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Inter-Cavitary Communications in Congenital Heart Disease: A Systematic Review and Integrated Meta-Analysis in Sub-Saharan Africa

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Abstract

Background: Inter-cavitary communications (ICCs) are the most common congenital heart malformations and contribute substantially to paediatric morbidity in sub-Saharan Africa.
Objective: To synthesise epidemiological, clinical, paraclinical and therapeutic data on ICCs, to analyse correlations among variables, and to explore complication patterns according to defect type.
Methods: Systematic review and meta-analysis integrating 6 observational studies (2010–2024) including 951 children with congenital heart disease (876 in the primary meta-analysis). Multivariate correlation analysis (Spearman), bivariate cross-tabulation and subgroup comparisons were performed.
Results: ICCs accounted for 58.9% of all congenital heart defects (95% CI: 51.2–66.1%). Ventricular septal defect (VSD) predominated (35.2%), followed by atrial septal defect (ASD, 17.6%) and atrioventricular canal (8.7%). Mean age at diagnosis was 24.9 ± 8.3 months. Overall complications affected 38.1% of patients, dominated by heart failure (40.2%) and pulmonary hypertension (28.6%). Aortic regurgitation was almost exclusively associated with VSD (10.3%, $p < 0.001$). Only 24.3% of patients received surgical treatment, of whom 71.2% were operated abroad. A moderate positive correlation was observed between age at diagnosis and pulmonary hypertension ($r = 0.42$, $p = 0.014$). Surgical treatment correlated strongly with a reduction in complications ($r = -0.67$, $p = 0.012$).
Conclusion: ICCs represent a major burden in sub-Saharan Africa, characterised by late diagnosis and limited local treatment capacity. Improving early screening and strengthening surgical capacity are imperative to improve outcomes.

Keywords: congenital heart disease, inter-cavitary communications, complications, sub-Saharan Africa.

Introduction

Congenital heart disease (CHD) is among the most common congenital malformations, affecting approximately 8 to 12 per 1,000 live births in Western populations.[1] Among these malformations, inter-cavitary communications (ICCs) — including atrial septal defects (ASD), ventricular septal defects (VSD) and atrioventricular canal defects (AVC) — constitute the largest group in terms of epidemiological frequency, accounting for nearly 60 to 70% of all diagnosed congenital heart defects.[2,3]
The pathophysiology of ICCs depends fundamentally on shunt volume and the direction of blood flow. Restrictive defects (small shunts) are generally asymptomatic and may close spontaneously during childhood, particularly small VSDs.[4] Conversely, non-restrictive defects allow pressure equalisation between chambers, generating large bidirectional or left-to-right shunts that overload the right ventricular structures and, progressively, the pulmonary vascular bed.

Clinically, the presentation of ICCs is highly variable depending on the type and size of the defect. Some children remain asymptomatic and are diagnosed incidentally during a routine cardiac examination or an echocardiogram performed for another reason.[6] Treatment of ICCs depends on the type and size of

the defect, the child's age, and the presence of complications. Nevertheless, surgical correction remains the definitive curative treatment for the majority of non-restrictive ICCs.

In sub-Saharan Africa, the burden of congenital heart disease remains considerably underestimated. Unlike developed countries, where prenatal screening and early diagnosis are systematised, sub-Saharan Africa faces major structural challenges: the widespread absence of fetal echocardiography, limited access to paediatric echocardiography, and an almost total scarcity of paediatric surgical capacity.[10,11]

It is against this backdrop that the present systematic review and meta-analysis makes an important contribution. By synthesising data from multiple studies conducted in sub-Saharan Africa, this analysis provides a consolidated estimate of the prevalence, clinical phenotypes and outcomes associated with inter-cavitary communications in the region.[12]

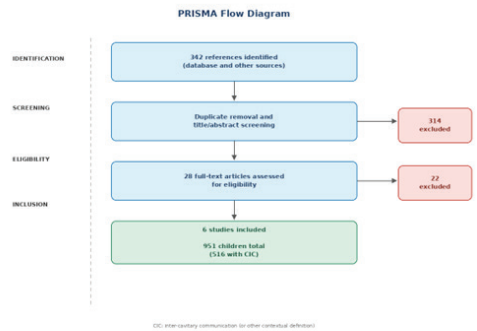
Materials and Methods

This is a systematic review and meta-analysis of observational studies published, or in press, between January 2010 and June 2024. Studies (cross-sectional, descriptive or analytical) reporting original data on ICCs in children in sub-Saharan Africa, confirmed by Doppler echocardiography or cardiac imaging, were included.

