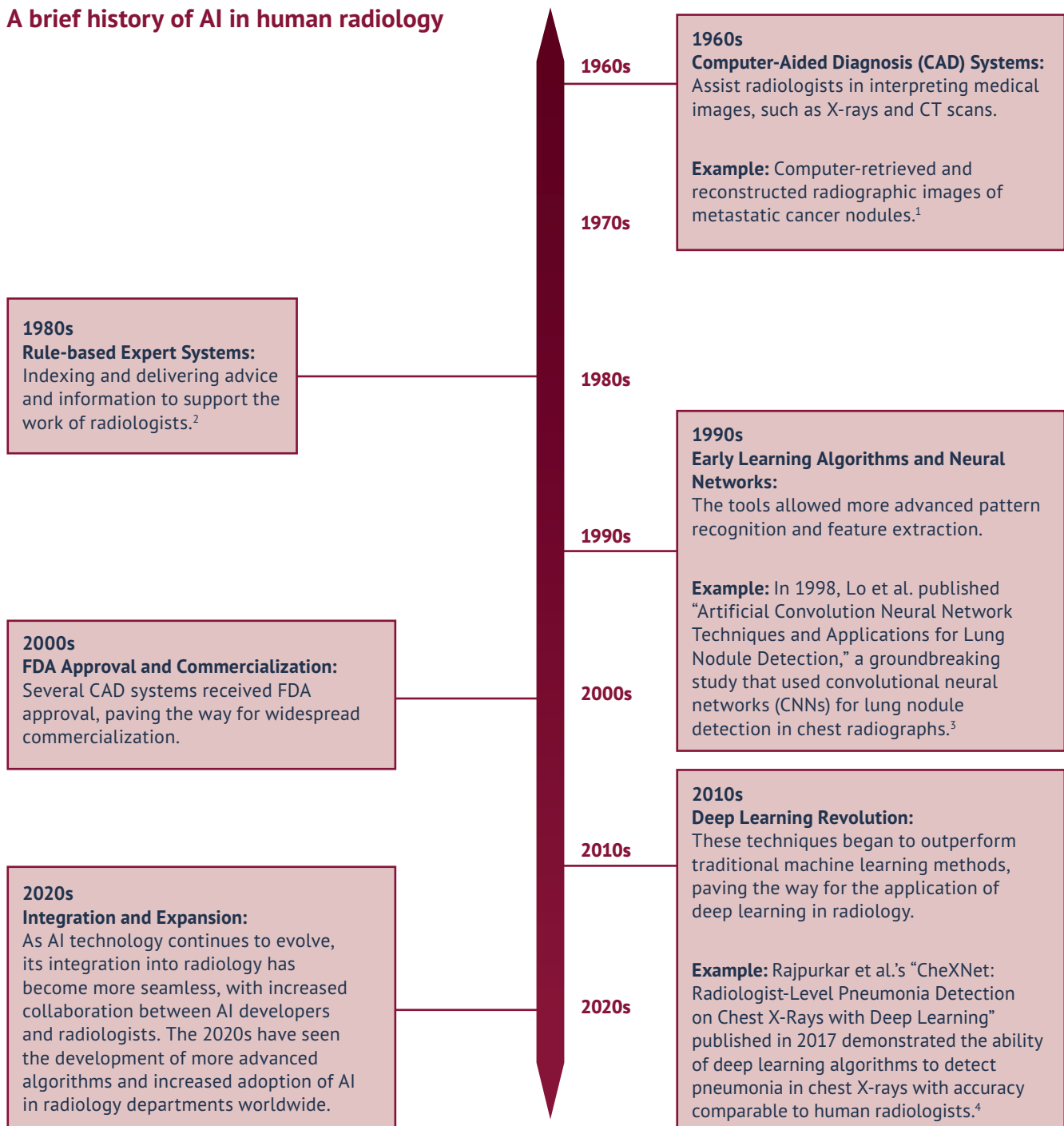
■ **Accessibility:** In many cases, veterinary data is localized within specific clinics or hospitals, making it challenging to access and collate large data sets. Data in human medical systems may be more accessible in terms of large, standardized data pools (such as the National Health Service in the U.K.), though it is less available due to data privacy regulations.



The progression of AI development in human radiology

The use of Artificial Intelligence in human radiology has a rich history dating back several decades. This interdisciplinary field combines computer science, medical imaging, and radiology to develop algorithms and software that can analyze medical images, improving the speed and accuracy of diagnosis for a limited number of specific indications. Here, we provide an overview of key developments, publications, and milestones in the use of AI in radiology.

A brief history of AI in human radiology



Human vs veterinary AI in radiology

Where the field of human radiology AI is well researched and already widely deployed to aid with efficiency and certain diagnoses, the field is still relatively new in veterinary medicine. Indeed, in 2021 alone over 2000 papers were published on radiology in human medicine, compared to just 10 in veterinary (see tables below).

