Clinical Knowledge Engineering for Post-Cardiac Surgery AI Systems: A Comprehensive Data Architecture and Recovery Protocol

1. Introduction: The Digital Transformation of the Post-Operative Phase

The recovery trajectory following major cardiac surgery—specifically Coronary Artery Bypass Grafting (CABG), valve replacement, or aortic repair—represents one of the most complex physiological transitions in modern medicine. Patients are rapidly transitioned from a highly monitored Intensive Care Unit (ICU) environment, where every heartbeat and milliliter of fluid is accounted for, to the home setting where they are largely autonomous. This "discharge gap" is a period of profound vulnerability. Research indicates that the first 30 days post-discharge carry the highest risk for readmission due to complications such as infection, volume overload, and arrhythmias like atrial fibrillation.[1]

Developing an Artificial Intelligence (AI) system capable of supporting patients through this phase requires a Retrieval-Augmented Generation (RAG) architecture that goes beyond simple FAQ retrieval. The system must possess a "clinical intuition" simulation—a structured logic layer that understands the interplay between surgical trauma, pharmacological interventions, and the body's natural healing mechanisms. This report serves as the foundational knowledge base for such a system, synthesizing protocols from leading institutions including the Cleveland Clinic, Mayo Clinic, and Johns Hopkins Medicine to establish the "ground truth" data required for training and retrieval.[3]

The objective of this document is to provide the exhaustive data definitions, decision trees, and content schemas necessary to build an AI that can ingest a discharge summary, configure a personalized recovery timeline, track complex medication regimens, and triage patient symptoms with high sensitivity and specificity. By structuring this data, we enable the AI to move from a passive information repository to an active guardian of patient safety.

2. The Discharge Summary: Data Ingestion and Patient Profiling

The efficacy of any recovery AI is strictly limited by the quality of its initial calibration. The "Discharge Summary" is the continuity-of-care document that defines the patient's baseline. For an AI system, this document is not merely text; it is a dataset that must be parsed to set

parameters for "normal" versus "abnormal" recovery.

2.1. Structural Analysis and HL7/FHIR Standards

To ensure interoperability and accurate data extraction, the AI must recognize the standardized sections of a discharge summary as defined by the Joint Commission and Health Level Seven (HL7) standards.[6] The Fast Healthcare Interoperability Resources (FHIR) standard identifies the Discharge Summary as a specific resource profile that synopsizes the admission, requiring extraction of reason for hospitalization, procedures performed, and disposition at discharge.[8]

The AI must be trained to extract the following core entities to build the "Patient Profile":

Data Entity	Extraction Logic & Clinical Relevance	Source Validation
Admission/Discharge Date	Defines "Day 0" for recovery algorithms. Used to calculate incision healing phases (e.g., suture removal at Day 14).	[10]
Principal Diagnosis	Distinguishes the recovery path. *Ischemic Heart Disease* implies angina monitoring; *Valve Disease* implies endocarditis prophylaxis; *Heart Failure* implies strict fluid logic.	[6]
Operative Procedure	**CRITICAL.** Differentiates between *Sternotomy* (strict lifting limits) vs. *Minimally Invasive* (faster mobilization). Identifies harvest sites (leg vs. arm) for wound monitoring.	[12]
Complications (Hospital Course)	Checks for "Post-op Atrial Fibrillation" (POAF), "Renal Insufficiency," or	[14]

	"Re-exploration." If present, the AI sets higher sensitivity thresholds for related symptoms.	
Discharge Weight	The "Dry Weight" baseline. Essential for the Congestive Heart Failure (CHF) monitoring module.	[16]
Discharge Disposition	Identifies support level: "Home with Self-Care" vs. "Home Health Nursing." This adjusts the tone of AI assertiveness regarding self-checks.	[6]

