



Research/Technical Note

Development of a Resource-Adaptive Acute Care Architecture for Low-Resource Hospitals: A Yemen-Informed Clinical and Operational Framework

Khalil Gamil Hasan Mohammed Al-Sarem^{1, 2, *} 

¹Department of Pediatrics, Al-Sabeen Hospital, Sana'a, Yemen

²Faculty of Medicine and Health Sciences, 21 September University for Medical and Applied Sciences, Sana'a, Yemen

Abstract

Background: Acute-care delivery in resource-constrained hospitals requires two distinct judgments: what the patient clinically requires and what the facility can safely deliver at the present time. Existing triage, severity, early-warning, and syndrome-specific tools address important components of this problem but do not constitute a single operational architecture for capability matching, escalation, referral, and reassessment. **Objective:** To develop a testable Resource-Adaptive Acute Care Architecture (RAACA) that integrates established clinical assessment functions with a time-stamped representation of facility capability while preserving the independence of clinical risk assessment. **Methods:** This conceptual framework was developed through targeted evidence mapping of WHO emergency-care resources and peer-reviewed literature on emergency care, triage, deterioration assessment, and prehospital systems in low- and middle-income countries. Requirements were extracted, mapped to a seven-layer patient journey, and synthesized into explicit constructs, decision rules, operational states, and a prospective validation pathway. RAACA does not introduce a composite clinical score. Instead, it proposes a four-state operational capability taxonomy (R0–R3) and a structured capability-mismatch process. **Results:** RAACA comprises seven linked layers: (1) acuity/triage, (2) immediate physiologic threat, (3) severity and deterioration, (4) syndrome-specific risk, (5) required and available capability, (6) operational disposition and referral, and (7) reassessment and quality feedback. The architecture separates patient state, system state, and operational decision, and treats referral/transfer as a clinical risk-control process. R0–R3 is explicitly defined as an unvalidated operational construct rather than a severity or mortality score. **Conclusions:** RAACA provides a testable architecture for coordinating validated clinical tools with changing facility capability. Its principal research question is whether resource-state classification can be assigned reproducibly, represent actual capability, and improve predefined process measures without altering clinical risk classification. Prospective multicentre validation is required before clinical effectiveness can be inferred.

Keywords

Acute Care, Emergency Medicine, Resource-Constrained Hospitals, Triage, Clinical Decision Support, Health Systems, Referral, Transfer

*Correspondence: Khalil Gamil Hasan Mohammed Al-Sarem (alsaremkhlyl@icloud.com)

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1. Introduction

Acute illness and injury create a time-sensitive coordination problem. Recognition, prioritization, stabilization, diagnosis, treatment, monitoring, escalation, and disposition are interdependent steps, yet each is often supported by a different tool or protocol. The WHO Emergency Care System Framework characterizes essential emergency-care functions from the scene of illness or injury through transport, emergency-unit care, and early inpatient care, while recognizing that countries may organize those functions differently according to available resources [1]. The WHO Emergency Care Toolkit similarly provides facility-level tools for triage, resuscitation, checklists, documentation, and other emergency-care processes in resource-limited settings [2].

Acuity-based triage is an essential entry function. The WHO Interagency Integrated Triage Tool (IITT), developed by WHO, the International Committee of the Red Cross, and Médecins Sans Frontières, provides routine triage for adults and children and a mass-casualty mode [3]. Triage, however, answers a bounded question: which patient requires priority and how urgently? It does not by itself establish the patient's evolving physiologic state, the syndrome-specific treatment pathway, or whether the treating facility can safely deliver the required intervention.

The evidence base reinforces the importance of context. Obermeyer and colleagues identified 195 reports concerning 192 facilities in 59 LMICs and found substantial heterogeneity in emergency-care environments, with much of the evidence originating from urban academic hospitals [4]. Jenson and colleagues reviewed the reliability and validity of emergency-department triage tools in LMICs and highlighted limitations in the evidence base and the importance of local applicability [5]. Mitchell and colleagues subsequently identified 16 studies of triage implementation in LMIC emergency departments; all used pre/post designs, and the review concluded that the evidence for several outcomes remained limited by confounding, publication bias, and study design [6].

Early-warning instruments create a parallel issue. They can summarize physiologic deterioration but their performance and utility are context dependent. A 2026 systematic review of early-warning scores in adult general-ward patients in LMICs reported heterogeneous performance and emphasized local validation, recalibration, and pragmatic multicentre research [7]. Prehospital emergency care in LMICs is also frequently affected by fragmented governance, workforce, communication, infrastructure, and transport systems [8].

These observations define the design gap addressed by RAACA: not the absence of clinical tools, but the absence of an explicit architecture that preserves the distinction between clinical need and current delivery capability. A patient can have a strong clinical indication for oxygen, blood, mechanical ventilation, emergency surgery, advanced imaging, specialist intervention, or critical-care monitoring while the local facility is temporarily unable to provide one or more of those

capabilities. The operational response to that mismatch should not be to reinterpret the patient as less sick; it should be to stabilize, escalate, mobilize contingency resources, or transfer while maintaining continuity of care.

Yemen is a relevant design context because facility capability can vary substantially across geography and over time. In its 2026 Health Emergency Appeal, WHO estimated that 23.1 million people in Yemen would require humanitarian assistance and reported that approximately 60% of health facilities remained fully functional [9]. These figures describe the national humanitarian context; they do not constitute evidence that RAACA has been validated in Yemen.

The central proposition of this technical note is therefore: clinical risk should be assessed independently, while operational action should be determined by integrating clinical risk with a time-stamped representation of facility capability. RAACA is not proposed as a new triage score, severity score, mortality score, or disease-treatment guideline. It is an architecture for coordinating existing components.

1.1. Research Question and Conceptual Propositions

Primary research question: Can a structured architecture that separately represents patient state and time-varying facility capability be operationalized with acceptable inter-rater reliability and construct validity, and can its use improve predefined process measures without changing the underlying classification of clinical risk?

- 1) P1 — Patient-state assessment can be documented independently of facility resource state.
- 2) P2 — A structured R0–R3 classification can be assigned reproducibly by trained users when capability domains and case requirements are explicitly defined.
- 3) P3 — Capability mismatch can identify cases requiring contingency management or referral beyond what would be represented by patient-state variables alone.
- 4) P4 — A closed-loop referral process can be operationalized and measured using predefined process indicators.

