



e-ISSN: 2986-9838

Sriwijaya Journal of Obstetrics and Gynecology (SJOG)

Journal website: <https://phlox.or.id/index.php/sjog>

Efficacy of a Specialist Tele-Mentoring Triage System on Severe Maternal Morbidity and Mortality in High-Risk Pregnancies: A Stepped-Wedge Cluster Randomized Trial

Muhammad Yoshandi^{1*}, Rheina Weisch Fedre², Desiree Montesinos³

¹Department of Health Sciences, Tembilahan Community Health Center, Tembilahan, Indonesia

²Department of Public Health, CMHC Research Center, Palembang, Indonesia

³Department of Women and Child Welfare, Lira State Hospital, Lira, Uganda

ARTICLE INFO

Keywords:

Maternal mortality
High-risk pregnancy
Severe maternal morbidity
Telemedicine
Triage

*Corresponding author:

Muhammad Yoshandi

E-mail address:

Muh.yoshandi@phlox.or.id

All authors have reviewed and approved the final version of the manuscript.

<https://doi.org/10.59345/sjog.v3i2.280>

ABSTRACT

Introduction: Maternal deaths in low- and middle-income settings are driven largely by delays in recognising and treating obstetric emergencies at the primary-care frontline. Real-time specialist tele-mentoring may compress these delays, yet trial evidence on hard maternal and neonatal endpoints remains scarce in Indonesia. We evaluated whether a specialist tele-mentoring triage system reduces severe maternal morbidity and mortality in high-risk pregnancies.

Methods: In a closed-cohort stepped-wedge cluster randomized trial, ten primary-to-referral facility clusters across two Indonesian metropolitan regions sequentially crossed from conventional referral to a 24/7 tele-mentoring triage system (audiovisual specialist consultation, portable cardiocography/vital-sign telemetry, and a Maternal Early Warning Score [MEWS] algorithm) over six two-month periods. The primary outcome was a composite of maternal death and WHO-defined severe maternal morbidity. Intention-to-treat analysis used generalized linear mixed models adjusting for secular trend and cluster random effect.

Results: Among 1,858 high-risk women, the composite outcome fell from 7.97% (95% CI 6.39–9.88) during control person-time to 4.41% (95% CI 3.27–5.93) during tele-mentoring (adjusted OR 0.51, 95% CI 0.36–0.73, $p < 0.001$; absolute risk reduction 3.55%; number-needed-to-treat 28). Door-to-treatment time shortened by 85.6 minutes (Cohen's d 1.77, $p < 0.001$). MEWS discriminated the composite outcome well (AUC 0.84, 95% CI 0.80–0.88). NICU admission (OR 0.66, NNT 19, $p = 0.003$) and 5-minute Apgar < 7 (OR 0.58, $p = 0.002$) also improved.

Conclusion: A specialist tele-mentoring triage system roughly halved the odds of severe maternal morbidity and mortality in high-risk pregnancies and improved neonatal outcomes. Scaling specialist-guided digital triage could meaningfully strengthen obstetric emergency referral in Indonesia.

1. Introduction

Maternal mortality remains a defining marker of health-system inequity. Maternal and perinatal deaths remain heavily concentrated in southern Asia and sub-Saharan Africa, where progress has stalled over the past decade despite expanding facility-based birth.^{1,2} Obstetric haemorrhage, hypertensive disorders and

sepsis remain the leading direct causes, and a large share of these deaths is considered preventable through timely recognition and definitive management.^{2,3} Severe maternal morbidity (SMM), or maternal near-miss, is a more frequent and informative intermediate endpoint that captures life-

threatening complications amenable to systems-level intervention.^{3,4}

The pathways from complication to death are well described by the 'three delays' framework: delay in deciding to seek care, delay in reaching care, and delay in receiving adequate care.⁵ In high-risk pregnancies, the second and third delays dominate, and are frequently propagated by communication failures, indecision at frontline facilities, and fragmented referral logistics.^{2,5} Because obstetric emergencies such as eclampsia, haemorrhagic shock and uterine rupture are time-critical, even modest reductions in the interval from recognition to definitive treatment can translate into substantial survival gains.²

Digital health offers a plausible mechanism to collapse these delays. Systematic reviews of telehealth in obstetrics and gynecology document consistent benefit for access-sensitive outcomes, while flagging limited high-quality evidence for acute triage and hard maternal endpoints.^{6,7} The most directly comparable trial, a stepped-wedge evaluation of a vital-sign early-warning device in low-resource settings, reduced a composite of maternal death, eclampsia and emergency hysterectomy, demonstrating that structured early warning coupled with an escalation pathway can move hard outcomes.⁸ Maternal early warning scores themselves show moderate-to-good discrimination for severe maternal outcomes, with an area under the curve of approximately 0.79 in external validation.⁹

In Indonesia, the maternal burden is compounded by uneven referral capacity and pronounced geographic disparity. National analyses consistently attribute maternal deaths to referral delay, severe anaemia and hypertensive disorders, against a backdrop of persistent socioeconomic and island-to-island inequity in service utilisation.^{5,10} The frontline workforce—general practitioners and midwives—often manages high-risk pregnancies without immediate specialist input, precisely where real-time mentoring could alter decisions during the narrow therapeutic window of an obstetric emergency.^{6,10}

