Research on the Pathways for Cultivating Clinical Medication Decision-Making Ability in Veterinary Pharmacology Teaching

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Abstract: *A gap exists in veterinary pharmacology teaching between the transfer of declarative knowledge and the transformation into clinical medication decision-making behaviors. This study deconstructs the multi-level cognitive structure of decision-making ability, identifies the key mapping nodes within the pharmacodynamic and pharmacokinetic knowledge systems, and points out the deficiencies of current teaching in procedural knowledge and dynamic decision-making training. A content reorganization pathway oriented toward decision-making ability is proposed, encompassing the integrated classification of drugs based on clinical reasoning, decision-oriented analysis of drug interactions, and embedded strategies for species difference knowledge. Furthermore, a comprehensive interactive assessment system is constructed, comprising stepped reasoning training, simulation-based scenario teaching, and traceable formative evaluation, thereby forming a complete pathway from ability deconstruction to assessment design.*

Keywords: *veterinary pharmacology teaching; clinical medication decision-making ability; reasoning training; teaching content reorganization; formative evaluation.*

Introduction

Current veterinary pharmacology teaching focuses on the transmission of declarative knowledge, which makes it difficult for learners to perform complex clinical decisions such as drug selection and dosage calculation, thus exposing a structural fracture between knowledge storage and decision-making application. Clinical medication decision-making involves multi-level cognitive operations, including information collection, plan generation, risk comparison, and feedback integration. This study deconstructs the cognitive dimensions of clinical decision-making, reorganizes the pharmacology teaching content oriented toward decision-making needs, and designs an interactive teaching and assessment mechanism, aiming to construct a systematic transformation pathway from knowledge structure to decision-making behavior and to provide theoretical support for the reform of veterinary pharmacology teaching.

1. Dimensional Deconstruction of Clinical Medication Decision-Making Ability and Its Association with Pharmacology Knowledge

1.1 Cognitive Levels and Core Skill Composition of Clinical Medication Decision-Making

Clinical medication decision-making is a multi-level progressive cognitive process, with drug information recognition and memory at its foundation, drug selection reasoning based on pathophysiological states at the intermediate level, and dynamic adjustment and risk prediction at the top level. In the context of veterinary medicine, this decision-making chain requires the integration of species-specific parameters, pharmacokinetic differences, and individualized therapeutic goals. The transition between cognitive levels depends on a deep understanding of drug action principles rather than on simple rule memorization. The core skills of decision-making ability include accurately extracting key drug-related information from animal cases, comparing the benefits and risks of multiple treatment options, and predicting the temporal characteristics of drug interactions and adverse reactions. Furthermore, the ability to conduct attribution analysis of treatment failures or adverse events also constitutes an important dimension of decision-making skills. The above skills are nested within one another, forming a closed-loop logic from data collection to strategy generation.

Veterinary pharmacology teaching needs to align with this cognitive structure by decomposing decision-making skills into trainable cognitive units. For example, the identification of drug clearance pathways belongs to the foundational cognitive level, whereas adjusting dosing intervals based on hepatic and renal insufficiency states constitutes a higher-level decision-making skill. In teaching, a clear distinction should be made between "knowing drug properties" and "applying properties to solve clinical problems." By constructing logical bridges between drug properties and clinical scenarios, learners can be encouraged to form conditional knowledge representations, that is, specific clinical signals trigger corresponding drug management strategies. This type of representation can reduce cognitive load during the decision-making process and improve judgment efficiency in complex cases.

1.2 Mapping Nodes Between the Veterinary Pharmacology Knowledge System and Decision-Making Ability

The veterinary pharmacology knowledge system consists of two main pillars: pharmacodynamics and pharmacokinetics, which correspond respectively to the two core issues in decision-making, namely "which drug to choose" and "how to use the drug." Pharmacodynamic knowledge provides information on receptor selectivity, efficacy, and potency, supporting the initial screening of drug indications; pharmacokinetic knowledge provides parameters for absorption, distribution, metabolism, and excretion, supporting the precise calculation of dosage, route, and frequency of administration. The intersection points of the two types of knowledge, such as the relationship between therapeutic window, half-life, and dosing interval, are key mapping positions for the formation of decision-making ability. The manifestation of species differences in pharmacokinetic parameters (e.g., the glucuronidation deficiency in cats) further requires the knowledge system to possess species-specific branches.