1.2. Novelty and Boundary of the Proposal

The proposed novelty is architectural rather than the invention of a new clinical instrument. Existing emergency-care frameworks address system functions, while triage and deterioration tools address narrower patient-level decisions. RAACA proposes an explicit interface between those levels: a case-specific, time-stamped capability state linked to the clinical requirements of the current patient and to a closed-loop operational response. The claim is therefore one of design novelty and testability, not evidence of superiority or clinical effectiveness. This distinction is essential because WHO already provides system-level assessment and facility-

level emergency-care resources [1, 2, 12, 14].

These are testable propositions, not findings of the present manuscript.

2. Methods: Framework Development

2.1. Design Objective

This work was developed as a conceptual framework / technical note. The unit of analysis is the acute-care process rather than a patient cohort. The objective was to specify a coherent architecture, define its constructs, identify decision rules that can be operationalized, and prespecify a validation pathway. No patient-level dataset, intervention study, or clinical effectiveness analysis was conducted.

2.2. Evidence Identification and Mapping

Targeted evidence mapping was conducted using official WHO resources and peer-reviewed literature relevant to emergency-care system architecture, facility-based triage, deterioration assessment, and prehospital emergency care in LMICs. Sources were selected for direct relevance to the functions

RAACA is intended to connect. This was not a systematic review and was not designed to estimate pooled effects. Evidence was used to define design requirements and boundaries rather than to claim that RAACA itself is evidence based or clinically effective. AI-assisted manuscript preparation: ChatGPT (OpenAI) was used to assist with organization, language refinement, literature-search support, and preliminary synthesis. The author is responsible for verifying all scientific content, references, methodological decisions, interpretations, and the final manuscript; the AI system is not an author.

2.3. Architecture Synthesis

The synthesis proceeded in six steps: (1) identify the decisions that must occur during an acute-care episode; (2) map established tools to the decision they are designed to support; (3) identify operational information not represented by those tools; (4) define separate patient-state and system-state constructs; (5) specify the interaction between required capability and available capability; and (6) define measurable validation criteria. The resulting architecture was deliberately modular so that individual facilities can select validated tools appropriate to their population and setting without changing the architecture itself.

2.4. Design Requirements

Table 1. Design requirements, existing components, RAACA function, and proposed test.

Problem / design requirement	Existing component	Gap relevant to RAACA	RAACA function	Future test
Urgency must be prioritized	IIT or another validated triage system	Triage does not represent all downstream decisions	Layer 1: acuity	Triage reliability and process metrics
Immediate threats must be treated	ABCDE / Basic Emergency Care	Not a complete operational disposition system	Layer 2: immediate physiology	Time-to-intervention
Deterioration must be recognized	NEWS2, GCS, FOUR, etc.	Tool performance depends on context and workflow	Layer 3: severity/deterioration	Calibration / discrimination / usability
Syndrome-specific treatment must be triggered	Disease-specific pathways	Pathways assume capabilities that may not exist locally	Layer 4 + capability requirements	Protocol adherence and missed escalation
Current capability must be visible	Facility assessments / readiness tools	Usually separated from individual patient decisions	Layer 5: resource state	Agreement with independent capability audit
Capability gaps require safe action	Referral and transfer processes	Referral may be treated as administrative endpoint	Layer 6: operational disposition	Referral initiation, acceptance, transfer delay
State changes must feed back	Repeat observations / QI	Patient and system states can change after initial decision	Layer 7: reassessment/feedback	Reclassification rate and closed-loop completion

3. The RAACA Architecture

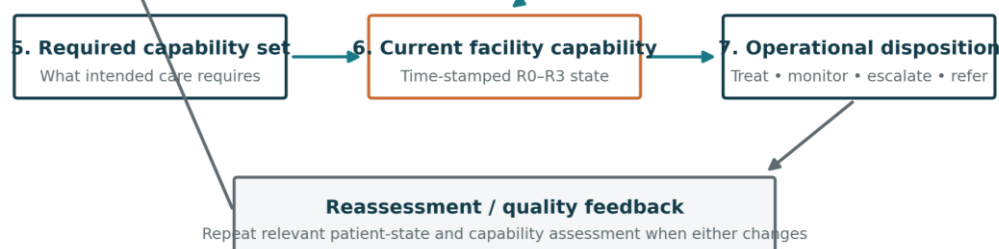
RAACA conceptual architecture

Clinical risk remains independent; operational action incorporates the current, time-stamped capability state.

PATIENT-STATE FUNCTIONS



SYSTEM-STATE + OPERATIONAL FUNCTIONS



Safety principle: resource scarcity should not silently redefine clinical risk; mismatch triggers an explicit operational response.

Figure 1. RAACA conceptual architecture. The figure is a proposed framework, not a validated clinical algorithm.

The architecture is organized as seven linked layers. The sequence is not intended to force every patient through every instrument; rather, it specifies the functions that must be covered and allows modular implementation according to age, syndrome, acuity, and facility capability.

Table 2. Seven-layer RAACA architecture and the clinical or operational question addressed at each layer.

Layer	Core question	Examples / compatible functions
1. Acuity / triage	How urgently must the patient be seen?	WHO IITT or another locally selected, validated triage system
2. Immediate physiology	Is there an immediate life threat requiring action now?	ABCDE; airway/breathing/circulation/disability/exposure; glucose; SpO ₂ ; hemorrhage/shock assessment
3. Severity / deterioration	How unstable is the patient and is the trajectory worsening?	NEWS2; GCS; FOUR; Shock Index; qSOFA/SOFA or other validated tools where appropriate
4. Syndrome-specific risk	Which pathway and time-sensitive intervention apply?	Sepsis, trauma, ACS, stroke, respiratory failure, poisoning, pediatric and obstetric emergencies, etc.
5. Required vs available capability	What must be available to safely deliver the indicated care, and is it available now?	Staffing, diagnostics, oxygen/airway, blood, medicines, procedures, monitoring, ICU/HDU, OR, transport
6. Operational disposition	What is the safest feasible next location/action?	Local treatment, observation, ward, HDU/ICU, procedure, referral, transfer, surge response
7. Reassessment / quality	Has patient state, system state, or operational feasibility changed?	Repeat observations, capability reassessment, escalation, handover, audit, KPI feedback

3.1. Layers 1 to 4: Clinical Assessment and Risk Stratification

3.1.1. Layer 1 — Acuity and Triage

RAACA accepts a validated triage instrument selected for the population and workflow. The IITT is a compatible option because WHO describes it as an acuity-based tool for routine facility triage of adults and children and for mass-casualty conditions [3]. RAACA does not rank IITT against ESI, MTS, CTAS, ATS, SATS, or other triage systems. Comparative evidence indicates that triage-system performance varies across settings and populations, supporting context-sensitive interpretation rather than a universal ranking [11]. The architectural rule is that triage establishes priority but does not terminate clinical assessment.