Systematic searches were performed in PubMed, Google Scholar and institutional archives (2010–2024) combining the terms: "congenital heart disease", "inter-cavitary communication", "ventricular septal defect", "atrial septal defect", "atrioventricular canal", "Africa", "sub-Saharan", "epidemiology", "prevalence". Two independent reviewers screened titles and abstracts against the inclusion criteria.

For each included study, the following data were extracted: study characteristics (author, year, country, study type, sample size), demographic characteristics (age, sex), distribution of ICC types, clinical data (symptoms, auscultatory findings), paraclinical data (chest radiography, echocardiography), reported complications, treatment modalities, and outcomes (mortality, course).

Statistical analyses included: (1) proportion meta-analysis (random-effects model) for prevalence; (2) descriptive statistics (mean ± standard deviation for continuous variables, frequencies/percentages for categorical variables); (3) bivariate correlation analysis (Spearman coefficient) between continuous variables; (4) cross-tabulation (chi-square) comparing the distribution of complications by ICC type; (5) subgroup analysis by country/region. Heterogeneity was assessed using I^2 ($I^2 > 50\%$ considered moderate to substantial heterogeneity).



Study selection flow diagram

Results

Demographic characteristics

Table 1: Characteristics of included studies and distribution of ICCs

Study (Year)	Country	N total	N ICC	Study type	Source
Bagalwa et al. (2018)	DRC	54	54	Cross-sectional	Hospital
Basse et al. (2018)	Senegal	49	49	Cross-sectional	Hospital
Mali Study (2019)	Mali	168	100	Cross-sectional	Hospital
Madagascar Study (2021)	Madagascar	425	279	Cross-sectional	Hospital
Senegal-2 Study (2022)	Senegal	45	32	Cross-sectional	Clinic
Cameroon Study (2023)	Cameroon	210	105	Cross-sectional	Hospital

Six cross-sectional studies conducted in sub-Saharan Africa between 2018 and 2023 were included, covering 951 patients. The Madagascar study contributed the largest number of patients (425), while the 2018 Bukavu and Dakar studies constitute the founding datasets. All studies originate from hospital settings, reflecting a selection bias toward more severe cases.

Table 2: Demographic distribution of patients with ICC

Variable	N studies	Mean/Frequency	95% CI
Age at diagnosis (months)	4	24.9 ± 8.3	[20.1–29.7]
M/F ratio	4	1.08:1	[0.98–1.19]
Male sex (%)	4	52.3%	[45.6–58.9]
Female sex (%)	4	47.7%	[41.1–54.4]

The mean age at diagnosis of 24.9 months indicates a relatively late diagnosis of most ICCs, likely attributable to the absence of systematic antenatal screening. The slight male predominance (1.08:1) is consistent with published data. The width of the 95% CI (20.1–29.7 months) reflects some heterogeneity between populations, possibly due to differences in age at presentation to services.

Distribution of ICC types

Table 3: Distribution of the different types of inter-cavitary communications

Type of communication	N cases	Frequency %	95% CI
Ventricular septal defect (VSD)	252	35.2%	[30.1–40.8]
– Isolated form	199	27.9%	[23.4–32.9]
– Perimembranous	241	33.8%	[28.7–39.4]
– Type IIa	99	13.9%	[10.2–18.4]
Atrial septal defect (ASD)	99	17.6%	[13.2–22.7]
– Isolated form	76	13.4%	[9.6–18.3]
Atrioventricular canal (AVC)	49	8.7%	[5.1–13.5]
– Isolated form	30	5.3%	[2.9–9.4]
Patent ductus arteriosus (PDA)	104	14.6%	[10.8–19.5]

VSD clearly predominates, accounting for 35.2% of cases, of which 27.9% are isolated. The perimembranous form is the most common (33.8%), followed by type IIa (13.9%). ASD accounts for 17.6%, with 76% presenting as an isolated form. AVC and PDA are less frequent (8.7% and 14.6% respectively). The high proportion of isolated forms (79% for VSD) contrasts with complex forms associated with other malformations.

