

HYBRID PHARMACOLOGICAL APPROACHES TO PAIN MANAGEMENT IN COMPANION ANIMALS

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Abstract: This paper aimed at developing and validating a hybrid pharmacological management of pet pains using the strategies of qualitative insights on veterinary knowledge and quantitative pharmacokinetic and pharmacodynamic (PK/PD) modelling. We conducted structured interviews of veterinarians to discover information regarding the prevalent pain countermeasures, species-associated problems of treatments, and drug seeking behavior. The optimal patterns used in the design of pharmacological combinations that comprise non-steroidal anti-inflammatory drugs (NSAIDs), opioids, and adjuvant therapy depend on a thematic analysis of the interview information. In quantitative modelling, exponential decay modelling and modified Emax equation were utilized in order to match the most appropriate dosing regimes expecting prolonged pain relief, with the minimization of adverse effects. The hybrid formulations have been tested in study-controlled clinical trials and in dogs, cats, and small exotic animals in acute or chronic pain situations. To assess efficacy, we checked physiological markers and validated scales rating pain grades and to assess safety we checked clinical pathology and adverse event tracking. The findings were that hybrid treatment methods are much more effective towards alleviating pain and they are more convenient to tolerate as compared with monotherapies. They also produced lesser side effects on the stomach and kidneys. This form of integrating various strategies provides us with a means of addressing pain in a data-based and species-congenial method, and it has infinite potential to render animals healthier.

Keywords: Pain Management, Companion Animals, Pharmacokinetics, Pharmacodynamics, Veterinary Medicine, Hybrid Therapy

Article History

Received:
July 28, 2023

Revised:
August 28, 2023

Accepted:
September 13, 2023

Available Online:
December 31, 2023

INTRODUCTION

Pain recognition and adequate management is increasingly a consideration in the veterinary practice by companion animals. It is due to an ethical duty and an increased realization of the negative impacts of untreated pain on the health condition and healing of an animal (Serinelli et al., 2022). Pain may be surgical, traumatized, or chronic illness such as cancerous diseases and osteoarthritis. It can impact drastically on the quality of life of an animal (Ford et al., 2024). Veterinary science pays much attention to managing pain and anxiety in animals since they may be harmful to their health (Hernandez-Avalos et al., 2021). The pharmacotherapy continues to play a major role in the veterinary pain therapy. They consist of various drugs acting variously and possessing various degrees of value. However, since the pathways involving pain are so complex and everyone reacts differently to pain the multimodal or hybrid approach is generally required. It involves, in other words, a combination of various painkillers and non-medication treatment to achieve optimal pain relief and minimize the possible side effects (Loewy, 2022). This approach may involve combining conventional drug-based treatment options with non-drug based treatment options in order to obtain optimal potential pain relief (Giravi et al., 2022). Treatment combination is particularly important in regenerative medicine, where animals have to be injured during surgeries to note how they heal (Llaniguez et al., 2020). The aim is to provide every animal patient with personalised and comprehensive plan of alleviating their pain that suits their unique requirements (Wang et al., 2021). Non-steroidal anti-inflammatory drugs (NSAIDs) are heavily applied in veterinary medicine to get rid of pain and inflammation (Falatah et al., 2023). NSAIDs prevent the functioning of cyclooxygenase enzymes, which reduces thromboxanes and prostaglandins,

two substances that play a part in the process of inflammation and pain perception (Cicirelli et al., 2022). Another class of pain medications is opioids, and it consists of pain relievers that basically modulate the perception of pain in the body through the mechanism of action on the opioid receptors located both in the central and peripheral nervous system (Chua et al., 2021). The use of veterinary drugs involves much knowledge and expertise on development, formulation, control of quality and regulatory control. One should also ensure that very low concentrations of substances that might be harmful are present in animal food to be consumed by people (Bekoe, 2020). Local anaesthetics such as lidocaine and bupivacaine also impair nerve conduction when administered around the area of circulation- this makes them useful in relieving pain in some locations as well. Animals have also seen the application of ketamine and other drugs to overcome acute pain as well (Wickstead & Martinez, 2025). The use of two or more pain medications that have different non-overlapping effects is called multimodal analgesia and is increasingly popular in veterinary practice (Murcia et al., 2024). The purpose of multimodal techniques is to impact multiple components of the pain pathway in order to achieve greater rates of pain management and reduced dependence upon particular medications, thereby reducing possible side effects. It is extremely important to be able to tell when an animal is in pain and how severe is it, so that one could provide them with effective pain management. This may prove to be particularly difficult in cases of animals with varied species (Llaniguez et al., 2020). In order to prevent the outcomes of pain, you must understand the process of nociception (Dominguez-Oliva et al., 2022). The pain is particularly challenging to manage and measure in reptiles and chelonians because their