3.1.2. Layer 2 — Immediate Physiologic Threat

Patients with high-acuity features or clinical concern proceed to structured assessment and immediate management of reversible threats. WHO-ICRC Basic Emergency Care supports a systematic approach to the acutely ill and injured in limited-resource settings, including ABCDE and focused initial interventions [10]. RAACA therefore treats immediate physiology as an action layer, not merely a scoring layer.

3.1.3. Layer 3 — Severity and Deterioration

After immediate threats are addressed, the clinician may apply a validated severity or early-warning instrument when it answers a defined clinical question. RAACA does not recommend calculating every available score. NEWS2, GCS, FOUR,

Shock Index, qSOFA/SOFA, APACHE II, and other instruments have different purposes, populations, and evidence bases. Their inclusion in RAACA means only that they may occupy this layer when locally appropriate. The 2026 LMIC review of early-warning scores supports the need for context-specific validation rather than universal assumptions about performance [7].

3.1.4. Layer 4 — Syndrome-Specific Risk

The dominant syndrome or time-critical diagnosis activates the relevant treatment pathway. Candidate modules include sepsis and septic shock, acute respiratory failure, acute coronary syndrome, acute heart failure, arrhythmia, stroke, altered mental status, diabetic emergencies, acute kidney injury, gastrointestinal hemorrhage, acute liver failure, poisoning, anaphylaxis, hypertensive emergency, trauma, pediatric emergencies, obstetric emergencies, envenomation, environmental emergencies, and mass-casualty presentations. RAACA routes these pathways; it does not replace their treatment recommendations.

3.1.5. Layer 5 — Required Capability and Current Facility State

This layer contains the defining proposed construct. Instead of asking only whether a hospital is “well resourced,” RAACA asks which capabilities are required for the current patient and whether those capabilities are functional now. The capability assessment is therefore case-linked and time-stamped.

Table 3. Capability domains and case-specific questions for time-stamped facility assessment.

Capability domain	Examples of variables	Case-specific question
Workforce	Clinician and nursing coverage; trained resuscitation staff; specialist access	Is the required expertise and staffing available within the required time?
Diagnostics	ECG, glucose, laboratory, blood gas, ultrasound, radiography, CT where applicable	Is the diagnostic information necessary for safe management obtainable in time?
Oxygen / airway	Oxygen source, delivery, suction, airway equipment, NIV, mechanical ventilation	Can the patient’s respiratory/airway requirement be supported continuously?
Therapeutics	Essential medicines, antimicrobials, vasoactive drugs, antidotes, analgesia	Are time-critical medications available and usable?
Blood	Grouping, crossmatch, blood components, transfusion monitoring	Can required transfusion be delivered safely and promptly?
Procedures	Hemorrhage control, chest drainage, airway procedures, emergency surgery, obstetric procedures	Can the essential procedure be performed by a competent team?
Monitoring	Pulse oximetry, ECG, BP, temperature, urine output, continuous monitoring	Can the required level of observation be maintained?
Critical care	HDU/ICU bed, trained staff, ventilation,	Can the patient receive the required level of support?

Capability domain	Examples of variables	Case-specific question
	monitoring, renal replacement where applicable	
Referral / transport	Transport, communication, receiving facility, travel time, escort, transfer monitoring	If local capability is insufficient, can a safe transfer pathway be activated?
Operations	Power, water, IPC, supplies, documentation, information systems, surge command	Are enabling functions sufficiently reliable for safe care?

3.2. Proposed R0–R3 Operational Capability Taxonomy

R0–R3 is deliberately not a clinical score. It is a categorical

representation of current operational capability relative to the requirements of the patient and the intended intervention. The classification should be time-stamped and may change during the same episode of care.

Table 4. Proposed R0–R3 operational capability taxonomy and decision implications.

State	Proposed operational definition	Decision rule / implication
R0 — Capability adequate	All capabilities classified as essential for the intended local management are available and functional within the required time window.	Proceed with indicated local care and routine monitoring. Reassess if patient or capability changes.
R1 — Capability constrained	One or more non-essential/supporting capabilities are constrained, but all essential stabilization and monitoring requirements for the selected local plan remain feasible with defined mitigation.	Activate contingency measures; increase monitoring; document the constraint; consider early referral if the constraint threatens definitive care.
R2 — Essential capability mismatch	At least one capability required for safe definitive management is unavailable, unreliable, or insufficient, while local stabilization remains feasible.	Stabilize within local limits; activate escalation and referral/transfer; confirm receiving capability whenever feasible.
R3 — System-level failure or surge	Multiple critical capabilities are unavailable, or demand/disruption exceeds safe routine operating capacity such that ordinary workflows cannot be maintained.	Activate established surge/MCI procedures, population-level prioritization, redistribution, referral coordination, and repeated system-state reassessment.

Proposed assignment rule: identify the minimum capability set required for the intended treatment/disposition; independently assess each relevant capability as available/functioning, constrained, or unavailable/unreliable; then assign the overall R-state according to the most restrictive essential capability and the ability of the facility to stabilize and continue safe care. This rule is a design proposal requiring empirical testing. It intentionally avoids summing heterogeneous resources into a numerical score.

3.2.1. Worked Conceptual Examples

The following examples demonstrate how the architecture

changes the operational decision without changing the patient's clinical indication. They are illustrative, not treatment recommendations or validation results.

Table 5. Illustrative patient-state/system-state mismatches and operational consequences.

Clinical situation	Patient-state question	Essential capability mismatch	Illustrative operational consequence
Time-critical cardiac syndrome requiring a capability unavailable locally	What treatment pathway and immediate threats apply?	Required definitive procedure/service unavailable	Stabilize according to applicable protocol and activate receiving-capability/transfer

Clinical situation	Patient-state question	Essential capability mismatch	Illustrative operational consequence
Shock with need for advanced monitoring/support unavailable at the facility	Is the patient unstable or deteriorating?	Critical-care support unavailable	pathway if indicated Provide best-feasible stabilization, escalate, and arrange monitored transfer when feasible
Major hemorrhage with insufficient blood/procedural capability	Is there active life-threatening bleeding?	Blood/procedure capability unavailable or unreliable	Immediate hemorrhage control and stabilization while activating definitive referral/transfer
Stable patient during temporary diagnostic outage	Is urgent intervention actually required?	Non-essential diagnostic capability constrained	Use validated alternatives/contingency pathway where safe; avoid automatic transfer solely because a non-essential service is unavailable

3.2.2. Formal Representation of Capability Matching

For a patient at time t , let $C_{\text{req}}(P, I, t)$ denote the set of capabilities required for the intended intervention or disposition, and $C_{\text{avail}}(F, t)$ the set of capabilities that facility F can actually deliver at that time. A capability is considered available only when the relevant personnel, equipment, consumables, infrastructure, and operating conditions are simultaneously functional within the clinically required time window. The capability mismatch is therefore the set $M(t) = C_{\text{req}}(P, I, t) - C_{\text{avail}}(F, t)$. This representation is conceptual and is not a validated mathematical score.