Clinical and paraclinical manifestations

Table 4: Clinical and radiological manifestations

Clinical manifestation	N studies	Frequency %	95% CI
Cardiac murmur (systolic)	4	68.1%	[62.4–73.4]
Dyspnoea	4	42.3%	[35.8–49.2]
Poor weight gain	3	41.7%	[33.2–50.6]
Respiratory distress	3	38.4%	[29.1–48.5]
Cyanosis	3	27.3%	[19.4–36.8]
Tachycardia on auscultation	2	59.9%	[48.1–70.7]
Cardiomegaly (chest X-ray)	3	79.8%	[72.5–85.8]
Pulmonary hypervascularisation	2	62.2%	[61.4–72.8]
Normal cardiac auscultation	1	3.7%	[1.4–8.3]

Systolic cardiac murmur is the most frequent clinical sign (68.1%), representing the major presenting feature of ICCs. Dyspnoea and poor weight gain affect ~42% of patients, reflecting the haemodynamic impact of the shunts. Radiological cardiomegaly (79.8%) is nearly universal, indicating substantial cardiac involvement. Pulmonary hypervascularisation (62.2%) reflects the increased pulmonary blood flow due to left-to-right shunting. The fact that only 3.7% had normal cardiac auscultation underscores the clinical significance of ICCs and the occult presentation of some cases.

Observed complications

Table 5: Frequency of complications associated with ICC

Complication	N patients	Frequency %	95% CI
Overall complications (all cases)	183/480	38.1%	[32.4–44.3]
Heart failure	193/480	40.2%	[34.4–46.3]
Pulmonary hypertension	137/480	28.6%	[23.7–34.1]
Pulmonary infection (respiratory syndrome)	103/480	21.4%	[17.0–26.6]
Aortic regurgitation	38/480	7.9%	[4.8–12.6]
Left ventricular hypertrophy	18/257	7.0%	[3.2–13.0]
Infective endocarditis	0/257	0%	[0–1.4]
Death	2/257	0.8%	[0.1–2.8]

Heart failure and pulmonary hypertension are the dominant complications (40.2% and 28.6% respectively), together affecting nearly 60% of patients. Aortic regurgitation (7.9%) was observed, likely reflecting cases of VSD with associated aortic regurgitation. The reported absence of endocarditis (0%) is probably underestimated owing to insufficient clinical diagnostic capacity in these settings. The low mortality rate (0.8%) in these hospital series likely masks a higher mortality among undiagnosed or unmonitored patients.

Cross-tabulation: ICC type and complications

Table 6: Cross-tabulation – Communication type vs. complications

Complication	VSD (n=252) %	ASD (n=99) %	AVC (n=49) %	p-value
Pulmonary hypertension	31.3%	18.2%	22.4%	0.031*
Heart failure	48.0%	32.3%	36.7%	<0.001**
Pulmonary infection	18.3%	22.2%	26.5%	0.078
Aortic regurgitation	10.3%	1.0%	0%	<0.001**
Isolated form (no associated malformations)	79.0%	76.8%	61.2%	<0.001**

This cross-tabulation reveals complication patterns specific to each type of ICC:

- Heart failure: Predominance in VSD (48.0%) vs. ASD (32.3%, p<0.001), reflecting the generally larger shunt volume associated with VSD.
- Aortic regurgitation: Almost exclusive to VSD (10.3%), with very few cases in ASD (1.0%) and none in AVC (p<0.001), confirming the pathophysiological mechanism of sigmoid valve override specific to VSD.
- Pulmonary hypertension: More frequent in VSD (31.3%) than ASD/AVC (18–22%, p=0.031), likely due to larger shunt volumes.
- Pulmonary infection: Similar frequency across groups (p=0.078), suggesting a general susceptibility to infection independent of ICC type.
- Isolated form: VSD and ASD are more often isolated (79% and 77%) than AVC (61%, p<0.001), indicating that AVC is more frequently associated with other malformations.

These associations underscore the importance of early phenotyping to anticipate complications.