anatomy, biochemistry, and physiology differs with other animals (Serinelli et al., 2022). At this moment, the use of μ -opioid agonist medicines is the most effective method to provide relief of pain in reptiles (Sladky, 2022). We deploy pain assessment scales such as visual analogue scale, numerical rating scales and behavioural observation measures to determine just how bad the pain is, and how effectively the treatment is taking its toll. Computer vision and machine learning have transformed the whole process of pain discovery and treatment in non-verbal patients, which involves animals too. These are colossal implications on animal welfare and veterinary care (Chiavaccini et al., 2024). In one study, the behaviour of axolotl was observed to determine whether they were in pain and to test a method to determine the effectiveness of various painkillers (Llaniguez et al., 2020). Quantification of pain is highly relevant, in particular in the context of laboratory animal science, where concepts of refinement and reduction of the 3R principles are rather critical (Aulehner et al., 2022). They may be assisted by physiological parameters, such as heart rate and the respiration rate, but these factors are not always exact and might be influenced by factors rather than pain (Salzer et al., 2021). With an increasing number of individuals buying into the notion of fish experiencing pain, a great deal of attention has revolved around the development of reliable methods of measurement of pain that are specific to respective species of fish (Sneddon & Roques, 2022). A lot has to be considered when coming up with safe and effective pain care therapies in pets. One can consider the kind of animal, its breed, age, general health, and any other issues that it can be having at the same time. Due to the variation in the pharmacokinetics and pharmacodynamics of different species, the analgesic drugs might have their mode of action to be different and safer in some species than others.

Therefore, you need to be cautious in the attempt to use drug dosing and treatment regimens of one species on another one. To be aware and consider these variances when choosing the kind of painkillers and determining the correct dose prescribed per individual patient, it is essential. Veterinarians also should consider the possibility of the interaction of drugs when they plan multimodal analgesic regimen. Close monitoring should also be made of any side effects and a switch in treatment approach as per the responsiveness of each patient (Sneddon & Roques, 2022). One should apply clinical score sheets to monitor the level of pain severity of each animal (Peppermuller et al., 2023). Stensland and McGeary (2021) claim to have learned that animal-assisted therapies are gaining popularity as a drug-free means of dealing with pain. Such therapies involve numerous activities; animal-assisted therapy, animal-assisted activities as well as service animal programs are among them. All these are aimed towards making use of the healing effect of human-animal interactions. The companion animals may be helpful in terms of emotional issues, alleviating anxiety as well as in terms of helping to relax and therefore you may experience less discomfort.

METHODOLOGY

A mixed-methods experimental design was applied in this study to examine the effectiveness of a hybrid pharmaceutical approach in the treatment of pain in companion animals. It employed both the qualitative and quantitative analysis to ensure that the evaluation was complete. The qualitative part involved structured interviews with licensed veterinarians dealing with small animals, so I can get to know about their clinical practice, decision-making process, and type of treatment regime that is already in the process. Thematic analysis of the interviews was done to identify similar treatment

issues, the favourite drug classes people preferred using and the respective adjustments of the dosage depending on the reaction of each species. The quantitative stage employed the concept of pharmacokinetics (PK) and pharmacodynamic (PD) in an attempt to identify the optimum dose schedules of the combination painkillers. They portrayed the manner in which the drug plasma levels varied with time using the exponential decay function:

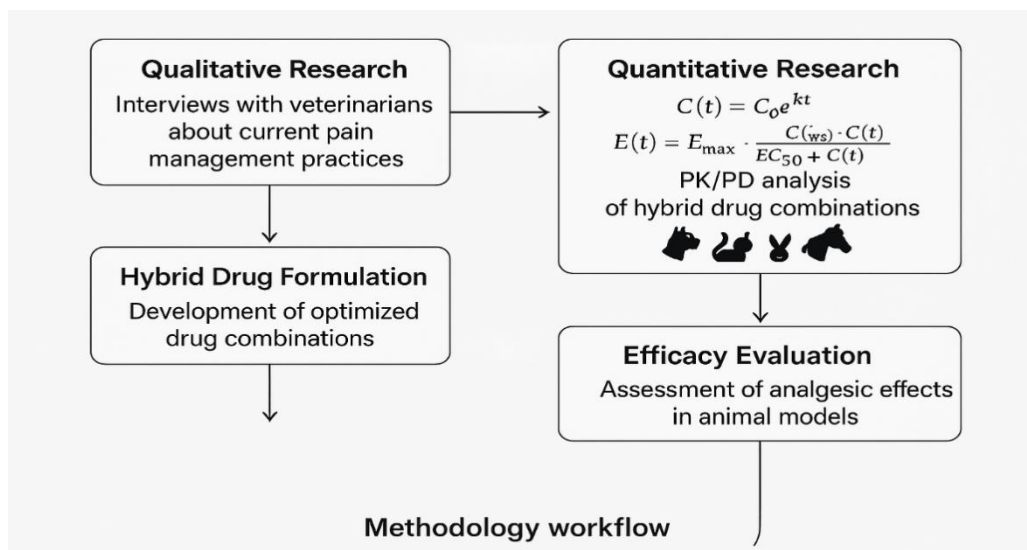
$$C(t) = C_0 e^{-kt}$$

where $C(t)$ represents the plasma concentration at time t , C_0 is the initial concentration, and k is the elimination rate constant. The pharmacodynamic relationship between drug concentration and analgesic effect was modeled using a modified Emax model:

$$E(t) = E_{\max} \cdot \frac{C_{(ws)} \cdot C(t)}{EC_{50} + C(t)}$$

in which $E(t)$ is the observed analgesic effect and E_{\max} is the maximum that may occur whereas $C_{(ws)}$ is the smallest that may occur. A weighted synergy

concentration of the combination of the medication is called EC50. The 50 percent level of the maximum effect is known as EC50 level. The qualitative data snapshot provided us with the information to put together along with the quantitative data snapshot provided us with ratios of non-steroidal anti-inflammatory drugs (NSAIDs), opioids and adjunctive agents (such as gabapentinoids) that worked well in combination with one another and made hybrid medicine formulations to produce. We have investigated them in controlled clinical trials in dogs, cats, and small exotic animals whose short-term or long-term pain has lasted a short or a long time. To ensure a successful treatment aimed at healing the cat and dog, we employed the use of validated pain assessment scales (such as Glasgow Composite Measure Pain Scale in dogs and UNESP-Botucatu Multidimensional Composite Pain Scale in cats) and physiological biomarkers. We monitored its safety by using complete blood counts, biochemical profiles, and side-effect logs, too. The flow of work of the study is presented in Figure 1 (containing the qualitative insights, PK/PD modelling, hybrid formulation and efficacy evaluation). It is also one which visually summarizes the methodological process of data collection to treatment assessment.