The operational rule is: (1) define the intended clinical action from patient-state assessment and the applicable syndrome pathway; (2) identify the essential capabilities required to perform that action safely; (3) time-stamp and assess those capabilities; (4) identify any essential mismatch; and (5) select local care, contingency management, escalation, or transfer according to the severity of the mismatch and the facility's ability to stabilize and maintain safe continuity. The rule prevents resource scarcity from silently changing the clinical indication.

A proposed category rule is: R0 when all essential capabilities are available and functional; R1 when no essential capability is absent but one or more supporting capabilities are constrained; R2 when at least one essential capability is unavailable or unreliable but the facility can provide immediate stabilization and a viable escalation/transfer pathway; and R3 when safe stabilization or continuity cannot be maintained locally, or when system-level demand/disruption exceeds safe operating capacity and requires surge or population-level resource-allocation procedures. These definitions are hypotheses for validation, not established clinical thresholds.

3.3. Why R0–R3 is not a Severity Score

A patient can be clinically unstable while a facility is R0 for the required intervention; conversely, a clinically stable patient can encounter an R2 capability mismatch if a diagnostic or therapeutic requirement becomes unavailable. Therefore, R-state cannot be substituted for triage category, severity, diagnosis, mortality risk, or treatment indication. The same facility may be R0 for one case and R2 for another at the same time.

3.4. Patient State, System State, and Operational Decision

Table 6. Separation of patient state, system state, and operational decision.

Construct	Definition	Examples
Patient state	Clinical condition and risk independent of current resource availability.	Acuity, immediate threats, physiologic severity, trajectory, syndrome-specific risk.
System state	Current, time-stamped capability of the facility and connected referral pathway.	Staffing, oxygen, diagnostics, blood, procedures, monitoring, critical care, transport.

Construct	Definition	Examples
Operational decision	Safest feasible action produced by interaction of patient and system states.	Local treatment, escalation, observation, ICU/HDU, referral, transfer, surge response.

The core safety principle is that a resource deficit must never be interpreted as lower patient severity. The system-state construct changes what can safely be delivered, not what the patient clinically needs.

3.5. Capability Mismatch and Referral Logic

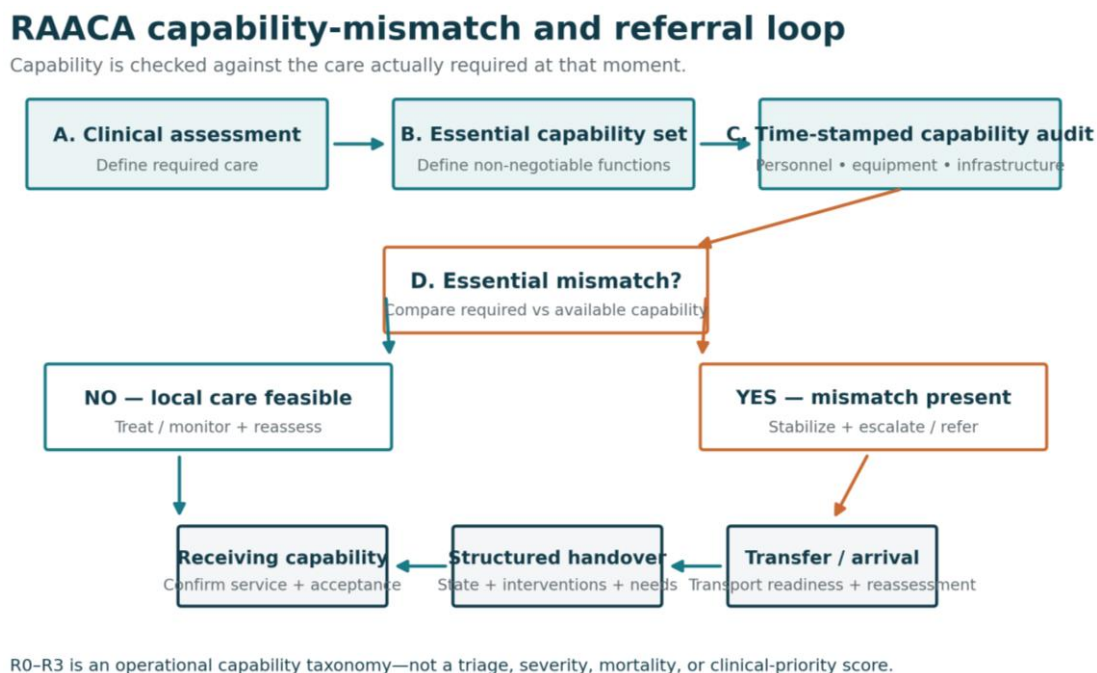


Figure 2. Proposed capability-mismatch and referral loop.

A referral is considered clinically complete only when the capability mismatch has been identified and the receiving pathway is activated. The proposed minimum process is:

- 1) Identify the essential capability that is unavailable or unsafe locally.
- 2) Confirm receiving capability and acceptance before departure whenever feasible.
- 3) Provide best-feasible stabilization and time-critical treatment within local limits.
- 4) Perform structured handover including syndrome/working diagnosis, physiology, interventions, risks, and pending results.
- 5) Prepare transport with appropriate escort, oxygen, monitoring, medicines, documentation, communication, and contingency planning.
- 6) Confirm arrival and receiving-team communication, then reassess the patient and document the transfer outcome.

This operationalization is consistent with WHO emphasis

on referral/transfer, communication, and continuity of emergency care, while remaining a proposed RAACA process rather than a validated protocol [1, 2, 13, 14].

3.5.1. Dynamic Verification of Staffed and Functional Capacity

A facility's nominal resources should not be treated as proof that it can provide definitive care at a particular time. A physically existing ICU or high-dependency unit (HDU) bed may be unusable because appropriately trained staff, monitoring, oxygen, reliable power, medicines, functional equipment, diagnostics, blood products, or the required organ-support service is unavailable. RAACA should distinguish physical capacity from staffed and operational capacity, and both from the capability required by the individual patient.