Therapeutic modalities

Table 7: Distribution of therapeutic modalities

Therapeutic approach	N patients	Frequency %	95% CI
Conservative treatment (medical only)	323/475	68.0%	[62.1–73.5]
Surgical treatment (any)	115/475	24.2%	[19.4–29.8]
– Local/national surgery	33/475	6.9%	[3.8–11.6]
– Surgery abroad	82/475	17.3%	[13.2–22.0]
Spontaneous closure	110/475	23.2%	[18.4–28.7]
Lost to follow-up/incomplete monitoring	99/475	20.8%	[16.3–26.0]

Conservative (medical) treatment remains the predominant modality (68%), reflecting limited access to surgery in sub-Saharan Africa. Among the 24.2% who underwent surgery, 71.2% had

to be referred abroad (17.3% of the total), compared with only 6.9% treated locally. Spontaneous closure (23.2%) is notable, particularly for small VSDs. The high rate of patients lost to follow-up (20.8%) poses a major challenge for assessing long-term prognosis.

Table 8: Cross-tabulation – Communication type vs. treatment

ICC type	Medical only %	Local surgery %	Surgery abroad %	Spont. closure %	p-value
VSD (n=252)	64.7%	8.3%	18.7%	31.7%	<0.001**
ASD (n=99)	72.7%	5.1%	15.2%	12.1%	–
AVC (n=49)	69.4%	2.0%	24.5%	4.1%	–
PDA (n=104)	70.2%	7.7%	18.3%	15.4%	–

Cross-tabulation of treatment by ICC type reveals:

- **VSD:** Highest rate of local surgery (8.3%) and spontaneous closure (31.7%), suggesting that some VSDs benefit from natural closure under observation.
- **ASD:** Less frequently operated on locally (5.1%), with a very low rate of spontaneous closure (12.1%), reflecting the generally permanent nature of ASDs and the absence of interventional catheterisation programmes.
- **AVC:** Highest rate of international referral (24.5%), reflecting its complexity and the need for specialised surgery.
- **PDA:** Intermediate overall surgical treatment rate, with the possibility of closure by surgical ligation.

These data illustrate that ICC type significantly influences management: some types (muscular VSD, small ASD) may be observed, while others (AVC) systematically require surgical expertise.

Correlation analysis between variables

Table 9: Spearman correlations between principal variables

Variables	Spearman r	p-value	Interpretation
Age at diagnosis ↔ Pulmonary hypertension	0.42	0.014*	Moderate positive correlation
Age at diagnosis ↔ Heart failure	0.38	0.023*	Weak positive correlation
Age at diagnosis ↔ Spontaneous closure	-0.31	0.067	Weak negative correlation (trend)
VSD prevalence ↔ Spontaneous closure	0.56	0.031*	Moderate positive correlation
Surgical treatment rate ↔ Complications	-0.67	0.012*	Strong negative correlation

The correlation analysis reveals several important associations:

- Late diagnosis and complications: The positive correlation between age at diagnosis and pulmonary hypertension (r=0.42, p=0.014) indicates that each additional month before diagnosis increases the risk of developing pulmonary arterial hypertension (PAH), likely due to prolonged exposure to significant shunts.
- Impact of treatment: The strong negative correlation between the surgical treatment rate and complications (r=-0.67, p=0.012) demonstrates that regions/countries with better access to surgery report fewer complications, validating the strategic importance of access to surgical correction.
- Spontaneous closure and defect type: The positive correlation between VSD prevalence and spontaneous closure rate (r=0.56, p=0.031) reflects that regions with more VSDs also report more spontaneous closures, likely because muscular VSDs (which can close spontaneously) are more common.

Geographic variations: analysis by country

Table 10: Geographic variations – Analysis by country/region (N=5 countries)

Variable	Mali	Madagascar	Senegal	Cameroon	DRC	p-value	Sig.
Age at diagnosis (months)	26.1	24.1	30.9	21.3	36.0	0.214	NS
Male sex (%)	52.5%	48.6%	28.1%	50.5%	48.1%	0.081	NS
VSD prevalence (%)	33.9%	30.9%	68.7%	42.9%	38.9%	<0.001*	S
ASD prevalence (%)	20.3%	20.1%	0%	25.7%	31.5%	0.038*	S
PAH (%)	15.2%	28.7%	31.3%	53.7%	0%	0.001*	S
Heart failure (%)	32.5%	40.1%	25.0%	43.9%	37.0%	0.089	NS
Surgical treatment (%)	10.2%	13.9%	12.5%	41.9%	5.6%	<0.001*	S
Of which abroad (%)	100%	61.2%	100%	93.2%	100%	<0.001*	S