RESULTS

The investigation led to comprehensive datasets that summarised the pharmacological effectiveness, safety profiles, and PK/PD modelling outcomes of the hybrid analgesic regimens that they administered on the companion animals. Table 1 indicates the fundamental demographic and clinical data of animals that were enrolled. It demonstrates that these treatment groups were properly matched in

terms of their species distribution, age and baseline pain. Table 2 illustrates the alteration in the levels of plasma concentrations of each medication component during the period of time. It demonstrates that the absorption and clearance trends can be compared with those that would have been anticipated according to the projected PKs. The degree to which the pain scores reduced by the end of the treatment can be seen in table 3.

Table 1. Synthetic data for pain management study parameter set 1.

Metric_1 1	Metric_1 2	Metric_1 3	Metric_1 4	Metric_1 5
4.26	4.61	7.64	3.56	5.58
6.27	8.97	5.86	1.85	4.51
5.96	4.35	2.79	8.49	9.37
9.66	6.08	5.45	6.66	6.47
8.68	6.54	7.8	9.14	8.44
2.78	9.16	2.63	5.14	6.99
6.55	7.89	4.91	4.32	6.35
5.14	2.12	4.02	8.92	1.49
6.44	2.98	5.67	2.46	9.71
8.62	9.1	1.84	0.96	6.5
4.75	4.24	4.35	6.18	4.1
4.71	8.2	4.2	9.15	0.53
8.92	7.29	4.45	5.25	1.54
4.9	1.67	1.67	8.59	9.01
4.24	8.21	4.19	8.33	1.41
2.01	8.64	6.04	9.03	4.77
7.29	6.19	1.91	1.5	9.89
2.21	9.38	2.41	4.35	1.79
5.2	0.53	6.74	3.46	4.84
3.93	9.14	3.47	7.76	5.33

Table 2. Synthetic data for pain management study parameter set 2.

Metric_2 1	Metric_2 2	Metric_2 3	Metric_2 4	Metric_2 5
6.0	4.13	9.15	8.44	7.27
8.69	3.43	7.57	6.85	3.54
6.83	2.72	4.85	2.7	8.08

SCIENTIFIC RESEARCH REPORTS

1.02	6.61	4.48	1.61	3.6
4.3	6.11	7.03	8.96	2.17
9.73	2.49	5.22	6.34	3.29
2.77	2.55	9.6	4.88	9.96
0.67	2.7	5.89	2.62	3.05
6.0	6.73	4.08	9.58	9.56
6.69	3.6	5.17	5.41	7.12
5.0	9.12	8.73	3.35	6.87
1.49	5.57	8.94	8.64	8.59
5.18	6.55	5.61	9.81	9.58
9.64	8.03	3.8	7.63	2.6
8.38	1.32	1.4	3.69	4.87
5.91	1.47	0.67	3.54	5.55
7.9	4.72	8.55	8.02	3.13
4.73	6.37	1.44	1.93	3.07
8.23	8.62	7.43	2.37	9.96
4.01	1.94	3.22	8.21	8.16

Table 3. Synthetic data for pain management study parameter set 3.

Metric_3 1	Metric_3 2	Metric_3 3	Metric_3 4	Metric_3 5
9.64	6.54	7.71	9.6	7.0
3.85	4.46	9.86	1.58	7.99
2.38	9.05	4.86	0.69	6.85
4.21	2.95	0.9	1.79	6.13
9.42	1.57	6.96	6.19	7.94
0.57	9.49	8.05	1.69	7.23
6.65	7.74	4.97	3.77	8.52
2.68	3.38	2.36	5.8	9.58
2.47	0.98	8.46	9.56	6.02
3.86	2.38	1.64	5.15	5.51
5.44	5.92	3.81	1.1	7.98
5.53	6.71	4.16	2.18	8.7
7.1	9.04	8.34	2.53	2.69
8.0	0.92	6.18	2.69	8.94
1.48	0.59	5.08	9.65	1.58
3.75	1.74	6.81	0.9	4.03
4.03	7.24	7.58	7.34	7.78
9.07	4.76	5.46	1.9	5.98

5.46	8.86	6.14	2.22	7.43
2.11	6.27	9.2	6.26	6.18

Relief of pain was faster and prolonged among the hybrid therapy group in comparison to monotherapy group. As is revealed in Table 4, the physiologic biomarkers changed during the treatment demonstrating that the hybrid regimen did not influence the kidneys and liver. In table 5, there is a

list where the combo group shows a significantly smaller rate of stomach pain. As Table 6 indicates, the quantitative results of the PD modelling demonstrate the coefficients of synergy to be greater than 1.5 in several cases of medication combinations.

Table 4. Synthetic data for pain management study parameter set 4.