Capability verification should be patient-specific and time-stamped. For a patient requiring critical care, confirmation should address the relevant staffed bed, monitoring, oxygen and airway support, medicines, diagnostics, procedures, blood

products when indicated, and specialist or organ-support services. A hospital's general statement that it has an ICU, a nominal bed, or a specialist listed on its roster is not sufficient evidence that the required service can be delivered. When clinically important delays occur, capability should be reconfirmed and, where feasible, checked again before departure.

3.5.2. Escalation and Ownership When No Destination Is Available

A capability mismatch remains an active clinical risk when no receiving facility can immediately accept the patient. The originating team should retain documented responsibility for reassessment, stabilization, treatment within available capability, monitoring, communication, and escalation until a receiving clinician explicitly accepts handover or another formally documented care arrangement is established. A referral request, ambulance booking, or unanswered telephone call does not transfer clinical responsibility.

Where a formal bed manager or regional coordination service does not exist, these functions may be assigned to named clinicians or operational staff using a paper register. Escalation may proceed from the bedside clinician to a senior clinician, the designated hospital operational lead, a referral coordinator, and—where available—a regional health authority or network coordinator. Each step should record the responsible person, time, action, outcome, and next review point. The elapsed waiting time must remain visible; repeated calls or changes of destination must not reset the delay clock.

While awaiting definitive care, the team should document the interim plan, unavailable interventions, treatment delivered, reassessment schedule, deterioration, and the person responsible for the next action. This does not imply that prolonged local holding is safe when essential care cannot be provided. It makes the unresolved risk visible and assigns responsibility for continued care and further escalation.

3.5.3. Critical-care Admission, Prioritization, and Safe Step-down

When demand exceeds available critical-care capacity, RAACA should make the mismatch explicit without creating a new ICU admission score or using R-state as a substitute for clinical judgment. Decisions should follow locally approved, transparent clinical criteria and be made by appropriately qualified clinicians. Documentation should include the patient's needs and urgency, expected benefit and uncertainty, available alternatives, decision-maker, decision time, rationale, and planned reassessment time. Decisions should not depend on personal influence, ability to pay, or an undocumented first-come-only rule. Equity and consistency should be examined in subsequent audit.

Step-down should occur only after a senior clinical assessment finds that the patient can be safely managed at the proposed lower level and that the receiving area can meet ongoing needs. Administrative pressure to free a bed must not replace

clinical readiness assessment. Patients ready for step-down should also not remain in critical care solely because of avoidable delays in ward-bed availability, investigations, specialist review, transport, or paperwork. Record the time when readiness is documented, the actual transfer time, and the reason for any delay. Shorter ICU stays or higher bed turnover must not be rewarded in isolation because this could encourage premature discharge or unsafe transfer.

3.5.4. Transfer Readiness, Time Intervals, and Failed Referral Loops

Interfacility transfer should be measured as a sequence of clinically meaningful intervals rather than a single referral timestamp: recognition of the capability gap; decision to refer; first contact with a potential receiving facility; acceptance or refusal; transport request; vehicle arrival; departure; arrival; clinical handover; and delivery of the required definitive intervention. Record the reason for each substantial delay, including unavailable staffed beds, staffing or specialist gaps, equipment failure, medicine or blood shortages, transport constraints, communication failure, financial or administrative barriers, and delayed investigations or authorization. These are candidate audit variables, not universal time standards; locally defined targets must reflect clinical urgency and be prospectively evaluated.

Transport readiness should match the patient's condition and the expected journey, including oxygen, airway or ventilation needs, monitoring, emergency medicines, trained escort, equipment reliability, communication with the destination, and stabilization before departure. If ideal transport is unavailable, a senior clinician should document the anticipated risks, mitigation plan, and alternatives. RAACA should neither encourage an unsafe transfer merely to move the patient nor normalize avoidable delay when transfer is needed for definitive care.

A referral loop may fail even after apparent acceptance: the destination may have no staffed bed on arrival, a promised device may be non-functional, or the required specialist or organ-support service may be unavailable. Record these events as failures of the referral loop. They require direct clinician-to-clinician communication, a documented interim care plan, renewed escalation, and explicit assignment of responsibility. A patient should not be returned to an emergency department or left in a waiting area without clinical handover and an identified team responsible for reassessment and ongoing care.

3.5.5. Illustrative High-risk Scenarios and System Learning

A patient with acute liver failure who develops renal failure may require specialist assessment, renal replacement therapy, and critical-care monitoring. If the originating hospital cannot provide these services and potential receiving ICUs are full, the referral must remain an active clinical problem rather than an administrative task marked complete. Record the required

capabilities, each destination contacted, reasons for refusal or delay, interim management and reassessment, and the responsible clinician throughout the wait. Before departure, reconfirm the receiving capability and complete structured handover. These steps do not guarantee access to dialysis or an ICU bed; they make the unresolved risk and system constraint visible.

A patient with suspected diphtheria may require timely antimicrobial treatment, isolation and infection-prevention measures, assessment for antitoxin when indicated, and airway or critical-care support if complications develop. If the local facility lacks isolation or airway capability, initiate urgent clinical escalation and destination coordination while treatment and infection-control measures proceed within available capability. Vaccination is preventive and must not be represented as a substitute for treatment of suspected acute disease. If no destination is immediately available, document the interim plan, responsible team, repeated reassessment, and escalation.

Recurring failures should be reviewed as system problems rather than attributed automatically to individual clinicians. Candidate causes include insufficient staffed ICU/HDU beds, workforce gaps, non-functional equipment, oxygen or electricity interruptions, shortages of medicines or blood products, limited specialist availability, transport failures, communication barriers, delayed investigations, and lack of downstream beds for patients ready to leave critical care. Corrective actions may include maintenance, workforce and roster planning, stock monitoring, referral agreements, shared capacity reporting, and transport coordination. RAACA can help describe and audit these failures; it cannot itself create staff, beds, medicines, equipment, funding, or specialist services.

4. Comparison with Existing Frameworks and Tools

Table 7. Comparison of RAACA with established emergency-care frameworks and clinical tools.