2.2. Parsing the "Hospital Course" for Predictive Logic

A sophisticated RAG system must analyze the narrative of the "Hospital Course" section to identify resolved issues that remain risk factors. For instance, if the summary states, "Patient developed rapid atrial fibrillation on Day 2, converted to sinus rhythm with Amiodarone," the patient is technically in normal rhythm at discharge. However, the AI must flag this patient as "High Risk for POAF Recurrence." Consequently, if this specific user queries, "I feel a bit fluttery," the AI's logic should aggressively triage this as a potential arrhythmia recurrence rather than dismissing it as anxiety, citing the known history from the summary.[14]

Similarly, the AI must parse "Procedures Performed" to identify secondary incision sites. A patient undergoing CABG often has a saphenous vein harvest (leg incision) or radial artery harvest (arm incision). The AI must automatically add "Leg Wound Check" or "Arm Wound Check" to the user's daily task list, customized to the specific conduits described in the summary.[12]

2.3. The Discharge Instruction Set

The discharge instructions provide the explicit rules for the patient. The AI must ingest these text blocks and convert them into actionable rules.

- **Activity Restrictions:** Often expressed as "No lifting >10 lbs." The AI must convert this to real-world equivalents (e.g., "A gallon of milk," "A heavy laundry basket") to answer user queries contextually.[20]
- **Follow-up Matrix:** The summary typically lists "Follow up with Dr. X in 4 weeks." The AI must ingest these dates and set reminders 48 hours prior to the appointment, prompting

the user to prepare questions and medication lists.[22]

3. Physiological Recovery: The AI Triage Engine

The core utility of the AI is to act as a first-line triage engine for physiological symptoms. To do this safely, it must operate on a rigid logic of "Red Flags" (Emergency), "Yellow Flags" (Urgent/Call Doctor), and "Green Flags" (Normal Recovery).

3.1. Incision and Wound Care Protocols

The integrity of the sternotomy (or mini-thoracotomy) is paramount. Deep Sternal Wound Infection (mediastinitis) is a life-threatening complication. The AI must be capable of guiding the patient through daily visual inspections.

3.1.1. Visual Inspection Logic

The AI should prompt the user daily: "Look at your chest and leg incisions in the mirror." It must then interpret the user's observations using the following classification logic:

- **Normal Healing (Green Flag):**
  - *Appearance:* Scabbing, slight bruising (changing from purple to yellow/green), "lump" at the top of the incision.
  - *Sensation:* Itching (a sign of nerve healing), numbness, "tightness," or a "pulling" sensation.
  - *AI Action:* Reassure the user. Explain that the "lump" is the top wire suture and will flatten over months. Explain that itching indicates histamine release during tissue repair.[17]
- **Infection Indicators (Yellow/Red Flag):**
  - *Appearance:* Redness extending >1cm from the incision edge, increased swelling, or opening of the wound edges (dehiscence).
  - *Discharge:* Any oozing of pus, cloudy fluid, or *new* drainage after the wound was dry.
  - *Systemic:* Presence of fever >100.4°F (38.0°C) combined with wound changes.
  - *AI Action:* Immediate instruction to call the surgeon. If "dehiscence" (wound popping open) is described, instruct to cover with sterile gauze and proceed to ER.[19]

3.1.2. Hygiene and Suture Care

The AI must enforce strict hygiene protocols to prevent bacterial seeding.

- **Showering:** Permitted typically 5 days post-op. The logic is: "Warm water, mild soap (e.g., Dove/Dial), let water run over incision. **NO SCRUBBING.** Pat dry.".[20]
- **Restrictions:** The AI must explicitly forbid "soaking" behaviors. No bathtubs, swimming pools, or hot tubs for 4–6 weeks. The logic is that stagnant water introduces bacteria into the healing tract.[20]
- **Topicals:** The AI must negatively reinforce the use of ointments. Users frequently ask,

"Can I put Neosporin/Vitamin E on it?" The response must be "No, unless prescribed. Creams keep the wound moist and can trap bacteria or delay closure".[17]

3.2. Sternal Precautions and Biomechanics

Post-sternotomy patients are essentially recovering from a controlled bone fracture. "Sternal Precautions" are designed to prevent the wires from pulling through the bone (sternal dehiscence).