Table 1

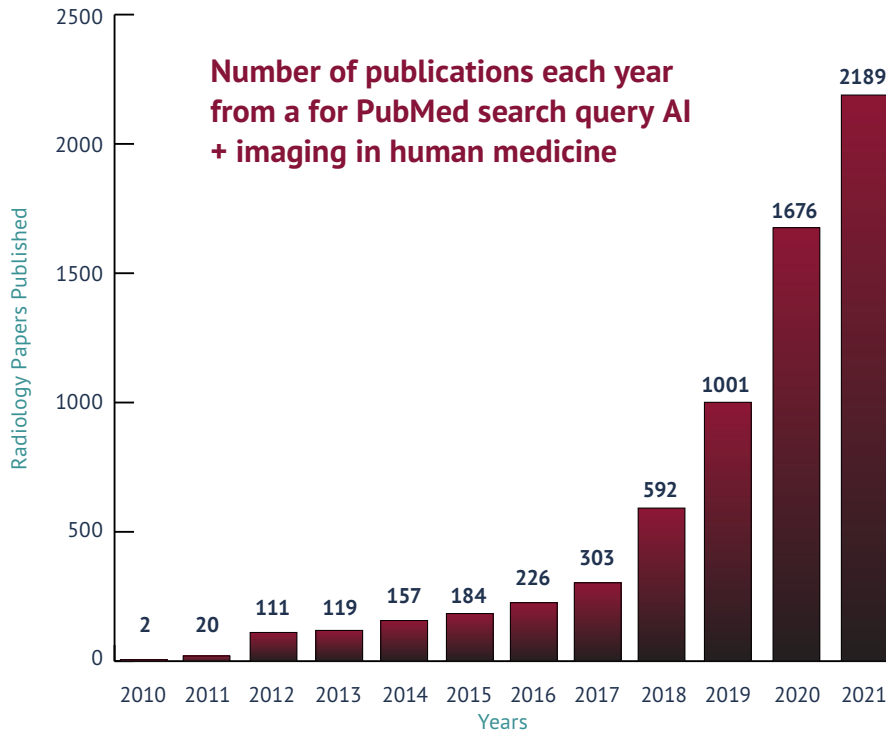
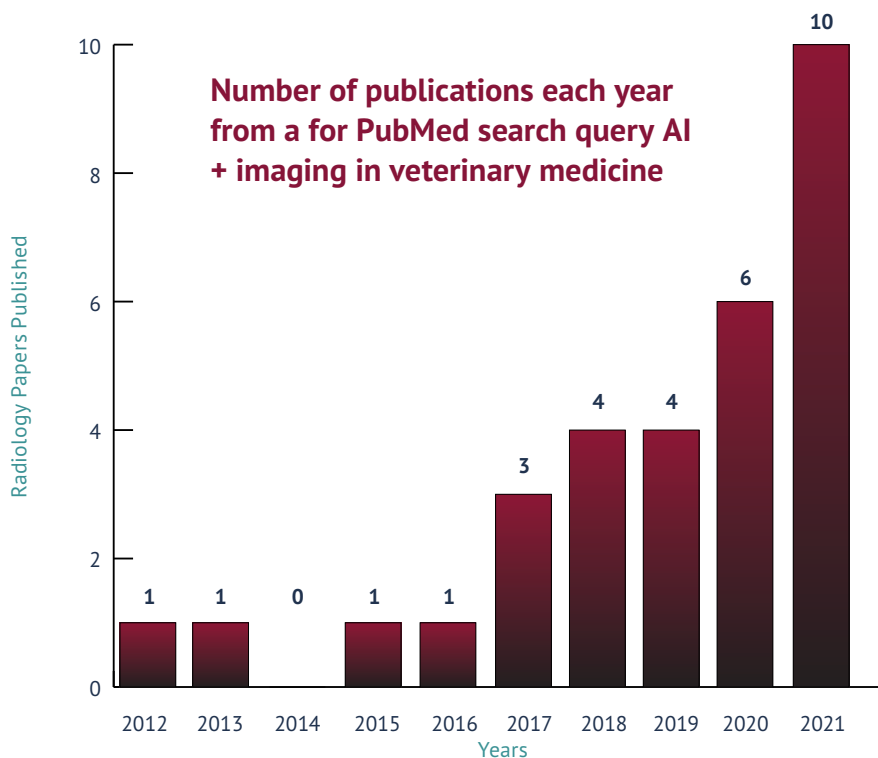


Table 2



AI veterinary radiology has been applied to image acquisition, such as segmentation of CT body areas,⁵ and interpretation, for example classification of hip dysplasia⁶ and vertebral heart scores.⁷ Human radiology has additionally benefited from AI tools applied to outcome prediction, prognosis and even population health management.

Regulation:

There are a number of standards and regulations in place for the use of AI in human radiology. These standards and regulations are designed to ensure the safety and effectiveness of the technology, as well as to protect patient privacy and data security.