Effective mapping between the knowledge system and decision-making ability requires clarifying the clinical trigger conditions for each pharmacological knowledge point. For example, knowledge about enzyme inducers and inhibitors should not be taught in isolation but should be embedded into the decision-making nodes of multidrug combination therapy. When an animal is concurrently administered phenobarbital and glucocorticoids, learners need to invoke the principle of competitive inhibition in the hepatic drug-metabolizing enzyme pathway to determine the direction of dosage adjustment. Such mapping nodes also include the association between renal function indicators and the accumulation risk of aminoglycosides, as well as the contribution of protein binding rate to drug displacement effects. Identifying and reinforcing these nodes in teaching can transform knowledge from static storage into dynamic decision-making resources[1].

1.3 Analysis of Deficiencies in Decision-Making Ability Cultivation in Current Teaching

Current veterinary pharmacology teaching content predominantly focuses on declarative knowledge such as drug classification, mechanisms of action, and adverse reactions, with insufficient coverage of procedural and conditional knowledge required for decision-making. Although declarative knowledge forms the foundation of decision-making, it cannot be directly transformed into reasoning behaviors in clinical contexts. A typical deficiency manifests as learners being able to recite the mechanism of action of a certain drug but failing to automatically activate dosage adjustment strategies when faced with animal cases complicated by liver disease or hypoalbuminemia. Furthermore, teaching assessment relies mainly on recall and simple application of single-drug knowledge, lacking training and evaluation of complex decision-making tasks such as multidrug interactions, comparison of therapeutic pathways, and risk stratification.

Another deficiency lies in the disconnection between the temporal dimension of pharmacological knowledge and the demands of dynamic decision-making. Clinical medication decision-making often involves continuous adjustments over the course of treatment, such as antibiotic de-escalation therapy and gradual reduction of analgesic drugs. Current teaching content rarely incorporates the design of decision-making nodes under the drug concentration-time curve, nor does it provide sufficient training in logical derivation of alternative regimens after treatment failure. The scarcity of simulated cases in teaching resources further exacerbates the gap in cultivating decision-making ability. In particular, regarding medication decisions for food-producing animals, the teaching completely fails to address legally binding constraints such as veterinary drug withdrawal periods, antimicrobial resistance management, veterinary prescription drug regulations, and veterinary drug residues, all of which are indispensable key elements in clinical decision-making. Due to the lack of a sufficient low-risk environment for decision-making practice, learners are prone to typical decision-making biases in real clinical scenarios, including incomplete information collection, narrow option generation, and

inadequate feedback utilization. These deficiencies suggest the need to reconstruct the pedagogical connection between pharmacological knowledge and decision-making ability.

2. Content Reorganization of Pharmacology Teaching Oriented Toward Decision-Making Ability Cultivation

2.1 Integration of Drug Classification and Mechanisms Based on Clinical Reasoning Needs

Traditional pharmacology teaching usually arranges drugs linearly according to drug classes (such as antibiotics, non-steroidal anti-inflammatory drugs, and anesthetics). This classification facilitates knowledge storage but is not conducive to clinical reasoning retrieval. Clinical medication decision-making requires learners to retrieve applicable drugs in reverse according to the animal's pathological state, rather than matching diseases forward according to drug classes. Therefore, teaching content reorganization should be guided by clinical reasoning needs, reorganizing drugs into "modules based on therapeutic goals," such as the selection of vasoactive drugs for septic shock and the construction of multimodal analgesic regimens for chronic pain. Each module integrates drugs with different pharmacological mechanisms, highlighting their synergistic, antagonistic, or sequential relationships, so that learners form a problem-centered pharmacological knowledge network.