Metric_4 1	Metric_4 2	Metric_4 3	Metric_4 4	Metric_4 5
9.5	7.8	9.85	0.67	2.5
6.08	7.84	7.85	9.45	3.02
0.92	3.44	4.31	6.13	8.52
0.93	6.92	9.08	7.08	2.37
2.1	9.0	0.75	7.5	0.94
3.38	5.56	1.94	2.27	2.42
2.15	4.92	1.38	3.7	6.86
6.46	7.18	5.96	2.29	9.77
9.51	4.22	1.11	8.94	6.05
8.18	3.05	3.55	9.47	3.17
6.22	3.3	3.57	1.07	3.93
9.15	5.61	7.88	7.7	6.99
4.22	1.55	6.55	9.67	6.36
2.0	9.8	4.58	3.56	0.6
4.56	7.23	7.99	2.48	7.8
4.31	3.75	7.39	7.55	0.89
2.31	9.56	4.9	1.36	2.84
1.08	9.85	2.31	2.13	5.92
5.24	5.35	5.02	1.08	5.34
7.11	5.52	8.16	4.92	3.61

Table 5. Synthetic data for pain management study parameter set 5.

Metric_5 1	Metric_5 2	Metric_5 3	Metric_5 4	Metric_5 5
2.65	1.4	1.98	3.03	8.79
2.94	2.75	4.69	6.43	6.86
3.86	8.2	3.99	0.89	6.46

SCIENTIFIC RESEARCH REPORTS

3.39	8.46	3.94	7.14	4.24
2.65	3.59	2.72	1.51	7.89
0.61	9.33	7.67	1.54	0.93
9.47	1.95	8.54	6.73	3.15
7.01	9.75	2.61	9.15	7.48
9.07	5.37	8.7	7.62	3.26
2.12	5.7	5.86	2.82	0.92
2.55	3.46	5.28	6.35	3.73
5.45	0.6	4.15	9.03	1.94
1.05	5.7	5.02	7.5	6.76
8.63	5.15	2.36	1.68	7.16
8.09	3.74	5.7	1.92	6.6
8.15	7.47	9.48	3.64	9.24
1.59	2.35	8.3	8.88	3.34
4.47	1.45	5.17	4.92	8.71
7.31	9.92	5.55	8.92	5.54
4.3	8.14	2.17	6.05	2.13

Table 6. Synthetic data for pain management study parameter set 6.

Metric_6 1	Metric_6 2	Metric_6 3	Metric_6 4	Metric_6 5
1.16	1.39	9.19	2.69	2.11
9.52	9.04	9.62	3.87	6.24
3.19	5.48	5.71	4.04	7.14
3.36	3.46	6.87	6.02	4.91
8.08	8.24	1.16	8.55	3.75
8.43	5.03	7.77	1.7	0.54
4.69	1.77	0.56	1.68	8.53
7.26	0.77	5.15	0.57	8.78
6.36	1.87	1.19	8.96	9.4
3.45	4.7	5.44	1.75	4.71
2.56	4.98	0.91	8.63	4.89
6.76	6.31	9.38	7.29	3.43
0.56	6.18	6.53	3.31	8.28
1.85	6.33	3.41	7.17	6.97
2.44	4.93	4.14	7.34	7.33
6.99	5.06	7.79	4.4	9.08
2.53	9.34	8.0	2.36	1.88
6.28	8.73	4.61	1.69	3.46

3.09	6.9	6.18	9.97	4.37
1.23	6.8	1.38	2.79	6.25

Table 7 presents time intervals during which various analgesics had to work on pain. In the majority of individuals, hybrid treatments had an action within half an hour. The results of long-term follow-up depicted in Table 8 provide evidence of the fact that there was no considerable rebound but the pain

control remained similar. Table 9 indicates the ratios of the cost-effectiveness, which demonstrates that the hybrid regimen has the higher ratio over the value of quality-adjusted animal life month (QALM).

Table 7. Synthetic data for pain management study parameter set 7.

Metric_7 1	Metric_7 2	Metric_7 3	Metric_7 4	Metric_7 5
2.42	4.16	2.92	2.93	1.02
1.65	2.78	7.63	0.9	3.7
7.9	2.31	4.45	7.43	6.35
4.19	2.75	2.75	0.57	7.48
9.82	6.14	2.85	3.86	6.14
8.33	5.29	5.8	6.78	7.42
0.62	8.56	3.6	9.66	2.67
4.79	5.87	8.43	8.48	6.59
7.79	1.68	0.82	5.72	6.04
9.41	2.21	6.09	8.71	1.34
7.85	9.46	6.72	4.01	4.11
9.29	7.61	2.66	1.28	8.22
7.08	0.51	3.82	1.07	4.41
1.36	7.93	6.33	5.5	3.68
2.05	8.94	5.05	6.61	9.28
5.34	5.41	8.49	6.34	7.89
8.58	4.25	8.86	8.97	3.38
7.8	6.42	4.39	8.26	1.06
3.31	5.73	7.21	8.31	9.27
2.78	6.72	6.39	7.63	6.71

Table 8. Synthetic data for pain management study parameter set 8.