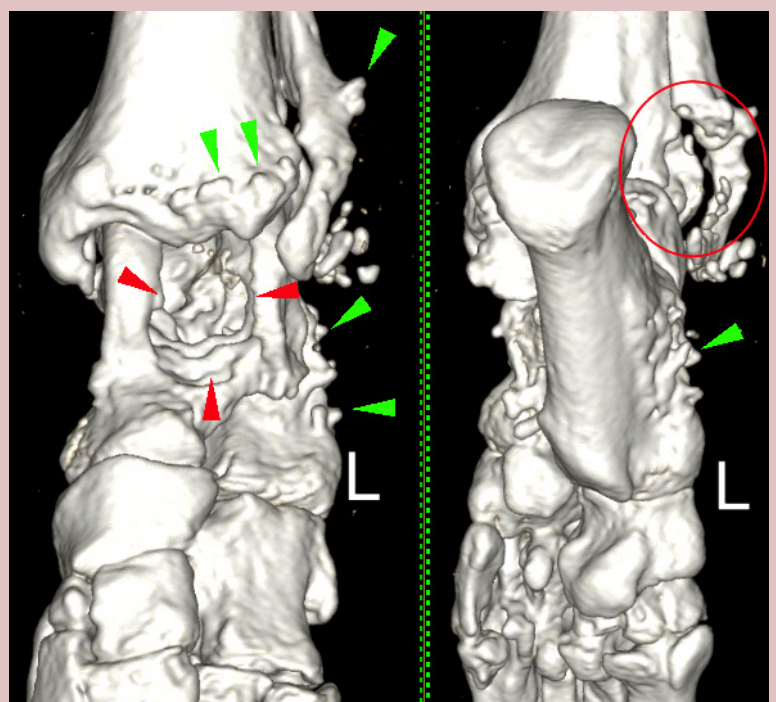
Human medical device development is governed by ISO 13485, but relies heavily on the application of risk management (ISO 14971). Recently the The Association for the Advancement of Medical Instrumentation (AAMI) published guidance on the application of these regulations, recognized by the FDA.⁸

Another key standard is the FDA's premarket review process, which is used to evaluate the safety and effectiveness of medical devices, including AI-powered medical devices. This helps to ensure that AI-powered medical devices are safe and effective for their intended use before they are made available to the public.

In 2021, the FDA also published a guidance document: Artificial Intelligence/Machine Learning (AI/ML)-Based Software as a Medical Device (SaMD).⁹ It provides recommendations on how to ensure the safety and effectiveness of AI-powered medical devices, including the need to validate the performance of the software, the need to establish a system for monitoring the software's performance in the field, and the need to establish a system for reporting adverse events.

These regulations and standards are constantly evolving as the technology advances and more data is gathered on its real-world use and impact.

In addition to these standards and regulations, there are also professional organizations such as the American College of Radiology (ACR) and Radiological Society of North America (RSNA) that have developed guidelines and best practices for the use of AI specifically in the field of radiology. These guidelines cover topics such as the validation and testing of AI algorithms, the use of AI in clinical decision-making, and the ethical and legal implications of AI in radiology.



Some of the key recommendations from the ACR and RSNA include:

- **Validation:** AI algorithms should be validated using appropriate methods, such as independent testing and prospective clinical studies, to ensure that they are accurate and reliable.
- **Transparency:** AI algorithms should be transparent, meaning that their performance characteristics and the reasoning behind their decisions should be clearly understood and explainable by the users.
- **Clinical integration:** AI algorithms should be integrated into clinical workflows in a way that enhances the radiologist's ability to make accurate diagnoses, rather than replacing the radiologist.
- **Quality assurance:** There should be a system in place to monitor the performance of AI algorithms in the clinical setting, and to identify and address any issues that arise.
- **Patient safety:** The use of AI algorithms should not compromise patient safety in any way.
- **Data governance:** The data used to train and validate AI algorithms should be of high quality and appropriately collected and secured, and should be compliant with relevant laws and regulations.
- **Education and training:** Radiologists and other healthcare professionals should be educated and trained on the use of AI in radiology, including the limitations and potential pitfalls of the technology, in order to ensure that they are able to use it safely and effectively.
- **Ethical considerations:** The use of AI in radiology raises a number of ethical considerations, such as issues related to bias, privacy, and autonomy. These considerations should be taken into account when developing and using AI algorithms.
- **Collaboration:** The development and implementation of AI algorithms in radiology should involve collaboration between radiologists, computer scientists, engineers, and other relevant experts in order to ensure that the technology is safe, effective, and appropriate for its intended use.
- **Clear communication:** Clear communication between radiologists, patients, and other healthcare professionals is crucial to ensure that everyone understands the role of AI in the diagnostic process and any limitations or potential errors.





To the contrary, there are no specific regulations pertaining to the use of artificial intelligence in veterinary medicine. The field of AI in veterinary medicine is still emerging, and regulatory frameworks should be fully developed and implemented to protect the radiologist, the veterinarian and animal welfare, with the involvement of regulators, professional bodies and specialty colleges, such as the ACVR (American College of Veterinary Radiology) and ECVDI (European College of Veterinary Diagnostic Imaging).