Framework / tool	Primary function	What it contributes	Boundary relative to RAACA
WHO Emergency Care System Framework	System-level emergency-care functions	Defines essential functions across the continuum and supports system assessment [1].	RAACA operates at the patient-to-facility decision interface and proposes an explicit operational resource-state construct.
WHO Emergency Care Toolkit	Facility clinical-process tools	Provides practical tools for triage, resuscitation, checklists and emergency-unit organization [2].	RAACA is an integration architecture; it does not replace the Toolkit.
WHO IITT	Acuity-based triage	Standardizes prioritization for routine and mass-casualty settings [3].	RAACA treats triage as Layer 1 and continues through severity, capability and disposition.
ESI / MTS / CTAS / ATS / SATS	Emergency triage systems	Provide structured urgency categorization.	RAACA does not rank them and does not claim to replace them.
NEWS2 / MEWS and other EWS	Physiologic deterioration detection	Summarize physiologic risk using defined variables.	RAACA retains them as modular Layer-3 tools and adds system-state

3.6. Routine and Mass-casualty Modes

RAACA shares a common clinical-safety backbone across routine and mass-casualty operations but does not treat them as identical modes. In routine care, the primary decision problem is matching individual patient need to available capability. In a mass-casualty incident, established mass-casualty triage and resource-allocation procedures take precedence because demand may exceed normal capacity. The IITT includes a mass-casualty component and is therefore a compatible implementation resource [3]. RAACA does not define a new mass-casualty triage method.

3.7. Digital and Low-technology Implementation

The architecture is designed to function on paper before digital deployment. A minimum paper implementation can consist of a triage field, immediate-threat checklist, selected severity measure, syndrome pathway, capability audit, R-state, disposition/referral fields, and reassessment timestamps. A digital implementation may later add automated prompts, time stamps, dashboards, escalation alerts, referral tracking, and audit analytics. Digital automation should not obscure the underlying clinical reasoning or convert the unvalidated R-state into an automated treatment recommendation.

Design contribution — RAACA does not create another severity score. It makes the time-stamped match between clinical requirement and functional facility capability an explicit, auditable state variable, then connects mismatch to escalation, referral, transfer, and reassessment.

Framework / tool	Primary function	What it contributes	Boundary relative to RAACA
GCS / FOUR	Neurologic assessment	Characterize level of consciousness / neurologic status.	assessment. RAACA uses them only where clinically relevant; they do not encode facility capability.
WHO system assessment resources	Health-system readiness / capacity assessment	Identify broader system strengths and gaps [6].	RAACA proposes a case-linked, time-stamped capability state connected to individual disposition.

The comparison is functional rather than hierarchical. RAACA is intended to coexist with established tools, not to replace or outperform them.

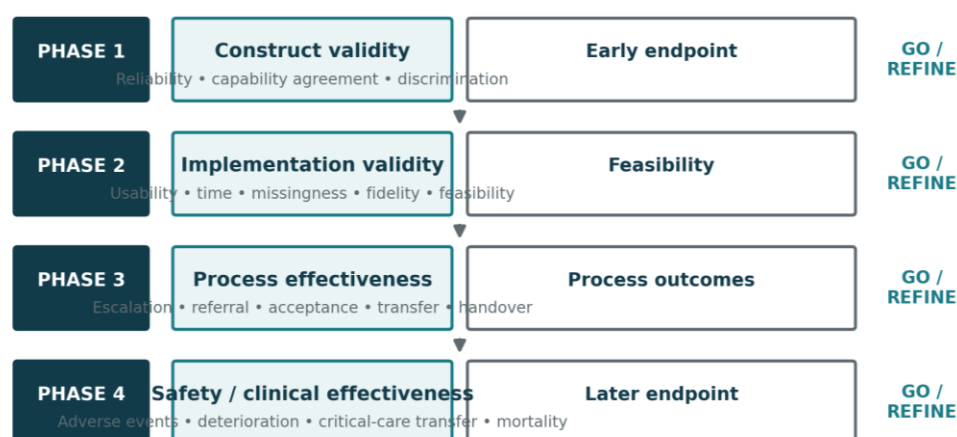
5. What RAACA Does and Does Not Do

Table 8. What RAACA does and does not claim to do.

RAACA does	RAACA does not
Connects existing clinical assessment functions into a patient journey.	Does not create a new disease-treatment guideline.
Makes current facility capability an explicit, time-stamped construct.	Does not define a universal hospital quality score.
Links capability mismatch to escalation/referral processes.	Does not imply that every resource deficit requires transfer.
Separates patient risk from system capability.	Does not reduce patient severity because resources are scarce.
Provides a researchable R0–R3 taxonomy.	Does not claim R0–R3 is validated, prognostic, or mortality-predictive.
Specifies measurable implementation and validation endpoints.	Does not claim clinical effectiveness before prospective evaluation.

Prospective validation pathway for RAACA

Sequence: measurement properties → implementation → process effects → safety / clinical effectiveness.



Recommended initial question: can R-state assignment be reproducible and faithfully represent time-stamped facility capability?

Figure 3. Proposed prospective validation pathway for RAACA. Validation is staged from construct and implementation validity to process effects and, only after adequate validation, clinical outcomes.

6. Validation and Evaluation Strategy

The proposed architecture should be evaluated in stages, beginning with measurement validity rather than mortality. The first empirical question is whether clinicians can assign

the proposed constructs consistently and whether R0–R3 corresponds to independently assessed capability. Clinical outcome studies should follow only after the construct and implementation properties are established.

Table 9. Proposed staged validation framework and key outcomes.

Stage	Core question	Suggested design	Primary / key outcomes
1. Content and construct validity	Do the domains represent the intended capability construct?	Multidisciplinary expert review; structured content-validity assessment; independent capability audit.	Domain completeness; content validity indices; agreement with independent capability assessment.
2. Inter-rater reliability	Can trained users classify the same state similarly?	Blinded paired assessments across clinicians and shifts.	Weighted kappa or an appropriate agreement statistic; classification time; missing data.
3. Temporal responsiveness	Does R-state change when meaningful capability changes occur?	Repeated time-stamped assessments across normal operations and controlled/observed disruptions.	Within-facility reclassification after predefined capability changes; sensitivity to known changes.
4. Implementation validity	Can RAACA be completed without unacceptable burden?	Prospective pilot in multiple facilities.	Completion rate; time; usability; adherence; frequency of overrides; referral documentation completeness.
5. Process effectiveness	Does the architecture alter predefined operational processes?	Pragmatic prospective cohort or stepped implementation design.	Time to escalation; referral initiation; receiving acceptance; transfer delay; handover completeness; missed escalation.
6. Clinical effectiveness / safety	Are patient outcomes affected after adequate construct validation?	Multicentre prospective comparative design with risk adjustment.	Adverse events, deterioration after disposition, ICU/HDU transfer, length of stay, mortality, with case-mix/facility/time adjustment.