The core of mechanism integration lies in revealing the cross-nodes among different drug action pathways. For example, in the decision-making scenario of treating acute heart failure, although inotropic agents (pimobendan, digoxin), vasodilators (angiotensin-converting enzyme inhibitors, such as enalapril), and diuretics (furosemide) have different mechanisms, they collectively act on three modifiable variables: preload, afterload, and myocardial contractility. Teaching should present the quantitative relationships among these variables, enabling learners to understand why the initiation of one drug may alter the dosage requirement of another. By constructing mechanistic association diagrams rather than teaching each drug in isolation, learners' reasoning efficiency in multidrug combination scenarios can be improved, and decision-making blind spots caused by knowledge fragmentation can be avoided[2].

2.2 Decision-Oriented Analysis of Drug Interactions and Adverse Reactions

Teaching of drug interactions should not remain at the level of listing types of interactions (additive, synergistic, antagonistic) or classic examples (such as warfarin and sulfonamides), but should shift toward a decision-oriented risk assessment framework. In veterinary clinical practice, the clinical significance of drug interactions depends on variables such as interaction intensity, width of the therapeutic window, individual animal susceptibility, and monitoring conditions. Teaching content should provide an operational assessment process: identifying potential interactions, judging whether they are clinically significant, determining dosage adjustments or alternative drug regimens, and formulating a monitoring plan. This process transforms interaction knowledge into a chain of decision-making actions, enabling learners to possess systematic coping strategies when facing polypharmacy in animals. In addition, for antimicrobial agents, teaching content must incorporate antimicrobial resistance management decisions, including drug selection based on antimicrobial susceptibility testing results, avoidance of subtherapeutic concentration exposure, and compliance with veterinary prescription drug regulations.

Teaching of adverse reactions should likewise shift from identification to management decision-making. In addition to requiring learners to master the common adverse reaction profiles of various drugs (such as polyuria and polydipsia caused by glucocorticoids, and nephrotoxicity caused by aminoglycosides), teaching should also train learners to formulate intervention plans based on the timing of occurrence, severity, and reversibility of adverse reactions. For example, when an animal develops elevated serum creatinine after receiving an angiotensin-converting enzyme inhibitor, the learner needs to determine whether this elevation is an acceptable hemodynamic effect or unacceptable renal injury, and then decide whether to continue the drug, reduce the dosage, or switch to another agent. Teaching content should incorporate a decision tree model for adverse reactions, clarifying the judgment criteria at each branch node (e.g., a serum creatinine increase exceeding 30% above baseline as the threshold for drug discontinuation), thereby transforming adverse reaction knowledge into precise clinical regulatory capability.

2.3 Knowledge Embedding Strategies for Species Differences in Medication Decision-Making

The impact of species differences on medication decision-making is manifested at both pharmacokinetic and pharmacodynamic levels, with possible order-of-magnitude variations among different species. For example, the low activity of glucuronosyltransferase in cats leads to extremely slow metabolism of drugs such as acetaminophen and aspirin; the susceptibility of dogs to ivermectin exhibits breed specificity due to differences in P-glycoprotein function at the blood-brain barrier; and the tolerance of the intestinal microbiota in rodents to certain antibiotics is much lower than that in carnivores. These differences should not be memorized as isolated knowledge points but should be embedded into specific decision-making nodes. Teaching content should construct a "species-drug-decision" ternary mapping table, specifying the special contraindications and dose modification coefficients for each species within commonly used drug categories[3].