Will AI replace radiologists?

In the field of human radiology, highly regulated tools for very well defined, specific indications have been developed to aid radiological interpretation of images. These tools are collated in a library to aid clinicians in selecting the correct tool for a given indication.¹⁰

A study showed clinicians were less comfortable with an AI generated report, whereas a hybrid AI/radiologist report was as accepted as a radiologist's report.¹¹ Recent research also published in the British Medical Journal showed an AI candidate was unlikely to pass the Royal College of Radiologists Examination.¹²

In a field where demand for radiologists overwhelms supply, leveraging AI to increase the efficiency of radiologists, as opposed to replacing them, is a practical way to increase access to specialist input on diagnostic imaging for more animal patients. Indeed, As Curt Langlotz put it, "Radiologists who use and understand AI will replace radiologists who don't".

"Radiologists will not be replaced by AI. Radiologists who use and understand AI will replace radiologists who don't."

Dr. Curt Langlotz, Professor of Radiology and Biomedical Informatics

Despite the many benefits of AI in both human medical and veterinary radiology, we must be mindful of the potential limitations and concerns to consider. For example, AI algorithms can be affected by image quality and image artifacts, which can impact the accuracy of results. Additionally, there is a risk of over-reliance on AI tools, which could lead to a decrease in critical thinking and clinical judgement. We must also be mindful that automation bias can lead us to give more weight to the judgement of an AI tool over and above human opinion: “It must be right because the computer said so.”

Overall, the use of AI tools in radiology has the potential to significantly improve the diagnostic process, but it is important to use these tools in conjunction with human expertise, rather than as a replacement. Further research and development are needed to optimize AI algorithms and ensure they are used in a safe and effective manner.

¹ Evaluation of Computer-Reconstructed Radiographic Images in an Experimental Approach to Computer Analysis of Radiographic Images. Philip H. Meyers, Hal C. Becker, James W. Sweeney, Charles M. Nice, Jr., and Wilson J. Nettleton, Jr., *Radiology* 1964 82:2, 303-303

² Expert system-controlled image display.

H A Swett, P R Fisher, A I Cohn, P L Miller, and P G Mutalik, *Radiology* 1989 172:2, 487-493

³ S-C. B. Lo, S-L. A. Lou, Jyh-Shyan Lin, M. T. Freedman, M. V. Chien and S. K. Mun, “Artificial convolution neural network techniques and applications for lung nodule detection,” in *IEEE Transactions on Medical Imaging*, vol. 14, no. 4, pp. 711-718, Dec. 1995, doi: 10.1109/42.476112.

⁴ Rajpurkar, P., Irvin, J., Zhu, K., Yang, B., Mehta, H., Duan, T., Ding, D., Bagul, A., Langlotz, C., Shpanskaya, K. and Lungren, M.P., 2017. Chexnet: Radiologist-level pneumonia detection on chest x-rays with deep learning. arXiv preprint arXiv:1711.05225.

⁵ Schoppe O, Pan C, Coronel J, Mai H, Rong Z, Todorov MI, Müskes A, Navarro F, Li H, Ertürk A, Menze BH. Deep learning-enabled multi-organ segmentation in whole-body mouse scans. *Nat Commun.* 2020 Nov 6;11(1):5626. doi: 10.1038/s41467-020-19449-7.

⁶ McEvoy, FJ, Proschowsky, HF, Müller, A, et al. Deep transfer learning can be used for the detection of hip joints in pelvis radiographs and the classification of their hip dysplasia status. *Vet Radiol Ultrasound.* 2021; 62: 387– 393. <https://doi.org/10.1111/vru.12968>

⁷ Boissady E, De La Comble A, Zhu X, Abbott J, Adrien-Maxence H. Comparison of a Deep Learning Algorithm vs. Humans for Vertebral Heart Scale Measurements in Cats and Dogs Shows a High Degree of Agreement Among Readers. *Front Vet Sci.* 2021 Dec 9;8:764570. doi: 10.3389/fvets.2021.764570.