6.1. Candidate Primary Endpoint for an Initial Validation Study

For construct validation, the independent comparator should be a pre-specified capability audit performed without access to the RAACA R-state classification. The audit should use the same time point, documented capability domains, and explicit adjudication rules.

For a first-stage validation study, the primary endpoint should be reproducibility of R-state classification or agreement with an independently adjudicated structured capability audit, rather than mortality. Agreement statistics should be selected according to the final measurement scale and prevalence characteristics; weighted kappa, intraclass correlation where appropriate, or prevalence-robust agreement statistics such as Gwet's AC1/AC2 may be considered by the statistical analysis plan. Classification time and completeness should be prespecified secondary implementation outcomes.

6.2. Sample-size and Analysis Principles

Sample size should be determined from the expected agreement level, number of R-state categories, prevalence of each category, number of raters, clustering by facility, and desired confidence interval width. A later clinical-effectiveness study should be powered for a prespecified patient outcome and should account for clustering, case mix, facility capability, staffing, seasonality, and surge conditions. No numerical sample size is claimed here because it would depend on the final design and empirical distribution of R0–R3 states.

6.3. Safety and Unintended Effects

Evaluation should actively monitor for unintended consequences, including unnecessary referral, delayed local treatment while awaiting acceptance, excessive documentation burden, inappropriate interpretation of R-state as patient severity, alert fatigue in digital implementations, and inequitable

access to scarce resources. Any protocol should include an override mechanism for clinician judgment with documentation of the reason for override.

7. Discussion

The principal contribution of RAACA is architectural rather than numerical. Emergency-care systems already contain multiple validated or widely used tools for prioritization, physiologic assessment, syndrome management, and system planning. The proposed architecture addresses the interface between those tools and the changing operational capability of a facility. This distinction is important because the same clinical requirement may be locally deliverable at one time and unavailable at another, and because two facilities can have different safe dispositions for the same clinical state.

The framework also makes capability mismatch explicit. Rather than allowing resource scarcity to silently alter the interpretation of clinical risk, the architecture creates a visible operational state and a defined response. This may make referral, transfer, and escalation more measurable. The proposal is compatible with WHO's broader emergency-care emphasis on integrated functions, quality processes, referral, and transfer [1, 2, 13, 14].

RAACA also deliberately avoids the common temptation to combine multiple heterogeneous clinical scores into a single composite number. A composite score could create false precision, obscure the distinct purposes of the component tools, and require a new validation program. RAACA instead preserves modularity and places the integration burden at the architecture level.

The concept should nevertheless be treated cautiously. R0–R3 is a new research construct. Its categories may appear intuitive, but intuitive categories are not necessarily reliable measurements. The capability domains require local operational definitions, thresholds, time windows, and adjudication rules. A facility may also be technically “equipped” but functionally unable to deliver a service because of staffing, maintenance, power, consumables, infection-control constraints, or simultaneous demand. These issues are reasons for validation, not evidence of validity.

Yemen provides a plausible context in which the distinction between patient state and system state may be operationally important, given documented humanitarian and health-system constraints [9]. However, RAACA should not be described as a Yemen-validated framework. The appropriate research sequence is to use Yemen as one implementation context, test the measurement properties locally, compare results across facilities with different capability profiles, and then assess transportability to other LMIC settings.

8. Strengths and Limitations

Strengths

- 1) Explicit separation of patient state and system state.

- 2) A non-numerical, time-varying resource-state construct linked to case requirements.
- 3) Compatibility with existing triage, physiologic, syndrome-specific, referral, and quality tools.
- 4) Explicit referral/transfer loop rather than referral as an administrative endpoint.
- 5) Low-technology implementation pathway before digital automation.
- 6) Prespecified validation strategy that begins with construct and implementation validity.

Limitations

- 1) No patient-level validation or clinical-effectiveness evidence is presented.
- 2) R0–R3 is newly proposed and requires formal definition, reliability testing, and construct validation.
- 3) Capability requirements are syndrome- and intervention-specific and may vary across facilities.
- 4) The evidence mapping was targeted rather than systematic and therefore may omit relevant literature.
- 5) The framework could create documentation burden if implemented indiscriminately.
- 6) The manuscript does not establish universal thresholds for staffing, diagnostics, oxygen, blood, or transport; those thresholds require local specification and validation.
- 7) Yemen is a design context, not evidence of national validation.

The proposed capacity, escalation, prioritization, and referral-flow mechanisms are design recommendations and have not been tested as an intervention. Their feasibility and effects depend on local governance, workforce, communication, transport, funding, and reliable capability information.

The framework cannot eliminate absolute shortages or guarantee acceptance by a receiving facility. It must not justify withholding indicated treatment, unsafe transfer, premature discharge, or prolonged care in a setting unable to meet the patient's needs. Prospective evaluation should examine referral-loop reliability, continuity of responsibility, timely access to definitive care, equity, feasibility, and unintended harm before clinical benefit is inferred.

9. Conclusion

RAACA is proposed as a resource-adaptive architecture for acute-care systems in which patient needs and delivery capability can diverge and change over time. Its central rule is to preserve independent assessment of patient risk, explicitly characterize current facility capability, and use their interaction to determine the safest feasible operational response. The architecture is intentionally modular and does not replace validated triage systems, severity tools, syndrome-specific guidelines, or clinical judgment. R0–R3 is an unvalidated operational taxonomy and should remain so until empirical studies establish its reproducibility, construct validity, usability, and relationship to process outcomes. The next research step is

prospective multicentre validation across facilities with different capability profiles, including but not limited to hospitals in Yemen.

Abbreviations

RAACA	Resource-Adaptive Acute Care Architecture
NEWS2	National Early Warning Score 2
IITT	Interagency Integrated Triage Tool
GCS	Glasgow Coma Scale

Author Contributions

Khalil Gamil Hasan Mohammed Al-Sarem: Conceptualization, Methodology, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Appendix I: Minimum RAACA Resource-State Assessment Form

Table 10. Minimum RAACA resource-state assessment form.