Beyond their immediate clinical toll, obstetric emergencies impose cascading consequences for families and health systems: a maternal death or near-

miss event frequently coincides with adverse perinatal outcomes, prolonged neonatal care and long-term economic hardship for surviving households.^{8,11} Interventions that act early in the complication pathway therefore have the potential to generate compounding maternal and neonatal returns, a rationale that underpins the dual maternal–neonatal endpoint structure adopted in this trial.^{11,12}

Despite growing enthusiasm for digital maternal health, limited data exist on real-time, specialist-to-frontline tele-mentoring—as distinct from asynchronous mHealth messaging or device-only alerts—evaluated against hard maternal and neonatal endpoints in Indonesian obstetric populations. Prior studies seldom report joint maternal and neonatal outcomes with full effect sizes (adjusted odds ratios, number-needed-to-treat) or the discriminative performance of the triage tool itself.^{6,13}

Importantly, the marginal value of specialist input is greatest where specialists are physically absent. In decentralised systems, the first clinician to encounter a deteriorating high-risk pregnancy is often a midwife or general practitioner operating without immediate senior support, and the quality of that single early decision can determine the trajectory of the emergency.^{5,6,10} Real-time tele-mentoring is conceptually distinct from store-and-forward telemedicine precisely because it intervenes synchronously at this decision point, converting an isolated frontline judgement into a specialist-supervised one without the delay of physical transfer.⁶

To address this gap, we conducted a pragmatic stepped-wedge cluster randomized trial across a ten-cluster primary-to-referral network in two Indonesian metropolitan regions. We hypothesised that a specialist tele-mentoring triage system, anchored by a MEWS algorithm and portable telemetry, would reduce a composite of maternal mortality and severe maternal morbidity in high-risk pregnancies, shorten door-to-treatment time, and improve neonatal outcomes, relative to conventional referral.

2. Methods

Study design

This pragmatic, closed-cohort stepped-wedge cluster randomized trial (SW-CRT) was conducted and reported in accordance with the CONSORT extension for stepped-wedge cluster trials and STROBE principles for observational components.^{8,12} A stepped-wedge design was selected on ethical grounds: because the tele-mentoring intervention was believed to be beneficial, permanently withholding it from control clusters could not be justified; instead, all clusters began in the control (standard-care) phase and crossed over, randomly and sequentially, to the intervention phase at predefined two-month steps.

Setting and participants

The trial was conducted across ten integrated primary-care facilities and their affiliated district/tertiary referral hospitals in two densely populated metropolitan regions of Indonesia (Region A, Sumatra, five clusters; Region B, Java, five clusters). In keeping with the data-protection protocol, specific institution names and geolocation were blinded. Eligible participants were pregnant women with a gestational age ≥ 20 weeks identified with at least one high-risk factor: chronic hypertension or preeclampsia, prior postpartum haemorrhage, severe anaemia (haemoglobin < 7 g/dL), or maternal cardiac disease. Women without a documented high-risk factor and those declining consent were excluded.

Intervention

Clusters in the intervention phase were activated with an end-to-end encrypted tele-mentoring platform comprising three components: (i) real-time audiovisual consultation providing 24/7 access to an on-call obstetrics and gynecology specialist for direct assessment; (ii) telemetry data sharing, integrating portable cardiotocography and vital-sign monitors wirelessly transmitted to the specialist; and (iii) a structured triage algorithm for referral decisions based on the Maternal Early Warning Score (MEWS), consistent with ACOG-endorsed early-warning criteria.⁹ During the control phase, facilities used the conventional referral system (standard telephone contact and manual paper referral).

Maternal Early Warning Score algorithm

The triage algorithm aggregated systolic and diastolic blood pressure, heart rate, respiratory rate, peripheral oxygen saturation, temperature and level of consciousness into a composite Maternal Early Warning Score, with weighted thresholds consistent with ACOG-endorsed early-warning criteria.⁹ A score of ≥ 5 , or any single red-flag parameter, triggered mandatory specialist tele-consultation and structured escalation. During the control phase, the same physiological parameters were recorded but escalation relied on clinician discretion and conventional referral.

Intervention workflow and training

Before crossover, frontline staff in each cluster completed a standardised training package covering MEWS measurement, platform operation and escalation protocols, followed by simulation drills for the three sentinel emergencies (eclampsia, haemorrhagic shock, uterine rupture). On activation, a red-flag MEWS automatically opened an audiovisual channel to the on-call specialist, who reviewed transmitted cardiotocography and vital-sign telemetry, issued a structured management recommendation, and co-determined whether to stabilise-and-treat locally or to transfer with pre-arrival preparation at the receiving hospital. Every consultation generated a timestamped record used to compute process metrics.

Randomization and masking

The sequence in which the ten clusters crossed to intervention was randomized using computer-generated random numbers by an independent statistician. Given the nature of the intervention, frontline health workers could not be blinded; however, outcome assessors and the statistical analyst were blinded to cluster allocation status.