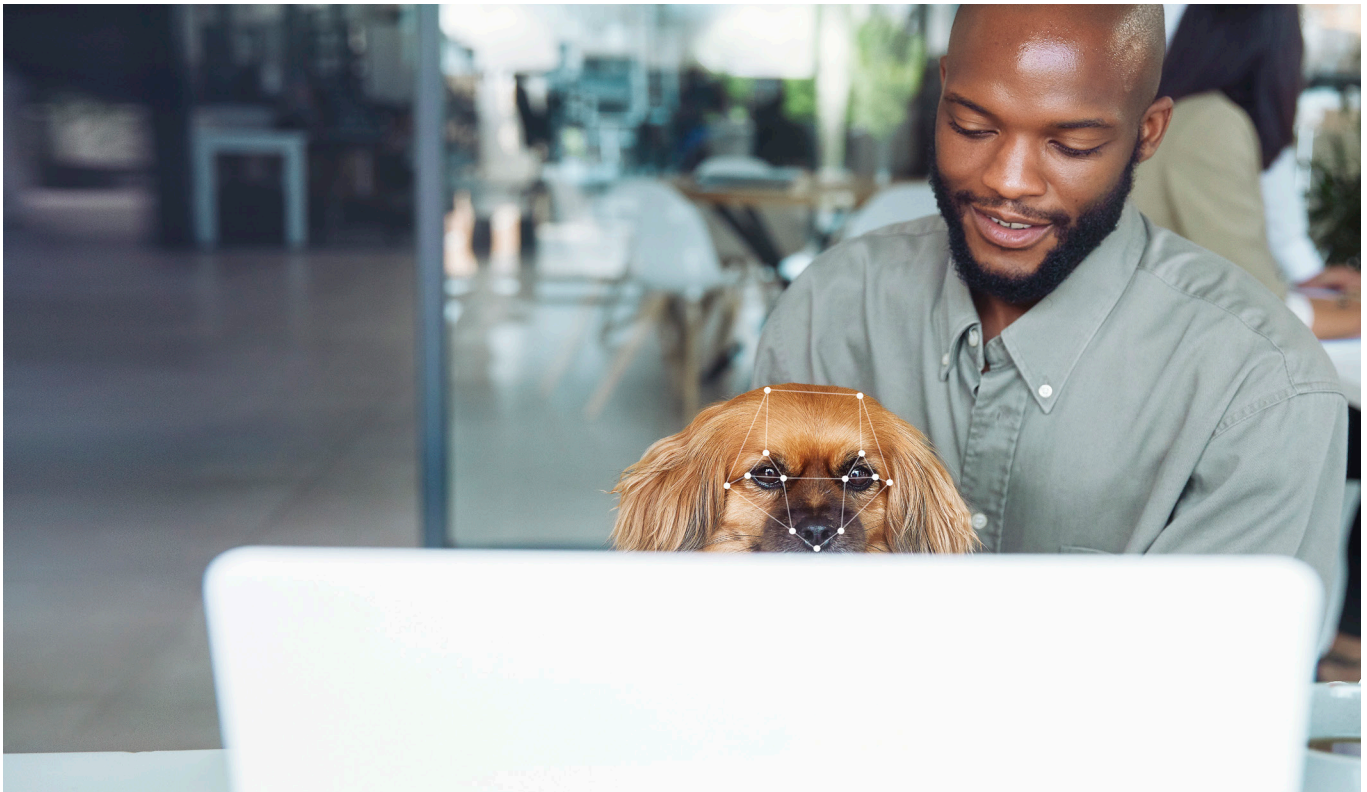
⁸ <https://array.aami.org/content/news/u-s-fda-recognizes-first-artificial-intelligence-guidance-among-updated-list>

⁹ https://www.fda.gov/media/145022/download?utm_medium=email&utm_source=govdelivery

¹⁰ <https://grand-challenge.org/aiforradiology/>

¹¹ Lim SS, Phan TD, Law M, et al. Non-radiologist perception of the use of artificial intelligence (AI) in diagnostic medical imaging reports. *Journal of Medical Imaging and Radiation Oncology.* 2022; <https://doi.org/10.1111/1754-9485.13388>

¹² Shelmerdine S C, et al. Can artificial intelligence pass the Fellowship of the Royal College of Radiologists examination? Multi-reader diagnostic accuracy study *BMJ* 2022; 379 :e072826 doi:10.1136/bmj-2022-072826



AI is now part of everyday life, impacting us in ways we are not even fully cognizant of. This increasingly complex non-human 'brain' brings an expansive resource that interprets the data it is provided with through a completely different algorithmic lens, beyond the bounds of our own physiological neural network functioning and capabilities. For centuries, the phrase; 'Two heads are better than one' has acknowledged the increased problem solving capacity and wider perspective. However, it's also been said 'Ask two doctors and get two opinions.' So who has the final say - man or machine?

The true power of AI lies in augmenting human understanding and freeing up more of our human resource for those social and relational duties that AI is unlikely to replace. Rather than concerning ourselves with skills loss or being replaced by machines, the profession will have to figure out how to live with AI 'colleagues' and integrate them into working life. Where AI may excel at the science of veterinary medicine, humans are key to applying knowledge in the emotive clinical setting - the 'art' of being a veterinarian is unlikely to ever be fully replaced by machines.

To empower the profession to apply the outputs of AI technology confidently and correctly, we need to provide our veterinary community with the background understanding of how AI tools are developed, in the same way we study cellular biochemistry in order to be able to understand the impact of medications on whole body systems. We need to apply informed questioning and critical thinking skills to spot errors and biases, in addition to upskilling in the use of AI tools themselves.