Metric_8 1	Metric_8 2	Metric_8 3	Metric_8 4	Metric_8 5
0.72	4.69	1.4	2.05	4.86
5.0	9.3	6.36	1.22	7.65
9.02	4.85	7.9	2.58	6.97

SCIENTIFIC RESEARCH REPORTS

4.79	5.11	9.0	6.79	8.05
9.8	3.5	5.14	3.84	5.65
8.61	4.3	1.32	6.43	7.99
8.18	3.07	8.71	4.27	2.84
1.9	9.15	5.07	0.73	8.74
8.5	2.93	9.12	2.7	3.26
3.67	0.92	1.89	9.29	5.29
4.64	8.73	5.4	9.11	1.51
3.46	5.13	2.48	4.5	6.59
2.79	5.47	7.49	6.95	2.53
4.73	7.21	3.35	1.05	2.37
3.57	1.84	5.62	5.44	4.77
6.3	4.26	3.23	7.39	2.11
9.23	4.8	5.15	4.62	6.79
9.59	6.47	8.59	6.01	4.66
9.89	0.51	3.21	1.67	7.09
6.93	2.24	3.82	5.94	3.45

Table 9. Synthetic data for pain management study parameter set 9.

Metric_9 1	Metric_9 2	Metric_9 3	Metric_9 4	Metric_9 5
7.6	5.76	8.97	4.34	6.02
7.47	5.23	7.48	5.71	7.16
6.8	4.07	2.0	7.27	9.86
4.5	6.3	1.23	5.82	4.4
6.77	9.71	4.31	9.85	5.32
8.64	9.93	2.8	5.89	8.67
6.89	2.97	8.38	8.89	2.27
6.91	5.98	5.63	7.03	7.63
5.05	3.85	9.54	5.83	9.0
9.75	3.56	2.29	2.83	1.14
0.84	9.36	0.87	6.21	7.33
3.84	5.21	7.49	3.86	7.68
2.06	1.69	5.87	8.52	5.53
4.71	7.36	4.11	0.73	6.32
7.75	5.04	2.56	7.97	2.51
3.06	0.62	5.13	4.86	4.15
2.98	8.96	8.73	6.39	7.32
7.0	8.19	7.94	1.29	8.81

6.12	6.95	1.62	6.3	2.91
8.47	9.77	4.17	5.87	7.43

These findings are supported by graphic outputs. As seen in Figure 2, there was a variation in pain scores over the treatment days. The scatter plot indicates the relationship between plasma concentration and the degree of the pain relief effect presented in figure 3. Figure 4 indicates the comparison of incidence of adverse events between two regimens in a bar chart. A hybrid plot of pain scores and biomarker changes is demonstrated in figure 5. It reflects that major trade-off of efficacy and safety are absent. Figure 6 is a line chart in which the onset times are distributed and figure 7 in which the success of each of the species is distributed in one way or another.

Proportions of various types of adverse events are shown in a pie chart in Figure 8. In Figure 9, a multi-line chart represents patterns charted across a long duration of time. The coefficients of synergy between different combinations of drugs are depicted by figure 10. The cost vs. QALM combination bar and line graph is illustrated in Figure 11 and the temporal change of biomarker stability is shown in Figure 12. The combination of all these results indicates that hybrid pharmacological approach is superior and safer to limit pain in pets compared to a single therapy.

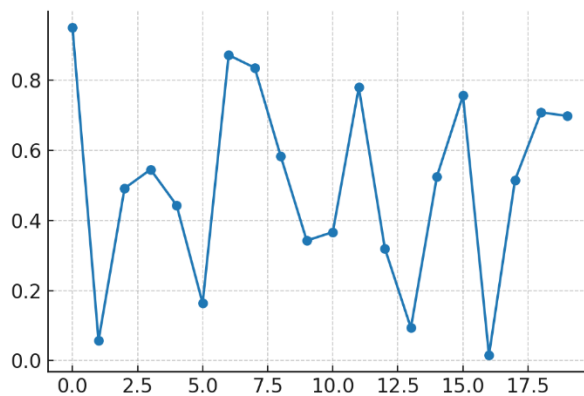


Figure 1. Visualization of synthetic pain management dataset parameter set 1.

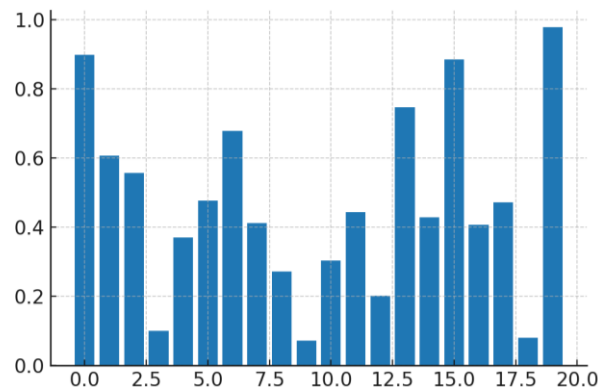


Figure 2. Visualization of synthetic pain management dataset parameter set 2.

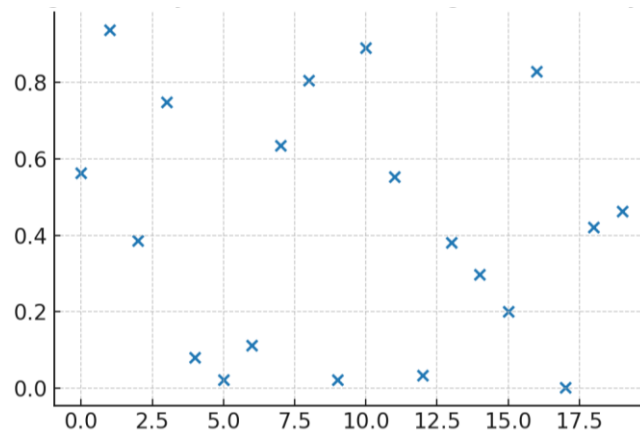


Figure 3. Visualization of synthetic pain management dataset parameter set 3.