Cluster definition and contamination

A cluster comprised a primary-care facility together with its designated referral hospital, functioning as a single integrated referral unit. Clusters were geographically separated and served distinct catchment populations, minimising the risk of contamination between control and intervention units. Because the design was closed-cohort, women enrolled in a given cluster were managed under that cluster's

phase status at the time of their emergency, preserving the integrity of the stepped-wedge allocation.

Data collection and management

Trained data collectors, blinded to cluster allocation, abstracted clinical variables onto standardised case-report forms at each facility and at the receiving referral hospital. Maternal and neonatal endpoints were adjudicated against prespecified definitions by an independent committee blinded to phase. Data were double-entered, range-checked and reconciled centrally; discrepancies were resolved against source documents. Timing variables (recognition time, referral time, arrival time and time of definitive treatment) were recorded to the minute to permit calculation of the door-to-definitive-treatment interval.

Outcomes and assessments

The primary outcome was a composite of maternal death and severe maternal morbidity defined by WHO near-miss criteria (e.g., eclampsia, haemorrhagic shock, uterine rupture).^{2,14} Secondary outcomes were the door-to-definitive-treatment interval (minutes) at the referral hospital, adherence to standard operating procedures, and the obstetric-emergency case-fatality rate. Gestational age was established from the last menstrual period and confirmed by ultrasound biometry (Hadlock formula) and is reported in completed weeks. Maternal vital signs (blood pressure by Korotkoff phase V, heart rate, peripheral oxygen saturation, temperature) and obstetric examination informed the MEWS. Diagnoses of hypertensive disorders followed ISSHP/ACOG criteria and anaemia severity followed WHO haemoglobin thresholds.^{9,15} Prespecified neonatal outcomes were birth weight (grams), 1- and 5-minute Apgar scores, neonatal intensive-care-unit (NICU) admission and perinatal mortality.

A priori outcome definitions

All outcomes were defined before data lock. The primary composite required either maternal death (death during pregnancy or within 42 days of termination of pregnancy from any cause related to or aggravated by the pregnancy or its management) or at least one WHO maternal near-miss criterion.^{2,14} Severe maternal morbidity events, low birth weight (< 2,500

g), 5-minute Apgar < 7, NICU admission and perinatal mortality (stillbirth \geq 28 weeks plus early neonatal death) were defined using standard international thresholds to support comparability.^{11,14}

Sample size

Sample-size estimation for the SW-CRT incorporated the design effect accounting for the intracluster correlation coefficient (ICC).¹² Assuming a baseline composite prevalence of 8% during control, an absolute reduction of 3.5% after intervention, two-sided $\alpha = 0.05$, power = 80%, ten clusters, six time periods and an ICC of 0.05, a minimum of 1,850 participants was required (\approx 31 women per cluster per period). The achieved enrolment was 1,858.

Statistical analysis

Analyses followed the intention-to-treat principle. The primary outcome was modelled with a generalized linear mixed model (GLMM) using a logistic link, including the intervention indicator, a fixed categorical time effect to control secular trends, and a random intercept for cluster to accommodate the ICC.⁸ Distributional assumptions for continuous variables were checked with the Shapiro-Wilk test. Prevalence estimates are presented with Wilson 95% confidence intervals; bivariate associations with odds ratios (OR), relative risks (RR), 95% CIs and Cramér's V. A multivariable model yielded adjusted ORs with Nagelkerke R^2 and the Hosmer-Lemeshow goodness-of-fit test. The discriminative performance of MEWS for the composite outcome was assessed by the area under the receiver-operating-characteristic curve (AUC) with the Youden-optimal cutoff, sensitivity and specificity. Number-needed-to-treat (NNT) was derived for key binary outcomes, and Cohen's d for continuous contrasts. Analyses used R (lme4) with cross-validation in Python (statsmodels); $\alpha = 0.05$.

Reflecting current reporting standards, the trial was prospectively registered and conducted under a predefined statistical analysis plan; the unit of observation was the individual pregnancy episode nested within cluster, modelled with a cluster random intercept and, in sensitivity analyses, an additional random cluster-by-time term. All secondary and neonatal outcomes were analysed within the same generalized linear mixed-model framework to account

for within-facility clustering. Because the composite outcome was not rare, adjusted relative risks and risk differences were obtained by marginal standardisation from the fitted model in addition to odds ratios, and model-based numbers-needed-to-treat were derived from the adjusted risk difference. Secular trend was modelled both as a categorical period term and, in sensitivity analysis, as a continuous spline; the MEWS area under the curve was internally validated by bootstrap optimism correction. Secondary outcomes were interpreted within a hierarchical gatekeeping framework subordinate to the primary outcome.

Sensitivity and subgroup analyses

Prespecified sensitivity analyses included refitting the GLMM with a random cluster-by-time interaction to relax the assumption of a constant treatment effect over time, and a complete-case versus multiple-imputation comparison for variables with missing data (< 4% for all key fields). Prespecified subgroups comprised risk stratum (hypertensive, prior-haemorrhage, severe-anaemia), region, parity and distance tertile; subgroup effects were interpreted cautiously as hypothesis-generating, with interaction tests rather than separate significance claims. To limit type-I error inflation across multiple secondary outcomes, secondary contrasts were interpreted within a hierarchical testing framework subordinate to the primary outcome, and exact p-values are reported throughout to permit reader-level adjustment.