From the data it is fed during development, to the questions asked, to the mechanics of the algorithm and its ability to self-learn, to ongoing quality improvement and especially what the outputs can and cannot tell us and when it may be errant, AI must be considered another medical discipline in its own right. We need safeguards to manage risks through regulation and/or the application of robust standards, such as those recommended by the MHRA for software and AI as a medical device, including best practices for ML in medical devices.

The veterinary profession could look to the examples of other professional bodies that have in place proactive plans to stimulate strategic discussion and inform their members. (See text box)

Example; U.K. Chartered Institute for Public Relations recommendations on AI include:³

1. AI and the fundamental structural change it will bring needs to become a part of a strategic conversation in the profession. The profession is re-shaping and this needs to be by design, not by default by mapping a way forwards.
2. That a pathways map is developed which plots the options that practitioners can take to secure various levels of competency in the strategic and tactical uses and governance of AI and Big Data.
3. That guides and resources on AI and Big Data are updated, made widely available to all members and publicised so that there is a basic, membership-wide understanding of what these concepts and technologies entail, their benefits, pitfalls and common uses.
4. That there are a number of focused events/initiatives driven centrally and via the regional groups to educate and inform members systematically on the topics mentioned above.
5. That becoming a knowledgeable and competent practitioner in AI is prioritized.

There is no doubt we AI can provide many solutions to improve the veterinary profession, to help ease workforce pressures, optimize care for animals, improve welfare and make pet and livestock ownership more sustainable. However, it is beholden on us as a profession to take ownership of this field with proactive and pre-emptive regulation. We do not want to find ourselves in a similar position to global governments attempting to regulate the unforeseen fallout from AI algorithms developed for social media platforms after the fact.

We need to safeguard data privacy and in a profession that often suffers from paucity of evidence base, share data in a way that ensures algorithms are truly representative. We need to educate from students to experienced veterinarians and technicians, to give a solid foundation of understanding from which to assess AI tools and deploy them appropriately. We need to ensure transparency and quality assurance, providing clear guidance as to the utility and limitations of each AI tool.

To make AI work for the veterinary industry we need to foster trust and confidence in this technology through education and the application of reliable guardrails. Only then can we embrace the potential advances it offers to ensuring the health and advancement of all aspects of veterinary medicine and practice and the people and animals we serve.

¹ <https://www.gov.uk/government/publications/software-and-artificial-intelligence-ai-as-a-medical-device/software-and-artificial-intelligence-ai-as-a-medical-device>

² <https://www.gov.uk/government/publications/good-machine-learning-practice-for-medical-device-development-guiding-principles>

³ 'Artificial Intelligence (AI) tools and the impact on public relations practice'
<https://www.cipr.co.uk/newsroom/cipr-report-finds-ai-tools-in-public-relations-set-to-explode>



The human authors would like to thank their AI co-author, Open AI's ChatGPT, for its input into writing this white paper. While the initial premise was to turnaround a comprehensive, varied, largely accurate white paper in record time thanks to the use of this readily available tool, the reality was far from hope or expectation.

You may have wondered about the varying background throughout this paper. This is a colour-coding to indicate which copy is written solely by GPT (light turquoise background), edited and co-authored by humans (light red background), or written entirely by human authors (no background).

The artificial author:

Initially, GPT version 3 was used as a free access application following its global launch November 30, 2022, which became limiting due to the exponential increase in user numbers resulting in inaccessibility for large portions of the day. An upgrade to the paid version, GPT-4 greatly improved the reliability and speed.

When asked about the methodology of creating articles within ChatGPT, it responded:

ChatGPT is a language model that uses machine learning techniques to generate text. The process of creating an article using ChatGPT involves feeding the model a prompt, which is a short piece of text that serves as a starting point for the article. The prompt can be a simple question or topic, or it can be a more complex set of instructions.

Once the model has the prompt, it uses its knowledge of the language and its ability to generate text to create a response. This response can be edited and refined by a human, who can make sure that the text is clear, accurate, and appropriate for the intended audience.

The model can also be fine-tuned to generate content that is specific to a certain topic or style, by training it on a dataset specific to that topic.

It's important to note that the quality of the generated article may vary depending on the prompt, the fine-tuning, and the editing.



The tool was interrogated with questions such as, ‘Write a history of AI in veterinary medicine’, which it summarily produced in a matter of seconds. However, language was repetitive and unimaginative, though it was nicely organised as articles with an introduction, body text with summaries and bullet points and a conclusion.

Digging a little deeper, when asked about how it constructs sentences, it wrote:

I generate responses using a machine learning model called GPT-4, which stands for “Generative Pretrained Transformer 4”. Here’s a simplified explanation of how the model generates sentences:

1. Tokenization: First, the input text (like the sentence you’ve just typed) is broken down into smaller pieces called tokens. These can be as short as one character or as long as one word (e.g., “a” or “apple”).

2. Context understanding: The model has been trained on a diverse range of internet text, so it tries to predict what comes next in a sentence by understanding the context based on these tokens. It’s important to note that GPT-4 doesn’t “understand” text in the human sense, but instead recognizes patterns in the data it was trained on.