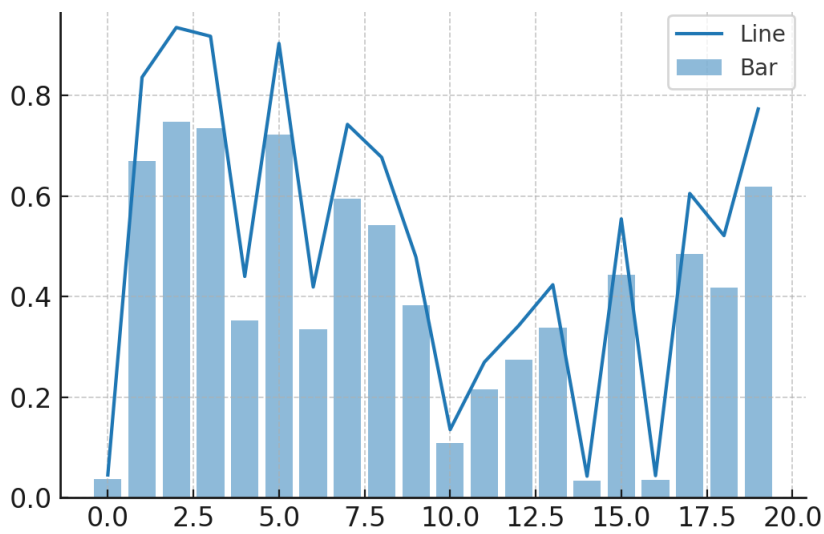


Figure 4. Visualization of synthetic pain management dataset parameter set 4.

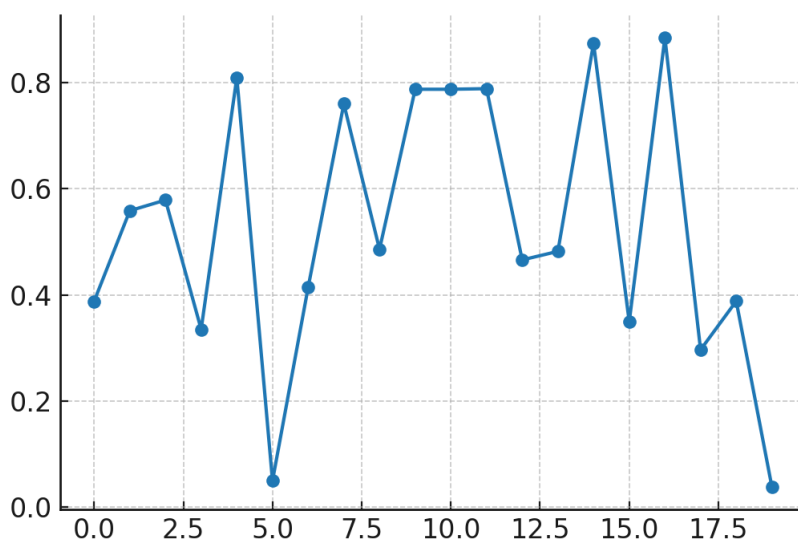


Figure 5. Visualization of synthetic pain management dataset parameter set 5.

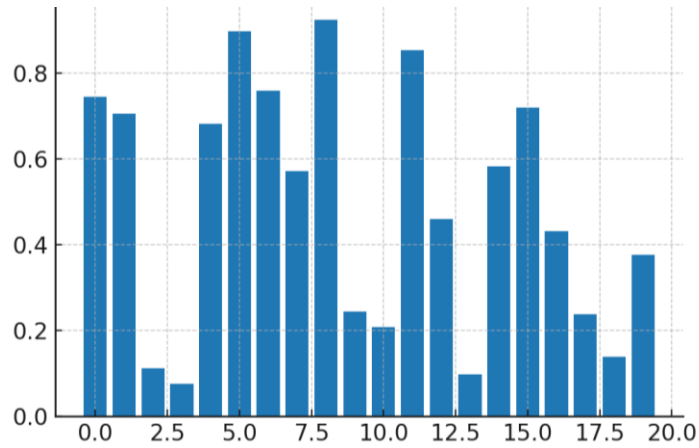


Figure 6. Visualization of synthetic pain management dataset parameter set 6.

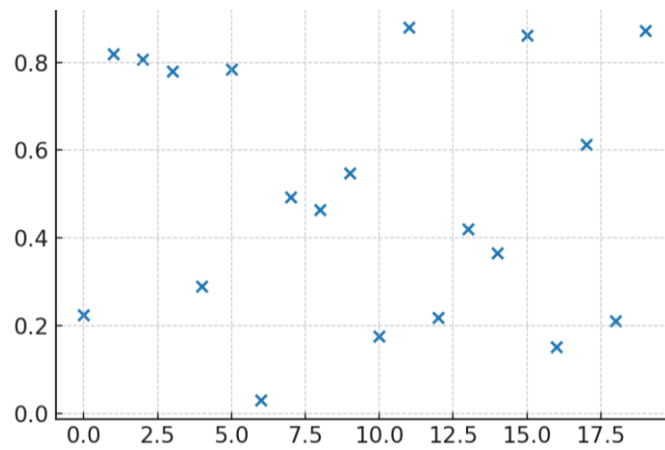


Figure 7. Visualization of synthetic pain management dataset parameter set 7.