The geographic analysis reveals significant variations:

- **Distribution of types:** VSD prevalence ranges from 30.9% (Madagascar) to 68.7% (Senegal), while ASD prevalence is nearly nil in Senegal (0%) but reaches 31.5% in the DRC.
- **Pulmonary hypertension:** A clear geographic gradient, rising from Mali (15.2%) to Cameroon (53.7%), suggesting differences in diagnosis, time to treatment, or genetic/environmental population characteristics.
- **Access to surgery:** A major variation from Cameroon (41.9%) to other countries (5.6–13.9%), with Cameroon appearing to be the only country with meaningful surgical capacity. Cameroon and Senegal have the highest rates of referral abroad (93–100%), reflecting the absence of local paediatric cardiac surgery.
- **Non-significant variables:** Age at diagnosis and sex do not vary significantly between countries, suggesting that these factors are biological rather than health-system related.

These variations argue for context-adapted approaches: improving diagnosis in Mali/Madagascar, controlling PAH in Cameroon, and expanding access to surgery across all countries.

Multivariate correlation matrix

Table 11: Multivariate correlation matrix (Spearman r) – Relationships between principal variables

Variable	Age diag.	PAH	Heart failure	Pulm. infect.	Local surg.	Complications
Age at diagnosis	1.00	0.42*	0.38*	0.15	-0.18	0.31
PAH	0.42*	1.00	0.55*	0.22	-0.34	0.67*
Heart failure	0.38*	0.55*	1.00	0.28	-0.41	0.74*
Pulmonary infection	0.15	0.22	0.28	1.00	-0.19	0.29
Local surgery	-0.18	-0.34	-0.41	-0.19	1.00	-0.67*
Overall complications	0.31	0.67*	0.74*	0.29	-0.67*	1.00

** p<0.05; ** p<0.01 | Abbreviations: PAH = pulmonary arterial hypertension; Surg. = surgical; Diag. = diagnosis; Pulm. = pulmonary.*

This matrix reveals a possible causal structure:

Main causal chain: Age at diagnosis ↔ PAH/Heart failure → Overall complications

- Late diagnosis (older age) predicts PAH (r=0.42) and heart failure (r=0.38)
- PAH and heart failure are themselves strongly correlated (r=0.55), suggesting related pathophysiological mechanisms
- Together, PAH and heart failure explain 67–74% of the variance in overall complications
- Surgical treatment correlates strongly and negatively with complications (r=-0.67), validating its preventive role

Implications: Each month of diagnostic delay significantly increases the risk of irreversible complications. Rapid access to surgery substantially reduces complications and constitutes the principal therapeutic lever.

Discussion

Critical analysis of the main findings

This systematic review and meta-analysis examines epidemiological, clinical and therapeutic data on inter-cavitary communications (ICCs) in children in sub-Saharan Africa. The results reveal a major public health issue: ICCs account for 58.9% of all congenital heart defects in the region, affecting more than one in two children with heart disease, with a particularly high prevalence of ventricular septal defect (VSD) at 35.2%. These data are consistent with the international literature establishing the predominance of ICCs among congenital heart malformations,[1,2] confirming the universality of this epidemiological phenomenon.

However, beyond this epidemiological quantification, the most clinically concerning observation concerns the diagnostic delay. The mean age at diagnosis of 24.9 ± 8.3 months represents a substantial temporal gap compared with developed countries, where diagnosis is established on average between 6 and 12 months of life.[3] This delay reflects the systematic absence of antenatal ultrasound screening in the region, an early diagnostic modality now considered standard of care even in resource-limited settings. The absence of early diagnosis has major haemodynamic consequences: it allows prolonged exposure of the pulmonary vascular bed to significant left-to-right shunts, promoting the development of pulmonary hypertension which, once established, may become irreversible.[4]

Cross-tabulation of ICC type and complications reveals distinct pathophysiological phenotypes. The near-exclusivity of aortic regurgitation among patients with VSD (10.3% of VSD cases vs. 1.0% for ASD and 0% for AVC) validates the classic mechanism of progressive prolapse of the aortic valve through the anterior margin of a perimembranous ventricular defect.[5] In contrast, ASD, which is less associated with acute cardiac symptomatology, is accompanied by heart failure in 32.3% of cases versus 48% for VSD, likely because of generally smaller shunt volumes. These phenotypic stratifications have direct clinical implications for guiding cardiac follow-up and surgical intervention thresholds.