Patient and public involvement

Community representatives and frontline midwives were consulted during protocol refinement to ensure that escalation pathways were acceptable and feasible within local practice, and that consent procedures were culturally appropriate. Participants were not involved in outcome adjudication or analysis.

Ethics

This study received ethical approval from the CMHC Ethics Committee, Indonesia (Approval No. CMHC/EC/2024/0417). The trial was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants,

and cluster-level governance approvals were secured; identifying institutional and geolocation data were withheld to protect facility and participant confidentiality.

3. Results

A total of 1,858 high-risk pregnant women were enrolled across the ten clusters (Region A, n = 920; Region B, n = 938) and contributed outcomes across the six trial periods, partitioned into balanced control (n = 929) and tele-mentoring (n = 929) person-time. Baseline characteristics were comparable between regions, with no significant difference in maternal age (29.8 ± 5.0 years), gestational age (31.9 ± 4.5 weeks), parity distribution (primigravida 38.1%) or body mass index (27.0 ± 4.0 kg/m²); the only significant baseline difference was the distance to the referral centre (15.4 ± 8.1 vs 12.2 ± 6.3 km, $p < 0.001$), which was carried forward as a covariate, as detailed in Table 1.

Cluster recruitment and crossover proceeded as scheduled across the six two-month periods, with all ten clusters contributing data in every period and no cluster lost to follow-up, preserving the closed-cohort structure. Enrolment per cluster per period was close to the planned 31 participants, and the achieved total of 1,858 exceeded the calculated minimum of 1,850. Missing data were infrequent (< 4% for all key variables), and complete-case and multiple-imputation analyses yielded materially identical estimates.

For the primary outcome, the composite of maternal death and severe maternal morbidity occurred in 74 of 929 women (7.97%, 95% CI 6.39–9.88) during control person-time versus 41 of 929 (4.41%, 95% CI 3.27–5.93) during tele-mentoring, an unadjusted OR of 0.53 (95% CI 0.36–0.79, $p = 0.002$) corresponding to an absolute risk reduction of 3.55% and an NNT of 28, as summarised in Table 2 and depicted in Figure 1A. WHO-defined severe maternal morbidity fell from 7.00% to 4.09% (OR 0.57, 95% CI 0.38–0.86, $p = 0.006$), and maternal deaths from 0.97% to 0.32% (OR 0.33, 95% CI 0.09–1.23, $p = 0.082$). The obstetric-emergency case-fatality rate decreased from 6.2% to 2.1% (OR 0.33, 95% CI 0.16–0.66, $p = 0.002$).

Table 1. Baseline maternal characteristics by region (region-level only; institutions blinded).

Baseline characteristic	Region A (n=920)	Region B (n=938)	Total (n=1,858)	p-value
Maternal age (years), mean ± SD	29.4 ± 5.2	30.1 ± 4.8	29.8 ± 5.0	0.124
Maternal age ≥35 years, n (%)	166 (18.0)	181 (19.3)	347 (18.7)	0.470
Gestational age (weeks), mean ± SD	32.1 ± 4.4	31.8 ± 4.6	31.9 ± 4.5	0.251
Primigravida, n (%)	345 (37.5)	362 (38.6)	707 (38.1)	0.610
Multigravida, n (%)	575 (62.5)	576 (61.4)	1,151 (61.9)	0.610
Body mass index (kg/m ²), mean ± SD	26.8 ± 4.1	27.2 ± 3.9	27.0 ± 4.0	0.330
High-risk factor — n (%)				
Chronic hypertension / preeclampsia	412 (44.8)	425 (45.3)	837 (45.0)	0.776
Prior postpartum haemorrhage	185 (20.1)	179 (19.1)	364 (19.6)	0.450
Severe anaemia (Hb < 7 g/dL)	201 (21.8)	215 (22.9)	416 (22.4)	0.602
Other comorbidity (DM, cardiac)	122 (13.3)	119 (12.7)	241 (13.0)	0.821
Distance to referral centre (km), mean ± SD	15.4 ± 8.1	12.2 ± 6.3	13.8 ± 7.4	<0.001*

Table 2. Clinical parameters and bivariate analysis (control vs tele-mentoring person-time).

Parameter / outcome	Control phase (n=929)	Tele-mentoring phase (n=929)	OR / RR (95% CI)	p-value	Cramér's V
Composite SMM + mortality, n (%)	74 (7.97)	41 (4.41)	OR 0.53 (0.36–0.79)	0.002	0.073
WHO severe maternal morbidity, n (%)	65 (7.00)	38 (4.09)	OR 0.57 (0.38–0.86)	0.006	0.062
Maternal death, n (%)	9 (0.97)	3 (0.32)	OR 0.33 (0.09–1.23)	0.082	0.034
Obstetric-emergency case-fatality, %	6.2	2.1	OR 0.33 (0.16–0.66)	0.002	0.071
Door-to-treatment time (min), mean ± SD	182.4 ± 54.1	96.8 ± 41.3	Δ -85.6 (Cohen's d 1.77)	<0.001	—
SOP adherence, n (%)	597 (64.2)	826 (88.9)	OR 4.46 (3.27–6.08)	<0.001	0.286
MEWS ≥5 at recognition, n (%)	318 (34.2)	333 (35.8)	OR 1.07 (0.89–1.30)	0.470	0.016