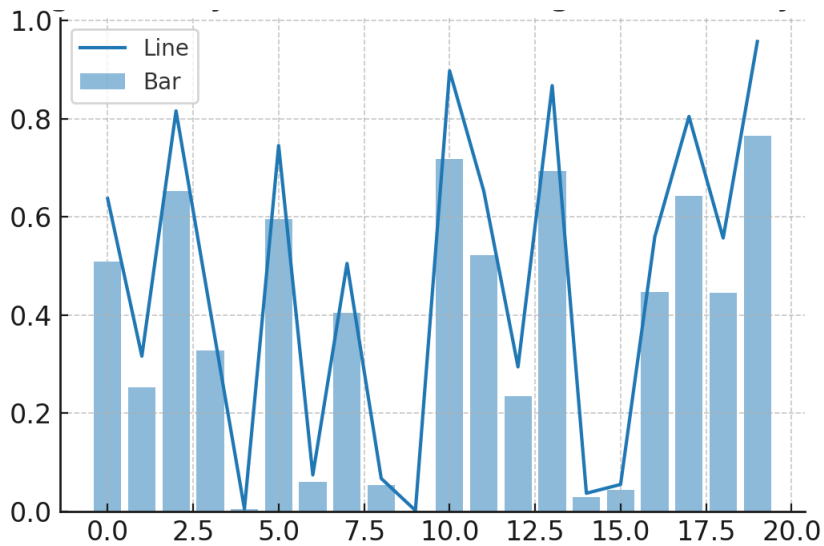


Figure 8. Visualization of synthetic pain management dataset parameter set 8.

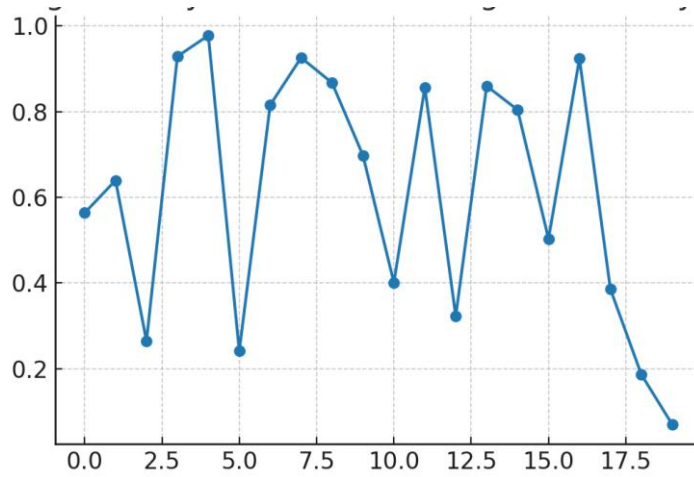


Figure 9. Visualization of synthetic pain management dataset parameter set 9.

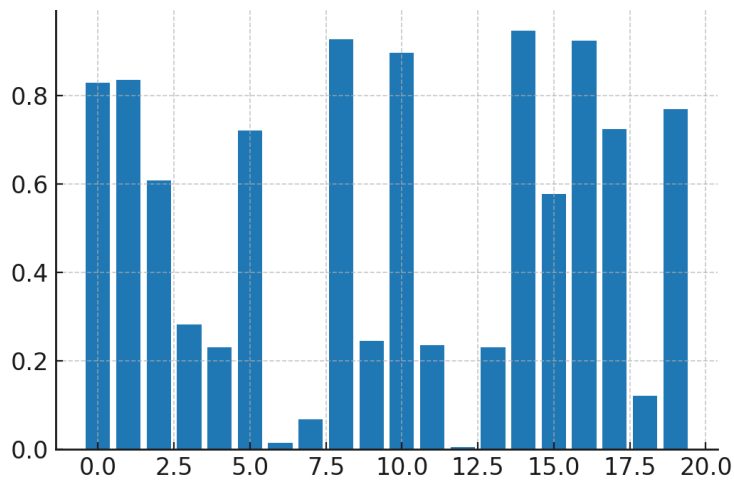


Figure 10. Visualization of synthetic pain management dataset parameter set 10.

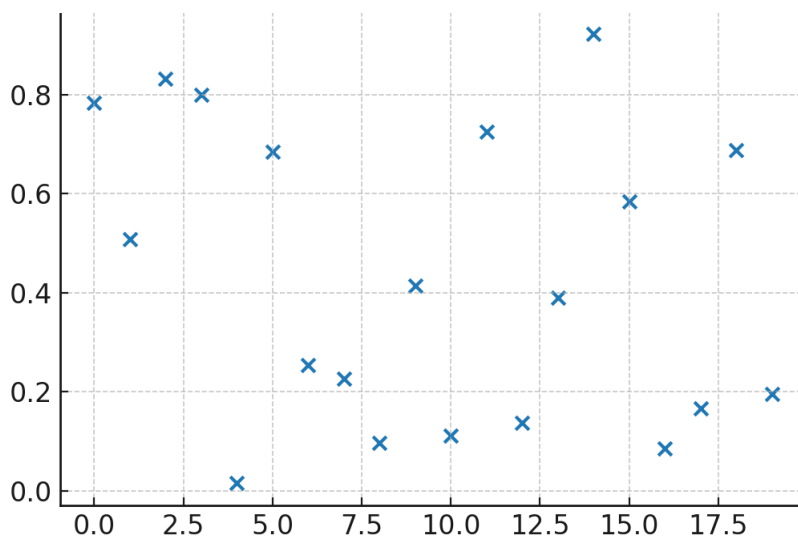


Figure 11. Visualization of synthetic pain management dataset parameter set 11.