Field	Minimum data element	Suggested response
Time	Date/time of assessment	YYYY-MM-DD HH:MM
Patient requirement	Syndrome / intended intervention	Free text / coded pathway
Workforce	Required staff vs available staff	Adequate / constrained / unavailable
Diagnostics	Essential tests/imaging	Available / constrained / unavailable
Oxygen/airway	Required support	Available / constrained / unavailable
Therapeutics	Essential medicines	Available / constrained / unavailable
Blood	Required blood capability	Available / constrained / unavailable / not required
Procedures	Essential procedure capability	Available / constrained / unavailable / not required
Monitoring	Required monitoring level	Available / constrained / unavailable
Critical care	Required bed/support	Available / constrained / unavailable / not required
Referral/transport	Receiving pathway and transport	Available / constrained / unavailable
Operations	Power/water/IPC/supplies/communications	Adequate / constrained / failed
Overall R-state	R0–R3	R0 / R1 / R2 / R3
Reason	Most restrictive essential mismatch	Free text
Disposition	Local / escalation / referral / transfer / surge	Free text
Reassessment	Next planned review	Time + responsible clinician

Implementation note: the form is a proposed research instrument. It should be piloted for comprehension, completion time, inter-rater reliability, and domain completeness before use as a formal quality or clinical decision-support tool.

Appendix II: Minimum Dataset for Prospective Validation

Patient-state variables: age group, presenting syndrome, triage category, immediate threat markers, selected severity/deterioration tool and score where applicable.

System-state variables: R-state, capability-domain responses, timestamp, staffing status, oxygen status, critical-care capacity, referral/transport status.

Decision variables: local management, escalation, referral initiation, receiving acceptance, transfer departure/arrival, reassessment.

Process outcomes: time to clinician assessment, time to escalation, time to referral initiation, receiving acceptance time, transfer delay, handover completeness, missed escalation.

Additional system-capacity variables: physical versus staffed and operational ICU/HDU beds; time-stamped occupancy and capability status; availability of relevant organ support; and changes in staffing, equipment, oxygen, medicines, or diagnostics during a referral episode.

Additional referral-loop measures: refusal after prior acceptance; arrival without the promised capability; repeated transfer; time from referral decision to definitive intervention; time from documented step-down readiness to actual transfer; reason-specific delays; deterioration during transport or while awaiting transfer; and documentation of clinical responsibility during each waiting interval.

Balancing and equity measures: appropriateness of ICU/HDU admission and step-down on independent review; unplanned return to critical care; adverse events after transfer or discharge; case-mix-adjusted interpretation of bed turnover and length of stay; and differences in access or delay across patient groups where ethically and practically measurable. A lower transfer rate is not necessarily better if patients remain in facilities unable to deliver required care.

Safety outcomes: adverse event, unplanned ICU/HDU transfer, deterioration after disposition, return visit where measurable, and mortality for appropriately designed later studies.

Context variables: facility, shift, day, surge/MCI status, staffing level, major infrastructure disruption, and relevant seasonal factors.

References

- [1] World Health Organization. WHO Emergency Care System Framework. Geneva: World Health Organization; 2018. <https://www.who.int/publications/i/item/who-emergency-care-system-framework>
- [2] World Health Organization. Emergency Care Toolkit. Geneva: World Health Organization. <https://www.who.int/teams/integrated-health-services/clinical-services-and-systems/emergency--critical-and-operative-care/essential-resources-for-emergency--critical-and-operative-care>
- [3] World Health Organization. Interagency Integrated Triage Tool. Geneva: World Health Organization. <https://www.who.int/tools/triage>
- [4] Obermeyer Z, Abujaber S, Makar M, Stoll S, Kayden SR, Wallis LA, Reynolds TA; Acute Care Development Consortium. Emergency care in 59 low- and middle-income countries: a systematic review. *Bull World Health Organ*. 2015; 93(8): 577-586. <https://doi.org/10.2471/BLT.14.148338>
- [5] Jenson A, Hansoti B, Rothman R, de Ramirez SS, Lobner K, Wallis L. Reliability and validity of emergency department triage tools in low- and middle-income countries: a systematic review. *Eur J Emerg Med*. 2018; 25(3): 154-160. <https://doi.org/10.1097/MEJ.0000000000000445>
- [6] Mitchell R, Fang W, Tee QW, O'Reilly G, Romero L, Mitchell R, Bornstein S, Cameron P. Systematic review: What is the impact of triage implementation on clinical outcomes and process measures in low- and middle-income country emergency departments? *Acad Emerg Med*. 2024; 31(2): 164-182. <https://doi.org/10.1111/acem.14815>
- [7] Tom   E, Ulica E, Alves C, Pascoal C, Jeremias A, Escoval A, Antunes ML. Effectiveness of early warning scores in predicting in-hospital mortality and adverse events in adult general ward patients in low- and middle-income countries: a systematic review. *Afr J Emerg Med*. 2026; 16(1): 100943. <https://doi.org/10.1016/j.afjem.2026.100943>
- [8] Bhattarai HK, Bhusal S, Barone-Adesi F, Hubloue I. Prehospital Emergency Care in Low- and Middle-Income Countries: A Systematic Review. *Prehosp Disaster Med*. 2023; 38(4): 495-512. <https://doi.org/10.1017/S1049023X23006088>
- [9] World Health Organization. Yemen: WHO Health Emergency Appeal 2026. Geneva: World Health Organization; 2026. <https://www.who.int/publications/m/item/yemen--who-health-emergency-appeal-2026>
- [10] World Health Organization, International Committee of the Red Cross. Basic Emergency Care: Approach to the Acutely Ill and Injured. Geneva: World Health Organization; 2018. <https://www.who.int/publications/i/item/9789241513081>
- [11] Zachariasse JM, van der Hagen V, Seiger N, Mackway-Jones K, van Veen M, Moll HA. Performance of triage systems in emergency care: a systematic review and meta-analysis. *BMJ Open*. 2019; 9: e026471. <https://doi.org/10.1136/bmjopen-2018-026471>
- [12] World Health Organization. EQUIP: establishing clinical quality improvement programmes. Geneva: World Health Organization. Available from: <https://www.who.int/teams/integrated-health-services/clinical-services-and-systems/clinical-quality-improvement>.
- [13] World Health Organization. Standardized Clinical Forms. Geneva: World Health Organization. Available from: <https://www.who.int/tools/standardized-clinical-forms>
- [14] World Health Organization. Essential resources for emergency, critical and operative care. Geneva: World Health Organization. Available from: <https://www.who.int/teams/integrated-health-services/clinical-services-and-systems/emergency--critical-and-operative-care/essential-resources-for-emergency--critical-and-operative-care>

Biography



Khalil Gamil Hasan Mohammed Al-Sarem is a Yemeni medical doctor (MBBS) and now pediatrician Arabic board trainer at alsabeen hospital with general-practice and acute-care experience and clinical exposure across emergency medicine, internal medicine, pediatrics, surgery, obstetrics and gynecology, and community medicine. His professional interests include acute and pediatric care, clinical education, emergency-care systems, patient safety, clinical decision support, and practical health-system research for resource-constrained settings.