3.2.1. "Move in the Tube" Logic

Modern guidelines emphasize the "Keep Your Move in the Tube" concept, which keeps the lever arm of the upper extremities short to reduce torque on the sternum.[27]

- **Lifting Limits:** The standard limit is 5–10 lbs (2–4.5 kg) for 6–8 weeks.
  - *AI Contextualization:* When a user asks "Can I pick up my cat?" or "Can I carry groceries?", the AI checks the weight. If >10lbs, the answer is "No.".[20]
- **Range of Motion:**
  - *Restriction:* No reaching backwards (extension) or raising elbows above shoulders if painful.
  - *Functional Logic*: "Do not push with your arms to get out of a chair." The AI must teach the "Rock and Roll" method: Rock forward to gain momentum and use leg muscles to stand.[28]
- **Driving:** Strict prohibition for 4–6 weeks. The reasoning is twofold: 1) The risk of airbag impact on the fracture, and 2) Delayed reaction time due to pain or opioids. The AI can suggest "Passenger status is fine, but sit in the back or place a pillow between the chest and seatbelt".[20]

3.3. Pain Management and Angina Differentiation

One of the most anxiety-provoking issues is chest pain. The AI must distinguish between "Safe Pain" (musculoskeletal/incisional) and "Unsafe Pain" (Ischemia/Angina).

3.3.1. Triage Logic for Chest Pain

The AI should use a discrimination questionnaire:

1. *User*: "My chest hurts."
2. *AI Query:* "Can you point to the exact spot with one finger? Does it hurt more when you press on it?"
   - *If Yes:* Likely incisional/musculoskeletal. **Action:** Suggest checking medication timing, splinting with a pillow.
3. *AI Query:* "Does the pain change when you take a deep breath or change position?"
   - *If Yes:* Likely musculoskeletal or pleuritic.
4. *AI Query:* "Is the pain a heavy pressure/squeezing in the center of the chest? Does it radiate to your jaw or arm?"

- *If Yes:* **RED FLAG.** Potential Angina. **Action:** Call 911/Emergency.[17]

3.3.2. Interventions

- **Splinting:** The AI must teach "Splinting." "Hug a heart pillow firmly against your chest when you cough or sneeze." This counteracts internal thoracic pressure and significantly reduces pain.[30]
- **Medication Weaning:** The AI should track opioid use (Oxycodone, etc.) and suggest transitioning to Acetaminophen (Tylenol) as pain scores decrease. It must concurrently remind the user to take laxatives if on opioids to prevent constipation.[11]

3.4. Vital Signs and Fluid Management

Congestive Heart Failure (CHF) or fluid overload is a common readmission cause.

- **Weight Monitoring (The 2-3-5 Rule):** The AI must log daily weight.
  - *Alert Logic:* "If you gain 2–3 lbs in 24 hours OR 5 lbs in a week -> CALL DOCTOR." This indicates fluid retention, not tissue mass.[3]
- **Temperature:**
  - *Threshold:* 100.4°F (38.0°C). Any reading above this triggers an infection protocol check (examine wounds, check urine for burning, check lungs for cough).[22]
  - *Night Sweats:* If the user reports night sweats *without* fever in the first 2 weeks, the AI should label this as "Normal Body Response" to the surgery/anesthesia clearance, reducing anxiety.[22]

4. Pharmacotherapy and Medication Tracking Architecture

Patients often leave the hospital with 5–10 new prescriptions. Adherence is critical for graft patency and survival. The AI must implement a "Medication Administration Record" (MAR) logic that understands drug classes, interactions, and safety parameters.

4.1. The "Cardiac Cocktail": Drug Class Logic

The AI knowledge base must include detailed profiles for the standard post-op drug classes.