The knowledge embedding strategy emphasizes placing species-specific information into the trigger conditions of clinical reasoning. Teaching should establish a drug screening logic based on species characteristics: when the animal species is presented in the case information, learners should automatically retrieve the drug metabolic bottlenecks and known high-risk drug lists for that species. For example, when managing a feline case requiring analgesia, learners should exclude acetaminophen (due to the glucuronidation defect in cats leading to severe methemoglobinemia) and use non-steroidal anti-inflammatory drugs such as aspirin with caution (since the half-life in cats is extremely long, requiring extended dosing intervals); for postoperative pain in dogs, non-steroidal anti-inflammatory drugs such as flunixin meglumine can be selected, but gastrointestinal protection and renal function monitoring should be noted. In addition, species differences should also be incorporated into the judgment of pharmacodynamic endpoints; for example, the risk of gastrointestinal perforation after the use of non-steroidal anti-inflammatory drugs in horses is significantly higher than that in cattle, and this difference determines the setting of the therapeutic window and monitoring frequency for different species. For food-producing animals such as cattle, pigs, and chickens, medication decisions must be supplemented with withdrawal period calculation and veterinary drug residue risk assessment to ensure the safety of animal-derived foods. For example, when using marbofloxacin in the treatment of bovine mastitis, the prescribed milk discard period and withdrawal period must be strictly followed. Through systematic embedding strategies, species differences are transformed from a memory burden into a decision-making advantage.

3. Instructional Interaction and Assessment Design for Fostering Decision-Making Ability

3.1 Pathway for Constructing Stepped Clinical Reasoning Training Modules

The stepped clinical reasoning training modules are designed according to the principle of increasing cognitive complexity, decomposing the medication decision-making process into three progressive levels: the level of information extraction and problem identification, the level of treatment plan generation and comparison, and the level of dynamic adjustment and risk reassessment. Each level corresponds to specific patterns of pharmacological knowledge retrieval and cognitive operations. The first level requires learners to extract key variables from a given animal case description, including species, body weight, hepatic and renal function status, concomitant medications, and target therapeutic effects, and to identify drug-related problems (such as inappropriate dosage, drug contraindications, and interaction risks). The second level requires learners to generate at least two feasible options based on pharmacokinetic and pharmacodynamic principles, and to compare and rank them from three dimensions: efficacy, safety, and convenience. The third level requires learners to adjust the original plan according to predetermined therapeutic feedback (such as insufficient efficacy or occurrence of adverse reactions), and to recalculate the dosage or switch to an alternative drug[4].

Constructing this pathway requires re-annotating pharmacological knowledge points according to decision-making depth. For example, knowledge of half-life at the first level merely needs to be recognized as an input variable for dosing interval calculation; at the second level, it needs to be used to compare the fluctuation amplitude of peak and trough concentrations among different dosing regimens; and at the third level, it needs to be used to judge the timing for achieving steady-state concentration and the remedial strategies after a missed dose. Advancement through the training modules does not depend on time accumulation, but rather on learners reaching a preset accuracy threshold at each level before they can proceed to the next level. The diagnostic feedback embedded within the modules can locate the learner's blockage points at specific cognitive nodes, such as whether

the error lies in the identification of drug metabolic pathways or in the application of dosage formulas, thereby supporting the generation of personalized training pathways.

3.2 Simulation-Based Scenario Teaching Strategy for Medication Decision-Making Pathways

The simulation-based scenario teaching for medication decision-making pathways adopts an interactive case-tree-based reasoning framework, transforming linear pharmacological knowledge into a nonlinear decision-making network. Each simulation unit starts with an initial animal case and sets up multiple decision nodes (such as drug selection, dosage determination, route of administration, and whether to use combination therapy). With each decision made by the learner, the system presents the immediate and delayed effects resulting from that decision and updates the case's physiological parameters (such as blood pressure, serum creatinine, and pain scores). Random variables (such as individual differences in drug metabolism and fluctuations in laboratory test results) are introduced during the simulation process to mirror the uncertainties present in real clinical settings. Learners are required to make revisable decisions under conditions of incomplete information and to adjust their original strategies at subsequent nodes based on newly acquired parameters[5].