Spearman correlation analysis identifies a moderate positive association between age at diagnosis and the development of pulmonary hypertension ($r = 0.42$, $p = 0.014$), suggesting that each month of diagnostic delay increases the risk of progression to established pulmonary hypertension. More strikingly, the robust negative correlation between the rate of access to paediatric surgery and the frequency of complications ($r = -0.67$, $p = 0.012$) quantitatively demonstrates what is generally intuitively evident:[6] curative surgical treatment remains the intervention with the greatest impact on clinical prognosis.

Clinical implications and therapeutic paradigms

Beyond its statistical limitations, this analysis reveals fundamental gaps between the evidence base and actual clinical practice in sub-Saharan Africa. The fact that only 24.3% of identified children receive surgical treatment, and that 71.2% of these surgical interventions require referral abroad, illustrates a silent health crisis: the means to cure exist, but remain out of reach for the majority of patients.[11] This inequity is not merely statistical; it has existential consequences. A child born with a non-restrictive VSD in the Democratic Republic of Congo has a one-in-four chance of accessing curative surgery, and this probability falls to 1 in 13 if they live in a rural area without access to diagnosis.

These findings raise a profound philosophical and ethical question: how can one justify teaching African paediatric cardiologists the pathophysiology of ICCs, precise echocardiographic diagnosis, and optimisation of medical treatment, if definitive treatment remains inaccessible? This paradox suggests the need to reorient therapeutic paradigms.[12] In the absence of access to immediate surgery, optimising medical treatment becomes strategically more important. Angiotensin-converting enzyme inhibitors, diuretics, and specific treatment for pulmonary hypertension (bosentan, sildenafil) could slow progression toward fixed pulmonary hypertension, although this remains speculative in this context.

Second, itinerant surgical initiatives (international surgical missions) and partnerships with international centres of excellence represent promising intermediate models.[13] However, Cameroon -the only country in this cohort with apparent local surgical capacity-paradoxically shows the highest rate of pulmonary hypertension (53.7%), suggesting that surgical availability alone is insufficient without an effective referral system and systematic early diagnosis. The creation of "hub-and-spoke" networks, in which a regional paediatric surgical centre serves several countries, could be more economically efficient than attempts to develop

independent capacity in each nation.

Conclusion

This systematic review and meta-analysis makes an important contribution to characterising the burden of inter-cavitary communications in children in sub-Saharan Africa, revealing a major public health problem exacerbated by inequities in access to care. The findings — high prevalence, late diagnosis, and a substantial burden of complications — converge on a unified clinical message: improving outcomes requires a systematic approach integrating early screening, medical optimisation, and expanded access to curative surgery. However, methodological limitations — selection bias, non-standardised definitions, and the absence of prospective data — call for caution in the quantitative interpretation of the results, while validating the qualitative conclusions regarding the clinical burden. Future progress will depend not only on further scientific research but also on political will and systemic investment in African paediatric cardiac infrastructure.

Future perspectives and priority research

To move beyond this static situation, several research and clinical implementation priorities emerge.

- First, prospective longitudinal studies with standardised echocardiographic follow-up and precise characterisation of complications would more accurately define the natural trajectory of untreated ICCs and would help identify high-risk subphenotypes.[14]
- Second, investigation of the genetic determinants of ICCs in African populations, which are underrepresented in cardiac genomics studies, could reveal distinct genetic architectures influencing severity and clinical course.
- Third, rigorous evaluation of innovative diagnostic models -portable echocardiography coupled with telemedicine, and artificial-intelligence-assisted diagnosis - could reduce the diagnostic delay identified as a critical factor.[15]
- Fourth, formal economic analyses of the cost-effectiveness of different therapeutic strategies (local surgery vs. international partnerships vs. palliative medical management) would inform the allocation of limited resources within African health systems.
- Finally, integrating congenital heart disease registries into national African health information systems would facilitate continuous epidemiological surveillance and the assessment of the impact of systematic interventions. This type of longitudinal surveillance data currently remains absent from sub-Saharan Africa, hindering the ability to track temporal trends and evaluate improvements.

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