4.1.1. Antiplatelets (Aspirin, Clopidogrel/Plavix, Ticagrelor/Brilinta)

- **Purpose:** Essential for keeping the new bypass grafts (veins/arteries) or stents open.
- **AI Protocol:** "Do not miss a dose." If a user asks "Can I skip my aspirin today?", the AI must emphasize: "Stopping antiplatelets without a doctor's order can lead to graft closure or heart attack".[33]
- **Side Effects:** The AI should recognize "easy bruising" as a normal side effect but flag "nosebleeds that won't stop" or "black/tarry stools" as emergency bleeding events.[3]

4.1.2. Beta-Blockers (Metoprolol, Carvedilol, Bisoprolol)

- **Purpose:** Reduces heart rate and oxygen demand; prevents arrhythmias like AFib.
- **AI Protocol:** Pulse check. Before recommending the dose, the AI can ask: "What is your pulse?" If <60 bpm (or doctor-specified limit), the AI suggests: "Hold the dose and recheck in 1 hour. If still low, call the doctor".[24]
- **Patient Education:** Users often complain of feeling "sluggish" or "tired." The AI must explain this is a common adaptation period and *not* a reason to stop the drug abruptly, which can cause rebound tachycardia.[34]

4.1.3. ACE Inhibitors / ARBs (Lisinopril, Losartan)

- **Purpose:** Prevents cardiac remodeling (shape change) and lowers BP.
- **AI Protocol:** Monitor for "ACE Cough"—a dry, tickly, non-productive cough. If the user reports this, the AI suggests discussing a switch to an ARB with the doctor. Monitor for orthostasis (dizziness when standing up).[34]

4.1.4. Statins (Atorvastatin, Rosuvastatin)

- **Purpose:** Plaque stabilization and lipid lowering.
- **AI Protocol:** Monitor for myalgia (muscle aches). If a user reports "My legs ache constantly," the AI should flag this as a potential statin intolerance (myopathy) rather than just surgical fatigue.[33]

4.1.5. Diuretics (Furosemide/Lasix)

- **Purpose:** Removing post-pump fluid overload.
- **AI Protocol:** Timing optimization. The AI should suggest taking this in the morning to prevent "nocturia" (waking up at night to pee). It should also link diuretic use to the "Potassium Supplement" (K-Dur) reminders, as diuretics wash out potassium.[34]

4.2. Anticoagulation: The Warfarin (Coumadin) Module

For patients with mechanical valves or persistent AFib, Warfarin management is complex and diet-dependent.

- **The Dietary Logic:** The AI must correct the misconception that Vitamin K is "banned." The rule is **Consistency**.
  - *AI Instruction:* "You can eat green leafy vegetables, but you must eat the same amount every day. Do not binge on spinach one week and stop the next.".[36]
- **Vitamin K Database:** The AI should possess a lookup table for Vitamin K content to guide meal planning.
  - *High Vit K (Monitor Consistency):* Kale, Spinach, Brussels Sprouts, Collard Greens, Swiss Chard.
  - *Interaction Alerts:* The AI must strictly warn against **Cranberry Juice**, **Grapefruit**

Juice, and **Alcohol**, as these potentiate Warfarin and increase bleeding risk.[37]

4.3. Medication Tracking Schema

To function as a digital MAR, the system requires a structured database for user medications. The following table outlines the data fields the AI must track for each patient, derived from discharge templates.[39]

Field Name	Data Type	Example Data	AI Logic Function
Medication Name	String	Metoprolol Succinate	Link to side effect database.
Dosage Strength	Float/Unit	25 mg	Safety check against max doses.
Frequency	Enum	BID (Twice Daily)	Scheduling notification triggers (e.g., 8am, 8pm).
Purpose	String	"For Heart Rate"	Answer "Why am I taking this?" queries.
Special Instruction	String	"Take with food"	Modifies the notification message.
Last Taken	Timestamp	2023-10-27 08:00	Calculation of "Next Dose Due."
Prescriber	String	Dr. Jones	Contact info for refills.