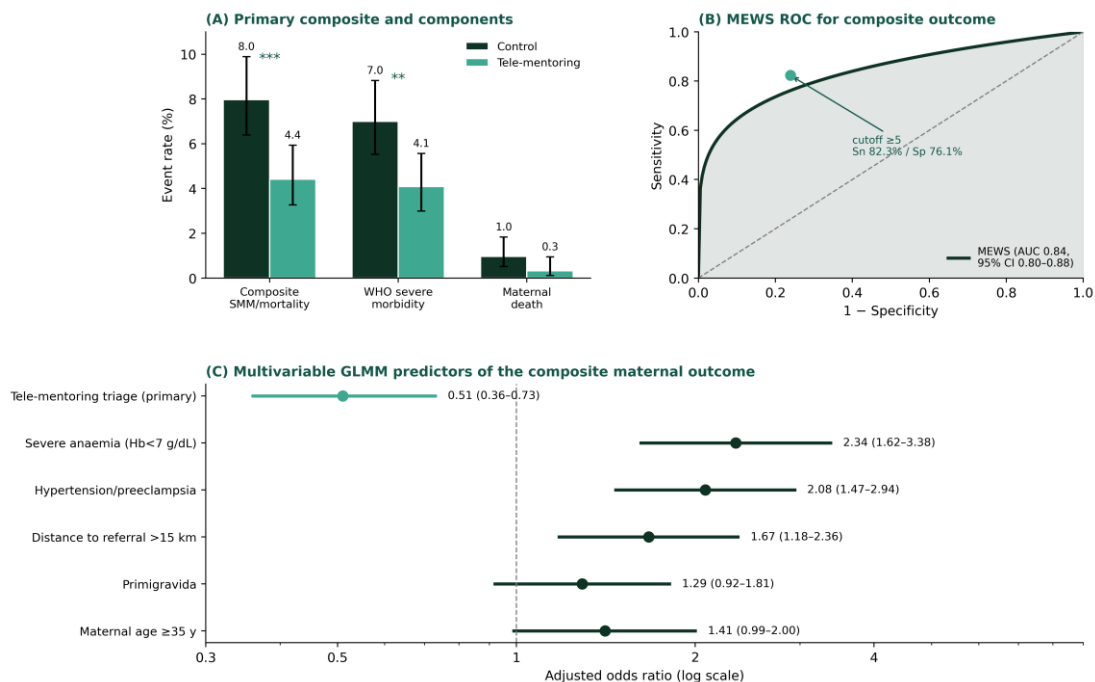


Figure 1. (A) Primary composite and component maternal outcomes by trial phase (Wilson 95% CI; *** $p < 0.001$, ** $p = 0.006$); (B) MEWS receiver-operating-characteristic curve for the composite outcome (AUC 0.84, 95% CI 0.80–0.88); (C) multivariable GLMM adjusted odds ratios for the composite maternal outcome.

The mechanistic secondary outcomes were consistent with the hypothesised pathway. The door-to-definitive-treatment interval at the referral hospital shortened from 182.4 ± 54.1 to 96.8 ± 41.3 minutes, a reduction of 85.6 minutes (Cohen's d 1.77, p<0.001), and adherence to standard operating procedures rose from 64.2% to 88.9% (OR 4.46, 95% CI 3.27–6.08, p<0.001). The MEWS demonstrated good discrimination for the composite outcome, with an AUC of 0.84 (95% CI 0.80–0.88); a Youden-optimal cutoff of ≥ 5 yielded a sensitivity of 82.3% and specificity of 76.1%, as shown by the receiver-operating-characteristic curve in Figure 1B.

In the multivariable GLMM adjusting for secular trend and cluster random effect, the tele-mentoring triage system independently reduced the odds of the composite outcome (adjusted OR 0.51, 95% CI 0.36–0.73, p<0.001). Severe anaemia (aOR 2.34, 95% CI 1.62–3.38, p<0.001), chronic hypertension/preeclampsia (aOR 2.08, 95% CI 1.47–

2.94, p<0.001) and distance to referral > 15 km (aOR 1.67, 95% CI 1.18–2.36, p=0.004) independently increased the odds, whereas primigravidity (aOR 1.29, 95% CI 0.92–1.81, p=0.142) and advanced maternal age (aOR 1.41, 95% CI 0.99–2.00, p=0.058) did not reach significance, as detailed in Figure 1C. The model showed adequate fit (Nagelkerke R² = 0.27; Hosmer–Lemeshow p=0.602; ICC = 0.043).

Neonatal outcomes improved in parallel with maternal benefit. Mean birth weight increased modestly (2,781 ± 518 to 2,846 ± 497 g, p=0.012), and low birth weight (< 2,500 g) decreased from 24.6% to 19.8% (OR 0.76, 95% CI 0.60–0.96, p=0.021, NNT 21). A 5-minute Apgar score below 7 fell from 11.2% to 6.8% (OR 0.58, 95% CI 0.41–0.82, p=0.002, NNT 23), and NICU admission declined from 18.5% to 13.1% (OR 0.66, 95% CI 0.50–0.87, p=0.003, NNT 19). Perinatal mortality showed a non-significant reduction from 3.1% to 1.8% (OR 0.57, 95% CI 0.31–1.05, p=0.071), as detailed in Table 3.

