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# AI Simulation of Pain Cognition Based on the Circulatory Structure Theory and Its Clinical Comparison: A Cyclical Understanding of Psychological Structures in Pain and Anesthesia

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Pain narrative, Pain cognition, Anesthesiology, Artificial intelligence, Generative AI, Simulation.

## Introduction
Pain is not merely a physical sensation; it is a multilayered experience shaped by emotion, cognition, memory, and social context. In anesthesiology, it is well established that how patients narrate their pain—whether in postoperative pain, chronic postsurgical pain (CPSP), or preoperative assessment of chronic pain—significantly influences the course of treatment. A patient's narrative can amplify bodily sensations or, conversely, help alleviate them. In other words, pain is modulated by the structure of its narrative.

Despite this, previous pain research has not sufficiently explained how pain narratives are psychologically structured, nor how these structures circulate to reinforce or weaken pain perception.

Recent advances in artificial intelligence have accelerated attempts to integrate AI with existing technologies, and simulation-based approaches are becoming central in AI research [1-3]. Building on this trend, the present study applies the Circulatory Structure Theory (D→H→B→N→A) to pain cognition and uses a generative AI model to simulate two full cycles—one representing improvement and the other deterioration. AI is positioned not as a decision-maker but as a mediating structure, enabling clinical judgment to be understood as a multilayered and continuously updated cognitive process emerging through human–AI interaction.

Furthermore, the simulation results are compared with real clinical cases to evaluate the theory's validity and its potential applicability in anesthesiology and pain medicine.

The Circulatory Structure Theory conceptualizes mental processes not as linear causality but as cyclical dynamics. Pain narratives evolve through circulating psychological components—factual recognition, emotional responses, cognitive bias, personal narrative, and approval dependency. This study implements these cyclical dynamics within an AI model to visualize structural changes in pain cognition.

## Fundamental Concepts of the Circulatory Structure Theory
The Circulatory Structure Theory conceptualizes mental processes as a five-stage cyclical system. Each stage interacts dynamically with the others, and the overall cycle may rotate toward improvement or deterioration, thereby reshaping pain cognition.

### D: Dual Persona (Discrepancy Between Facts and Narrative)
This stage captures the divergence between objective physical facts (e.g., the patient can walk) and subjective narrative (e.g., "I cannot walk"). In pain contexts, the meaning attributed to pain is formed here. The greater the discrepancy, the more readily pain is interpreted as a threat.

### H: Dissonance (Emotional Discord)
Contradictions between factual reality and personal narrative elicit emotional reactions such as fear, anger, or resignation. Strong dissonance increases the likelihood that pain will be perceived as dangerous, amplifying bodily sensations.

### B: Bias (Cognitive Bias)
Cognitive distortions—including catastrophizing, over-generalization, and selective attention—become reinforced.

Examples include: "This pain will never improve", or "It will definitely get worse again". Such biases play a central role in the chronicity of pain.

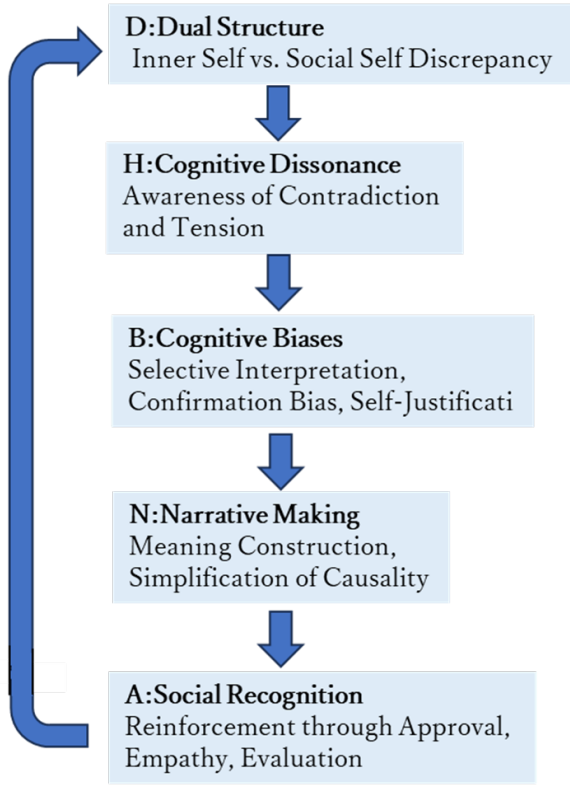
### N: Narrative Rigidity (Rigid Personal Narrative)

The personal narrative becomes fixed and loses flexibility. Examples: "Pain controls my life", "Pain determines my future". Once rigid, the narrative becomes resistant to therapeutic intervention.