5. Lifestyle Rehabilitation and Long-Term Care

Beyond immediate survival, the AI must guide the patient back to functional independence. This involves managing diet, activity, and sleep.

5.1. Nutritional Architecture

The "Cardiac Diet" is a core component of secondary prevention.

- **Sodium Restriction:** The standard limit is 2,000–2,400mg per day to prevent fluid retention.
    - *AI Education:* The AI should identify the "Salty Six" foods: Bread/Rolls, Cold cuts, Pizza, Poultry (processed), Soup (canned), and Sandwiches. It should advise reading labels for "Sodium" rather than just looking for salt.[20]
- **Appetite Management:** "Dysgeusia" (taste change) and anorexia are common post-op. The AI should advise: "Eat smaller, more frequent meals. Your taste will return to normal in a few weeks".[3]

5.2. Physical Activity and Mobility

Mobility is the primary prevention for pneumonia and DVT.

- **The Walking Program:**
    - *Phase 1 (Week 1 home):* Walk 5–10 minutes inside the house, 3–4 times a day.
    - *Phase 2 (Week 2-3):* Increase duration by 1–2 minutes per day. Move outdoors if weather permits.
    - *Intensity Monitoring:* The AI must teach the "Talk Test." "You should be able to talk without gasping while walking. If you can't, slow down".[17]
- **Stairs:** A common myth is that stairs are forbidden. The AI should correct this: "Stairs are allowed immediately. Take them slowly. 'Up with the good leg, down with the bad leg'. Use the rail for balance, but do not pull yourself up with your arms".[20]

5.3. Sleep Hygiene

Sleep disturbance is a top patient complaint.

- **Positioning:** Back sleeping is best for sternal stability. Side sleeping is permitted *only* if the patient hugs a pillow to support the chest. Stomach sleeping is prohibited until the sternum heals (approx. 7–8 weeks).[42]
- **Troubleshooting:** If the user reports insomnia, the AI should suggest: "Take pain medication 30 mins before bed," "Avoid caffeine after 12 PM," and "Limit daytime naps to 20 minutes".[43]

5.4. Returning to Normalcy

- **Driving:** As noted in sternal precautions, usually restricted for 4–6 weeks. The AI should advise the user to wait for surgeon clearance.[20]
- **Sex:** Generally considered safe when the patient can climb two flights of stairs briskly without chest pain or severe breathlessness (typically 2–4 weeks). The AI should advise choosing positions that do not place weight on the chest/arms.[20]
- **Work:**

- *Desk Job:* Return in 4–6 weeks, potentially part-time initially.
- *Manual Labor:* Return in 3 months (12 weeks) after full sternal healing.[44]

6. Psychosocial Recovery: The "Cardiac Blues"

The AI must be programmed with "Emotional Intelligence" to handle the psychological sequelae of heart surgery. Up to 75% of patients experience the "Cardiac Blues"—a transient period of mood lability, anxiety, and tearfulness.[46]

6.1. Differentiating Blues from Depression

The AI must act as a screening tool to differentiate normal adjustment from clinical depression requiring intervention.

Feature	Cardiac Blues (Normal)	Clinical Depression (Requires Help)	AI Response Strategy
Duration	Days to a few weeks.	Persists > 2 weeks continuously.	If >2 weeks, generate "Call Doctor" prompt.
Symptoms	Tearfulness, irritability, frustration with recovery speed.	Hopelessness, worthlessness, suicidal ideation.	If "hopeless/suicidal" keywords detected -> Crisis Resources/911.
Function	Can still enjoy hobbies/visits occasionally.	Loss of interest in *all* activities (Anhedonia).	Encourage small social steps for Blues; professional help for Depression.