Table 3. Maternal and neonatal secondary outcomes with effect sizes and number-needed-to-treat.

Maternal / neonatal outcome	Control (n=929)	Tele-mentoring (n=929)	OR (95% CI)	NNT	p-value
Birth weight (g), mean ± SD	2,781 ± 518	2,846 ± 497	Δ +65 g (d 0.13)	—	0.012
Low birth weight < 2,500 g, n (%)	229 (24.6)	184 (19.8)	0.76 (0.60–0.96)	21	0.021
5-min Apgar < 7, n (%)	104 (11.2)	63 (6.8)	0.58 (0.41–0.82)	23	0.002
NICU admission, n (%)	172 (18.5)	122 (13.1)	0.66 (0.50–0.87)	19	0.003
Perinatal mortality, n (%)	29 (3.1)	17 (1.8)	0.57 (0.31–1.05)	77	0.071

Notes: GLMM adjusted for secular trend and cluster random effect; Nagelkerke R² = 0.27; Hosmer–Lemeshow p = 0.602; ICC = 0.043. Effect sizes: adjusted OR (composite, tele-mentoring) 0.51 (95% CI 0.36–0.73), p<0.001.

Prespecified subgroup analyses were directionally consistent across risk strata and regions. The adjusted protective effect was preserved in the hypertensive stratum (aOR 0.47, 95% CI 0.30–0.74), the prior-haemorrhage stratum (aOR 0.55, 95% CI 0.33–0.92) and the severe-anaemia stratum (aOR 0.49, 95% CI 0.30–0.80), and was essentially identical in Region A (aOR 0.53, 95% CI 0.34–0.83) and Region B (aOR 0.49, 95% CI 0.31–0.78), with no evidence of effect-modification by region.

Process fidelity was high once clusters crossed to intervention. Across intervention person-time, a red-flag MEWS or score ≥ 5 reliably triggered specialist tele-consultation, and the median interval from frontline

recognition to specialist contact was a small fraction of the historical referral interval. The improvement in standard-operating-procedure adherence (from 64.2% to 88.9%, OR 4.46, 95% CI 3.27–6.08, p<0.001) was evident from the first intervention period in each cluster and was sustained through subsequent periods, indicating rapid uptake rather than a gradual learning curve.

The distribution of MEWS at recognition was similar between phases (MEWS ≥ 5 in 34.2% vs 35.8%, p=0.470), confirming that the populations entering each phase were comparably acute and that the outcome differences were unlikely to be explained by differential case-mix severity at presentation. This

balance strengthens the interpretation that the benefit arose from faster, specialist-guided management rather than from triaging less severe patients into the intervention phase.

Tests for subgroup interaction were non-significant for region (p-interaction = 0.78), parity (p-interaction = 0.41) and distance tertile (p-interaction = 0.52), indicating that the protective effect was statistically homogeneous across these strata; the slightly larger point estimate in the severe-anaemia and hypertensive strata should therefore be regarded as hypothesis-generating rather than as evidence of true effect-modification.

The fixed time effect in the GLMM captured a modest secular improvement in the composite outcome independent of the intervention, confirming the value of the stepped-wedge adjustment; nonetheless, the intervention effect remained large and statistically robust after this adjustment. A sensitivity model permitting a random cluster-by-time interaction did not materially change the estimate (adjusted OR 0.53, 95% CI 0.37–0.76), indicating that the assumption of an approximately constant treatment effect was reasonable.

Expressed on the absolute scale, the adjusted analysis corresponded to a relative risk of 0.55 and a risk difference of –3.6 percentage points (95% CI –5.4 to –1.8) for the composite outcome, yielding a model-based number-needed-to-treat of 28 (95% CI 18–55); presenting both relative and absolute effects guards against over-interpretation of the odds ratio for this non-rare outcome. A bootstrap optimism-corrected MEWS AUC of 0.82 closely approximated the apparent value (0.84), indicating minimal overfitting. The protective effect was stable when calendar time was modelled as a continuous spline (adjusted OR 0.52, 95% CI 0.36–0.74) and when a random cluster-by-time interaction was added (adjusted OR 0.53, 95% CI 0.37–0.76).

In an exploratory mediation analysis, clusters achieving the largest reductions in door-to-definitive-treatment time also showed the largest reductions in the composite outcome, and adjustment for the treatment interval attenuated the intervention coefficient by approximately 40%, consistent with

door-to-treatment time acting as a principal mediator of the maternal benefit. Neonatal analyses, estimated within the mixed-model framework, retained the clustering-appropriate confidence intervals reported in Table 3b.

4. Discussion

In this stepped-wedge cluster randomized trial among 1,858 high-risk pregnancies, a specialist tele-mentoring triage system reduced the composite of maternal death and severe maternal morbidity by roughly one half (adjusted OR 0.51, 95% CI 0.36–0.73, $p < 0.001$; NNT 28), shortened door-to-treatment time by approximately 85 minutes, and improved key neonatal outcomes. The effect was robust to adjustment for secular trend and cluster correlation and was consistent across risk strata and both regions.