### A: Approval Dependency (Dependence on External Validation)

The patient increasingly seeks approval or empathy from others, socially reinforcing the pain narrative. High approval dependency amplifies the narrative and reinitiates the cycle.

Figure 1. Cyclical Structure of the Mind




## Characteristics of the Theory

### Bidirectionality (Improvement vs. Deterioration)

The cycle can rotate in either direction.

- **Improvement:** Discrepancy (D) narrows, dissonance (H) weakens, bias (B) diminishes, narrative (N) becomes flexible, and approval dependency (A) declines.
- **Deterioration:** The opposite pattern emerges—D widens, H intensifies, B becomes entrenched, N hardens, and A increases.

### Narrative as a Driver of Pain Experience

Pain is not solely a bodily sensation; it is shaped by narrative structure. Rigid narratives amplify pain, whereas flexible narratives attenuate it.

### Clinical Interventions as Modulators of the Cycle

Cognitive-behavioral therapy, postoperative explanations, and reassurance can rotate the cycle toward improvement by reducing discrepancy and emotional dissonance.

## AI Simulation Method

### Simulation Conditions

- **Subject:** Patient with chronic low back pain (pain level 6/10, work-related stress)
- **AI model:** GPT-based generative AI
- **Cycles:** Two full rotations
- **Output:** Improvement and deterioration scenarios
- **Evaluation:** Each stage rated from 1 to 5 with concise justification

### AI Prompt Used in the Study

You are an AI specializing in pain psychology analysis. Using the circulatory structure (D→H→B→N→A), evaluate changes in pain cognition across two cycles. Rate each stage from 1 to 5 and briefly explain the reason. Generate both improvement and deterioration scenarios. Describe the output as structural analysis, not diagnosis.

## AI Simulation Results

### Improvement Scenario

#### First Cycle

- **D: 2** — Pain is present but walking is possible; discrepancy is small.
- **H: 2** — Moderate dissonance; the contradiction ("It hurts but I can move") is accepted.
- **B: 1** — Minimal bias ("Perhaps it will gradually improve").
- **N: 1** — Flexible narrative ("I'll move within what I can manage today").
- **A: 1** — Low approval dependency; the cycle concludes with self-evaluation.

#### Second Cycle

- **D: 1** — Pain decreases from 6→5; discrepancy further reduced.
- **H: 1** — Emotional reactions stabilize.
- **B: 1** — Bias nearly disappears.
- **N: 1** — Narrative shifts toward a positive "recovery process".
- **A: 1** — Approval dependency nearly zero; self-efficacy increases.

→ The improvement pathway demonstrates a decaying cycle and increasing narrative flexibility.

### Deterioration Scenario

#### First Cycle

- **D: 4** — Pain is 6/10 but the narrative states "I cannot walk".
- **H: 4** — Strong dissonance; pain is interpreted as danger.
- **B: 5** — Catastrophizing ("I'll end up bedridden").
- **N: 4** — Rigid narrative ("I will never recover").
- **A: 4** — High approval dependency; repeated complaints restart the cycle.

### Second Cycle

- **D: 5** — Discrepancy widens further.
- **H: 5** — Dissonance intensifies.
- **B: 5** — Bias becomes entrenched.
- **N: 5** — Narrative becomes part of the patient's identity ("I am a chronic pain patient").
- **A: 5** — Approval dependency strengthens; the cycle accelerates.

→ The deterioration pathway shows an amplifying cycle and progressive narrative hardening.

### Comparison with Clinical Case

### Clinical Case (50-year-old woman with chronic low back pain)

- Initial pain: 7/10
- Catastrophizing present
- Intervention: cognitive-behavioral therapy + exercise therapy
- After 4 weeks: pain reduced to 4/10; narrative became more flexible

### Consistency with AI Improvement Scenario

The clinical trajectory mirrors the AI-generated improvement pathway:

- Reduced discrepancy (D)
- Weakened dissonance (H)
- Reduced bias (B)
- Increased narrative flexibility (N)
- Lower approval dependency (A)

→The Circulatory Structure Theory provides a coherent structural explanation for changes in pain cognition.

### Applicability to Anesthesiology and Pain Medicine

- **Postoperative pain prediction:** Preoperative narrative rigidity (N) and approval dependency (A) may influence postoperative pain persistence.
- **CPSP risk assessment:** High catastrophizing (B) is associated with increased CPSP risk.
- **Evaluating postoperative explanations:** Effective explanations may rotate D and H toward improvement.

## Conclusion

The Circulatory Structure Theory offers a robust framework for understanding the complex psychological processes underlying pain cognition. AI-based simulation clearly distinguishes improvement and deterioration patterns, and alignment with clinical cases supports the theory's validity. This approach provides a novel evaluative axis for interpreting patient narratives in anesthesiology and pain medicine.

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