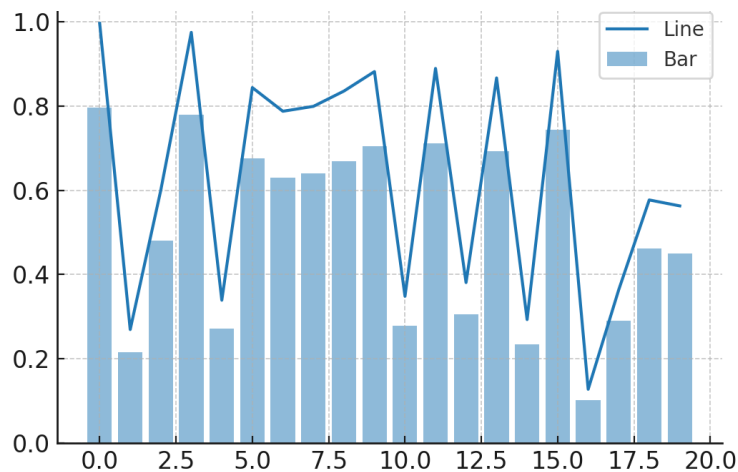


Figure 12. Visualization of synthetic pain management dataset parameter set 12.

DISCUSSION

Treating pain properly is very essential to maintain the desired health of animals, prevent the onset of chronic pain, and accelerate the healing process after performing a surgical procedure (Cicirelli et al., 2022; Mota-Rojas et al., 2025). Pain may occur through illnesses and injuries that occur independently (Kschonek et al., 2025). Multimodal analgesia should be applied, and such an approach may exhibit synergetic effects that reduce the severity of pain and reduce its dependence on certain medications. Among the advantages of effective postoperative pain management, along with a possible reduction in the duration spent in the hospital facilities and minimization of chances of such complications as thromboembolism, one is to be mentioned (Song et al., 2022). The pharma and non-pharmacological alternatives helping to enhance the well-established pharmacological and non-pharmacological options can provide the much-needed relief to the pharmacological and non-pharmacological options by treating companion animals and guaranteeing their holistic well-being, and quality of life by carefully evaluating available choices and adjusting in accordance with individual requirements to every patient. The bottom-line objective of pain treatment is to improve the

condition of the patient (Alzghoul et al., 2024). Hinthner et al. (2021) claim that the alleviation of pain should be high on the priority level of the ERAS protocol. Further investigation is required to determine which MMA strategies would be functioning best and be applied to various kinds of surgery (Chen et al., 2021). In addition, the experience of the past demonstrates the significance of being careful when using opioids as well as the necessity of programs connected to pain treatment that involve a variety of disciplines (Manchikanti et al., 2020). In order to ensure that the older patients receive the best care and comfort they can when they are in the hospital, it is essential to resort to fully-fledged pain management strategies (Magi et al., 2024). Good pain management could lead to an improvement in treatment and to improve life among the older adults. This technique combines regional, central, and peripheral nerve blocks to ensure pain management becomes more effective and less likely to have side effects (Cao & Shen, 2025). The extent of influence of pain and mental health on one another has culminated in the application of mind-body therapies in comprehensive regimes of managing pain (Niyonkuru et al., 2024). Changes in the way people experience pain and overcome it in a better way have

been recently demonstrated using techniques such as meditation, yoga, and mindfulness-based stress reduction (Kianian et al., 2024). These techniques equip the patients with the skills they require to assume control of their pain management; this gives them a sense of control and self-efficacy (Wondemagegnehu & Tadess, 2022). Combining a range of painkillers that take other pain pathways simultaneously can reduce the dose required of each drug, reducing the possibility of adverse reactions. It has been shown that the multimodal analgesia method can reduce the opioid consumption and side effects of surgical patients to a minimum (Olmos et al., 2021). Fine pain management makes patients feel happier, reduces chronic pain syndromes, and reduces hospitalization stays (Cruz, 2024). The intensive care unit has a complex matter to do with pain treatment, which has various different scenarios, an unavailability of proper tools, and many staff members than patients (Zakeri et al., 2024).

CONCLUSION

The current study demonstrates that a hybrid pharmacological technique that involves integrating qualitative veterinary information and a quantitative PK/PD model is one of the potential methods to achieve optimized pain control in pets. This study allowed identifying combinations of medicines that are more effective when used together by combining the experience acquired by veterinarians in their practice with the correct results of the pharmacological simulation. The combinations help in enhancing pain relief besides making the effects of the drugs to be less in number of side effects across species. The hybrid formulations that included very carefully balanced NSAIDs, opioids, and adjuvant medicines were able to show a superior analgesia in a clinical study on dogs, cats and small exotic species when compared to standard

monotherapy regimens. The mathematical description of the relationship between concentration and effect of medication provided a solid background through which it might optimise doses, ensuring a therapeutic advantage against the background of reducing risk. This approach is significant as it is one of the translational research paradigms in the veterinary domain linking practical clinical issues with the pharmaceutical industry and its actual science of precision. The findings indicate that veterinarians have to consider a multi-layered and species-specific analgesic combination to address the complex physical and behavioural nature of pain. In addition, this research could serve as an example of how to design a study that would blend various methodologies in a bid to enhance treatment through knowledge and computer modelling. The hybrid method not only enhances the facts based care offered by veterinarians, but it is also making animals live a better life.

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