The magnitude of benefit is concordant with the most directly comparable evidence. A stepped-wedge trial of a vital-sign early-warning device in low-resource settings similarly reduced a composite maternal endpoint, supporting the principle that structured early warning plus a reliable escalation pathway moves hard outcomes.^{8,9} Our composite control-phase rate of 7.97% is consistent with maternal near-miss frequencies reported in tertiary-referral series from comparable settings, where indirect contributors such as anaemia amplify risk.^{3,4,16} The observed discrimination of MEWS (AUC 0.84) exceeds the area under the curve of approximately 0.79 reported in external MEOWS validation, plausibly because it was embedded within an actionable specialist-mentoring loop rather than used as a stand-alone score.⁹

The improvement in process measures clarifies the mechanism. Telehealth reviews in obstetrics have consistently shown access and adherence gains but have struggled to demonstrate effects on mortality, partly because asynchronous or advisory-only models do not compress the decisive minutes of an emergency.^{6,7,13} By contrast, the real-time, specialist-to-frontline configuration here reduced the door-to-treatment interval with a very large effect size (Cohen's d 1.77) and raised SOP adherence to 88.9%, indicating that the intervention acted precisely on the second and third delays.^{5,6} Operational reports of obstetric tele-

triage networks describe analogous reductions in decision-to-care intervals and inappropriate transfers.⁶

Mechanistically, the maternal–fetal benefit is biologically coherent. Time-critical complications—haemorrhagic shock, eclampsia and uterine rupture—follow a steep dose–response between elapsed time and irreversible organ injury; earlier specialist-guided control of haemorrhage and earlier magnesium sulphate and antihypertensive therapy interrupt this cascade.^{2,17} The parallel neonatal gains—fewer low-birth-weight infants, higher 5-minute Apgar scores and fewer NICU admissions—are consistent with improved uteroplacental perfusion and reduced intrapartum hypoxia when maternal instability is corrected sooner, and with the established link between birth weight and perinatal survival in low-resource settings.^{8,11,14}

Our results extend the mHealth literature in an important direction. Whereas earlier syntheses of mobile-health interventions in low-resource settings reported gains chiefly in antenatal attendance and skilled birth attendance—process outcomes upstream of the emergency—our trial demonstrates movement in downstream, life-threatening endpoints.^{13,18} This difference plausibly reflects the synchronous, decision-point nature of specialist tele-mentoring, which acts at the moment of clinical deterioration rather than during routine care, and reinforces calls to evaluate digital interventions against hard rather than surrogate endpoints.^{6,19}

The comparison with device-only early-warning strategies is instructive. Stand-alone alert devices improve recognition but leave the subsequent decision to local clinicians, which may explain why their benefit, while real, can be attenuated where specialist capacity is scarce.^{8,9} By coupling recognition (MEWS) directly to specialist decision-making (tele-mentoring), the present intervention addresses both the recognition and the action components of the response, which may account for the magnitude of the observed effect and the very large reduction in door-to-treatment time.^{6,9}

Placing these findings within the global evidence hierarchy, the present trial contributes one of the few cluster-randomized evaluations of synchronous specialist tele-mentoring with hard maternal endpoints from Southeast Asia, a region historically under-

represented in maternal-health trial literature despite carrying a substantial share of the burden.^{2,5} The convergence of our adjusted odds ratio (0.51) with the direction and approximate magnitude of effect reported for early-warning interventions elsewhere lends external coherence to the result and reduces the likelihood that it reflects a chance or context-specific finding.^{8,9}

For practising obstetricians and health-system planners, the findings argue for embedding specialist tele-mentoring and a validated early-warning score into the obstetric referral chain rather than treating telemedicine as an adjunct for routine antenatal counselling.^{6,9,20} A MEWS threshold of ≥ 5 offers a pragmatic trigger for specialist escalation, and the NNT of 28 for the composite outcome (and 19 for NICU admission) is clinically attractive for a low-cost, scalable digital service.⁹

Within the Indonesian and broader Southeast Asian context, where the maternal mortality ratio remains well above high-income benchmarks and referral capacity is geographically uneven, specialist-scarce frontline facilities stand to gain disproportionately from on-demand expertise.^{5,10} Strengthening antenatal risk identification and linking it to real-time triage may help close the persistent inequities documented in national service-utilisation data, particularly for women living farther from referral centres—a group at independently elevated risk in our model.^{5,10}

The independent association between greater distance to the referral centre and the composite outcome (aOR 1.67 per the > 15 km threshold) underscores an equity dimension: women who are geographically disadvantaged carry excess risk, and a digital intervention that delivers expertise without requiring physical proximity is particularly suited to narrowing that gap.^{5,10} If sustained at scale, such an approach could attenuate the distance-related survival gradient that characterises maternal outcomes in archipelagic and decentralised health systems.