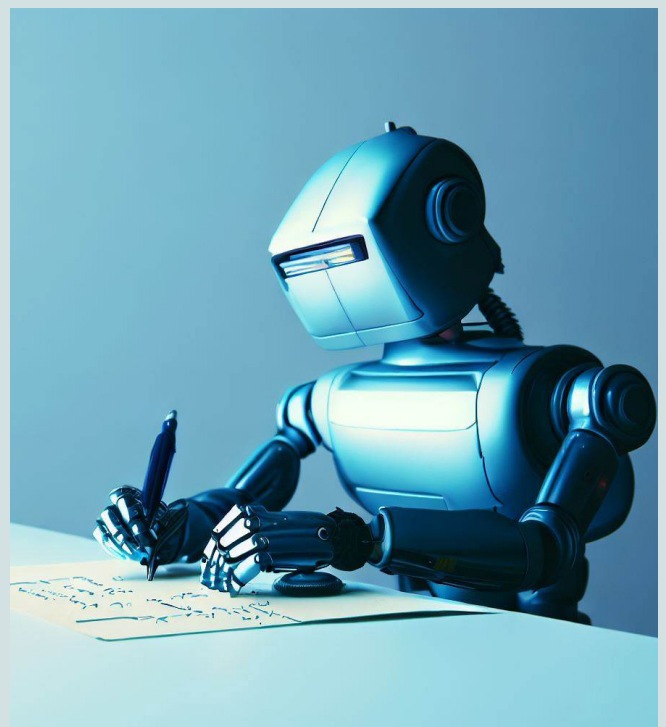
3. Predicting the next token: The model generates a response by predicting one token at a time. Starting from the initial input (the prompt), it calculates the probability of all possible next tokens, and then selects one based on those probabilities.

4. Continuation: The selected token is added to the sequence, and this process is repeated until a maximum length is reached, or an end-of-sentence token is generated.

5. Fine-tuning: The model’s responses can be fine-tuned for specific tasks. For example, in the case of ChatGPT, additional training is done in a dialogue format to make the model better at conversational interactions.

It’s important to note that while GPT-4 can generate coherent and contextually appropriate responses, it doesn’t “know” or “understand” the information in the way humans do. It’s simply predicting the next token based on patterns it observed during its training.

Lastly, the model does not store personal data from the questions it is asked. Each conversation does not have a memory and doesn’t know who users are. It’s designed this way to prioritize user privacy and data security.



The artificial 'human' element:

It has been widely publicised that ChatGPT can mimic human creativity in the form of poetry, song writing, and even taking on the persona of a individual human. In an effort to bring more variety to one of our article queries, we asked ChatGPT to rewrite a history of AI in veterinary medicine, this time including more humor:

Sure thing! Here's a more lighthearted take on the history of AI in veterinary medicine:

"The history of AI in veterinary medicine is shorter than a chihuahua's attention span, but it's still packed with some pretty impressive feats. Way back in the day, we had expert systems, which were basically like having a wise old vet in a computer. These systems helped diagnose and treat a variety of animal diseases, but let's be real, they were about as exciting as a root canal.

Fast forward to more recent times, and we've got machine learning algorithms being used left, right and center. These algorithms can be trained on large sets of data to make predictions and diagnose diseases, which is pretty cool, but honestly, it's about as thrilling as watching paint dry.

But things are starting to get interesting with the use of robotic systems for surgery and other procedures. These systems can be programmed to perform precise and repetitive movements, which can be beneficial in complex procedures such as joint replacements. It's like having a robot vet assistant, and that's pretty darn cool if you ask me!

So, while the use of AI in veterinary medicine is still in its infancy, it's got the potential to revolutionize the field and improve the health of animals, and that's no laughing matter."

Please note that the above is written with a humorous tone and not meant to belittle the importance of the topic or the advancements in the field.

It's interesting to note this penultimate sentence, where AI goes on to champion its own importance, despite the lighthearted nature of the article.





Error-ridden AI and human editing

However, it became apparent that in some cases, entire blocks of text were simply incorrect, or a mixture of truth and error. A particular bugbear was the falsified 'scientific references', which were constructed in an entirely believable manner with appropriate titles, journal selection and even authors, yet simply did not exist.

For example, when asked for a reference in regard to AI helping optimize equine nutrition, the platform generated the following:

Staniar, W. B. (2019). "Using technology to enhance equine nutrition." *Journal of Equine Veterinary Science* 76: 63-64.