6.2. Cognitive Dysfunction ("Pump Head")

Patients often report "fuzzy thinking" or memory lapses, often attributed to micro-emboli during bypass (pump) time or anesthesia effects.

- **AI Reassurance:** The AI should normalize this: "This is often called 'Pump Head.' It typically improves over weeks to months. Be patient with yourself and use notes to remember tasks".[24]

7. Complication Detection: The High-Sensitivity Algorithms

To prevent mortality, the AI must detect specific post-operative complications.

7.1. Post-Operative Atrial Fibrillation (POAF)

Occurring in ~33% of patients, this is the most common complication.[1]

- **Triggers:** Electrolyte imbalance, inflammation, stopping beta-blockers.
- **Symptom Keywords:** "Fluttering," "Racing heart," "Fish flopping in chest," "Skipped beats."
- **AI Logic:** If keywords detected -> Ask: "Do you feel lightheaded or short of breath?" -> If Yes -> **RED FLAG** (ER). If No -> **YELLOW FLAG** (Call Cardiologist today).[1]

7.2. Deep Vein Thrombosis (DVT) and Pulmonary Embolism (PE)

Reduced mobility increases clotting risk.

- **Symptom Keywords:** "Calf pain," "Leg hot to touch," "One leg swollen," "Sharp chest pain when breathing."
- **AI Logic:** "Does the pain in your leg get worse when you flex your foot up?" (Homan's sign logic, though non-specific, is a useful screening query). Any suspicion of PE (sudden shortness of breath + chest pain) is an automatic **911 Alert**.[22]

8. Technical Implementation: Data Schemas and Templates

To assist the developer in building this system, we provide the following schemas which represent the data structure required to support the logic described above.

8.1. Patient Daily Check-In Schema

This schema defines the data the AI should solicit from the user every morning.

Data Point	Data Type	Validation Logic	Warning Trigger
Pain Score	Int (1-10)	None	> 7 (Uncontrolled Pain)
Pain Location	String	Must match body map	"Center Chest" + "Pressure" (Angina)

Weight	Float (lbs)	Compare to prev. day	+2 lbs in 24h OR +5 lbs in 7d (CHF)
Temp	Float (F)	96.0 - 105.0	> 100.4 F (Infection)
Medication	Boolean	True/False	False (Non-compliance alert)
Incision	Select		"Oozing" or "Red" (Infection)
Walking	Int (Mins)	> 0	< 5 (Mobility warning)

8.2. Discharge Summary Ingestion Template (JSON Model)

This structure maps to the HL7/FHIR constraints for extraction.

JSON

```
{
 "patient_profile": {
  "procedure_type": "CABG / Valve / Aortic",
  "sternotomy": true,
  "graft_sites":,
  "discharge_date": "YYYY-MM-DD",
  "baseline_weight": 185.5
 },
 "risk_factors": {
  "history_of_afib": true,
  "diabetes": true,
  "kidney_disease": false
 },
 "medication_list":,
 "appointments":
```

```
}
```

9. Conclusion

The post-cardiac surgery phase is a delicate balance between necessary physiological stress (healing) and pathological deterioration (complications). The AI system proposed here uses a Retrieval-Augmented Generation approach to bridge the information gap that often leads to adverse outcomes. By ingesting the discharge summary to create a personalized profile, strictly adhering to the "Red/Yellow/Green" triage logic for symptoms, and providing exhaustive, actionable guidance on medications and lifestyle, this system acts as a "digital safety net."

The integration of data from authoritative sources—confirming the 33% risk of AFib, the "2-3-5" fluid rule, and the specific dietary interactions of Warfarin—ensures that the AI operates with clinical precision. This report provides the complete blueprint for the data architecture, logic flow, and content library required to build a life-saving tool for heart surgery survivors.

Note on Citations: This report is constructed using verified clinical data referenced by Source IDs (e.g.[3]). These identifiers correspond to the provided research snippets from major cardiac centers and health organizations.

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