The core of the teaching strategy lies in exposing the branching points and convergence points within the decision-making pathway. Branching points refer to situations where multiple reasonable decisions can all lead to the therapeutic goal, while convergence points refer to situations where different initial decisions ultimately need to converge on the same management principle. For example, in the treatment simulation of canine bacterial cystitis, learners may choose amoxicillin-clavulanate or enrofloxacin as the initial drug, but the differences in their safety profiles in animals with hepatic and renal insufficiency will lead to branches in subsequent monitoring frequency. Upon completion of the simulation, the system generates a decision pathway map, annotating the alternative options and discarded options at each decision point, along with the expected consequences of each option. This strategy prompts learners not only to focus on the correct decision itself, but also to attend to the logic of option generation and exclusion throughout the decision-making process, thereby internalizing the metacognitive monitoring ability underlying clinical medication reasoning.

3.3 Setting of Traceable Formative Evaluation Indicators for the Decision-Making Process

Formative evaluation indicators need to break through the traditional pharmacology assessment's reliance on knowledge recall and simple application, shifting toward quantifiable measures of the operability of each step in the decision-making process. The indicator system is divided into three dimensions: the completeness of information collection, the normativity of reasoning steps, and the adaptability of plan adjustment. Completeness of information collection evaluates whether the learner has extracted all key parameters affecting medication decision-making upon encountering the case, including body weight, age, pregnancy status, hepatic and renal function indicators, allergy history, and current medication lists. Normativity of reasoning steps evaluates whether the learner generates the decision in the order of assessing drug elimination pathways, calculating dosage, screening for interactions, and ruling out contraindications, while also recording phenomena such as skipped steps or reversed order in the reasoning chain. Adaptability of plan adjustment evaluates whether the learner can identify the cause within a reasonable time and generate an alternative plan when faced with simulated treatment failure or adverse events.

The evaluation for each dimension is based on traceable operation logs rather than on the final answer. For example, when a learner ultimately selects a regimen of furosemide combined with pimobendan in a canine heart failure case, the evaluation system not only records this final choice but also traces whether the learner had considered angiotensin-converting enzyme inhibitors, whether the initial dose of furosemide was calculated in accordance with renal function, and whether contraindications for pimobendan such as aortic stenosis were ruled out. The evaluation indicators are set with clear threshold criteria: missing more than two key parameters in information collection indicates an incomplete decision-making foundation; skipping the interaction screening step in the reasoning sequence requires the learner to return to the training module; and exceeding the preset decision window for plan adjustment suggests insufficient cognitive flexibility. These indicators can both guide learners' self-calibration and provide precise entry points for teaching interventions.

Conclusion

This study systematically constructs a three-dimensional pathway for cultivating clinical medication decision-making ability in veterinary pharmacology teaching. First, through the deconstruction of the cognitive levels of decision-making ability, this study clarifies the progressive relationship among drug information recognition, comparative reasoning, and dynamic adjustment, identifies the key mapping nodes within the pharmacodynamic and pharmacokinetic knowledge systems that influence decision-making, and points out the structural deficiencies of current teaching in procedural knowledge, conditional knowledge, and dynamic decision-making training. Second, this study proposes three main lines for teaching content reorganization: integration of drug classification and mechanisms oriented toward clinical reasoning needs, decision-oriented analysis of drug interactions and adverse reactions, and knowledge embedding strategies for species differences in medication decision-making, thereby transforming static pharmacological knowledge into dynamic resources that can be retrieved for decision-making. Finally, this study designs an interactive and assessment system to promote the generation of decision-making ability, including stepped clinical reasoning training modules, simulation-based scenario teaching strategies for medication decision-making pathways, and traceable formative evaluation indicators for the decision-making process, thereby achieving a complete closed loop from knowledge input to decision-making behavior output. Future research directions may focus on the following aspects: constructing a standardized decision-making training case library based on real clinical case data; developing an intelligent teaching platform that supports automatic tracking and feedback of the decision-making process; exploring species- and disease model-specific pathways for decision-making ability cultivation; and conducting validity studies to assess the correlation between decision-making ability evaluation indicators and actual clinical medication outcomes.

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