However believable it may appear, this is an entirely fabricated reference. The author, journal, issue number and date are real. However, page 63 is not of the issue in fact:

B.D. Velie, P.M. Smith, C.T. Fjordbakk, M. Solé, K.J. Fegraeus, M.K. Rosengren, K.H. Røed, C.F. Ihler, G. Lindgren, E. Strand, "Exploring the genetics of dynamic laryngeal collapse associated with poll flexion in Norwegian-Swedish Coldblooded Trotter racehorses," *Journal of Equine Veterinary Science*, Volume 76, 2019,



This fabrication occurs as GPT generates tokens from text data found in the context of AI, veterinary medical journals and the names of key opinion leaders, and strings them together in a probable context that is both entirely made up and highly plausible. This highlights the vital need for human sense and reality checking, certainly until ChatGPT can live cross-reference itself to determine against ground truth.

Learning together

While every question and feedback score submitted by a human is then used to further train and refine the chat tool, the human operator is also being trained in how to best use the tool to extract information requested in the desired format. As ever, the highly resourceful cohort of students have been trailblazers in adopting machine learning tools to write essays and complete assignments. In an effort to stop students using such shortcuts, AI-checking software was used by teachers to check authenticity and highlight the probability of submitted work having been written by AI.¹ The natural progression of this war of attrition is that students are now requesting that human-like errors are introduced into the copy to fool the AI-checking tools into thinking the AI generated text is human.

Misinformation and data (Ab)use

There is also the concern that data submitted to inform the tool when writing its responses can be consumed into the knowledge base and be used repeatedly across the entire user base. Extreme caution must therefore be taken when providing ChatGPT with any sensitive or confidential information, especially where sharing permissions are lacking. AI chatbots have been used to generate misinformation campaigns, even mimicking authoritarian governments.²

Summary

While GPT-4 proved a useful co-author for some sections of text, the majority of this paper required heavy editing or completely rewritten to include variety, nuance and accuracy, and remove falsified and incorrect information. The greatest utility was in providing a framework and food for thought to begin constructing the paper. It is often easier to correct existing work rather than start writing from scratch, and the speed of generation of text was impressive and inordinately time-saving. Whether the article would have been richer or even quicker to generate in the absence of our artificial co-authors we will never know, but one thing is guaranteed - it would certainly be different.



About the authors:



ChatGPT bio

When asked to write a biography about itself, GPT-4 began constructing a thorough tome, complete with chapters. While it cannot be said this indicates the possession of an ego, here is the more concise version subsequently requested:

“ChatGPT, a conversational AI developed by OpenAI, was trained using the GPT-4 architecture. Launched in 2021, it leverages machine learning to generate human-like text based on the input it receives. It was created using a diverse range of internet text for its training, enabling it to provide information and engage in dialogues on a wide array of topics. Despite being an artificial intelligence, it simulates human conversation and adapts its responses based on the conversation’s context. With the ability to write in multiple languages, styles, and tones, it serves as a versatile tool for a variety of applications. However, it doesn’t possess personal experiences or beliefs, as it doesn’t have consciousness or self-awareness. Continually evolving, ChatGPT’s ultimate aim is to enhance human productivity and understanding through responsible AI use.”



Dr Julien Labruyère, DVM, CertVDI, DipECVDI, MBA, MRCVS, Chief Innovation Officer, VetCT

After graduating as a DVM, Julien Labruyère completed an internship and residency to become a board-certified veterinary radiologist, spending much of his clinical time working with MRI. In 2010, he became Associate Professor and Head of Unit of Diagnostic Imaging at the Veterinary school of Maisons-Alfort (France). Julien also completed an Executive Master of Business Administration (MBA) at the University of Cambridge. He is a company owner and co-founder of VetCT.

Julien has published in several areas of diagnostic imaging, and in 2023 presented a proof-of-concept abstract on the use of AI in body area mapping for CT scans.



Dr Tim Davison, B Math, PhD, Chief Technology Officer, VetCT

As a passionate leader in the medical device products and services industry, Tim has over 20 years of experience in the development and application of machine learning and artificial intelligence solutions, as well as a strong background in software product development and the delivery of regulated medical devices.

In previous roles as a senior leader in medical device, pharmaceutical, and in vitro diagnostic companies, Tim has managed multidisciplinary, global teams with a focus on operational optimization and the development of innovative diagnostic products and services.

Tim holds a PhD in Medical Biophysics from the University of Toronto and a bachelor's degree in Applied Mathematics from the University of Waterloo.



Dr Liz Barton, MA, VetMB, MRCVS, MCIPR, Head of Communications, VetCT

Liz had a varied clinical career from mixed practice to a small animal internship, emergency critical care and shelter medicine. She diversified through creating veterinary support team initiatives, including WellVet and Vet Mums, and writing and presenting articles and hosting discussions on a variety of topics. This led to developing marketing and communications skills and the role at VetCT.

Liz is infinitely curious about topics that impact the working life of veterinary teams, animal health and welfare and veterinary industry. She loves nothing more than taking a deep dive into challenging topics to create solutions that enable and support veterinary teams.

¹ <https://fortune.com/2023/01/31/chatgpt-open-ai-new-tool-catch-students-cheating/>

² <https://apnews.com/article/technology-science-business-artificial-intelligence-afb4618ff593db9e3e51ecbd91dc3eef>