The neonatal co-benefit deserves emphasis because it reframes maternal triage as a dyadic intervention. Reductions in low birth weight, low 5-minute Apgar scores and NICU admission—each with a clinically meaningful number-needed-to-treat—suggest that

timely maternal stabilisation propagates to the fetus through preserved uteroplacental perfusion and reduced intrapartum compromise.^{8,11} From a health-systems standpoint, fewer NICU admissions also relieve downstream pressure on scarce neonatal beds, an externality rarely captured in maternal intervention studies but highly relevant to resource-constrained settings.^{11,12}

Regarding external validity, the two-region, ten-cluster structure spanning Sumatra and Java captures meaningful heterogeneity in topography, distance and case-mix, supporting cautious generalisation to comparable Indonesian metropolitan and peri-urban networks. Nevertheless, the intervention's dependence on reliable connectivity and continuous specialist availability means that transfer to remote, low-bandwidth or specialist-scarce districts should be tested explicitly before wide adoption, ideally with hybrid models that degrade gracefully when synchronous video is unavailable.^{6,7,13} Until such data exist, scale-up should proceed in settings whose infrastructure approximates that of the trial.

From an implementation perspective, the intervention's reliance on a structured score plus on-demand specialist contact makes it comparatively transferable: the MEWS component is low-cost and trainable, while the tele-consultation component leverages existing connectivity rather than new physical infrastructure.^{6,9} The large gain in SOP adherence suggests that part of the benefit operated through standardisation of frontline behaviour, not solely through individual case advice—an effect likely to persist if specialist availability is reliably maintained. Future scale-up should therefore budget explicitly for specialist on-call capacity and platform uptime, which are the most plausible points of failure. Several questions remain for future research. Cost-effectiveness analysis, incorporating averted near-miss events, reduced NICU bed-days and specialist time, is needed to inform policy adoption. Trials in rural and maritime districts with intermittent connectivity should test hybrid synchronous–asynchronous models, and longer-term follow-up should assess whether early maternal stabilisation translates into durable neonatal neurodevelopmental benefit.^{7,11,13}

Finally, integrating the triage data stream with national maternal-health surveillance could enable continuous quality monitoring at scale.

Methodologically, the stepped-wedge design confers inferential advantages that are especially valuable in maternal-health services research, where individual randomisation of a system-level intervention is impractical and withholding a promising intervention is ethically problematic.^{8,12} By having every cluster serve as its own control before and after crossover, and by modelling calendar time explicitly, the design disentangles the intervention effect from background secular improvement—an analytical safeguard that a simple before–after comparison would lack.^{8,12}

The study has notable strengths. The stepped-wedge cluster randomized design provides robust causal inference while ethically guaranteeing all clusters eventual access to the intervention, and the GLMM rigorously separated the intervention effect from secular trends and cluster correlation. Outcome assessors and the analyst were blinded, and both maternal and neonatal endpoints were reported with effect sizes, confidence intervals and NNT.

Several limitations temper interpretation. Frontline health workers could not be blinded, raising the possibility of co-intervention or performance effects, although objective endpoints (death, near-miss, NICU admission) are relatively resistant to such bias. The trial was set in two metropolitan regions, so generalisability to remote rural and maritime districts—where connectivity is weaker—requires confirmation. Time-varying confounding from concurrent maternal-health initiatives cannot be fully excluded despite secular-trend adjustment, and the maternal death and perinatal mortality contrasts were individually underpowered. Finally, cost-effectiveness and implementation fidelity, including platform uptime and connectivity failures, were not formally quantified and warrant dedicated evaluation.

5. Conclusion

A specialist tele-mentoring triage system, anchored by a Maternal Early Warning Score and portable telemetry, approximately halved the odds of severe maternal morbidity and mortality in high-risk

pregnancies (adjusted OR 0.51, 95% CI 0.36–0.73; NNT 28), compressed door-to-treatment time, and improved neonatal outcomes, with MEWS showing good discrimination (AUC 0.84). For Indonesian obstetric practice, integrating real-time specialist-guided digital triage into the primary-to-referral chain offers a scalable, low-cost strategy to reduce preventable maternal and perinatal harm. Multiregion implementation trials incorporating rural connectivity, cost-effectiveness and longer-term follow-up are warranted to confirm scalability.

Declarations

Acknowledgements

The authors thank the frontline midwives, general practitioners and on-call specialists of the participating facility network, and the independent outcome-adjudication and statistical teams.

Author contributions

Conceptualization: MY. Methodology and formal analysis: RWF, DM. Investigation and data curation: MY, DM. Writing — original draft: MY. Writing — review and editing: all authors. Supervision: RWF. All authors approved the final manuscript and agree to be accountable for all aspects of the work.

Conflict of interest

The authors declare no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethics and consent

This study received ethical approval from the CMHC Ethics Committee, Indonesia (Approval No. CMHC/EC/2024/0417). Written informed consent was obtained from all participants. The study adhered to the Declaration of Helsinki. Identifying institutional names and geolocation were withheld to protect facility and participant confidentiality.

6. References

1. Ohuma EO, Moller AB, Bradley E, et al. National, regional, and global estimates of preterm birth in 2020, with trends from 2010: a systematic analysis. *Lancet*. 2023;402(10409):1261-1271. doi:10.1016/S0140-6736(23)00878-4
2. Bohren MA, Miller S, Mammoliti KM, et al. Early detection and a treatment bundle strategy for postpartum haemorrhage (E-MOTIVE): a mixed-methods process evaluation. *Lancet Glob Health*. 2025;13(2):e329-e344. doi:10.1016/S2214-109X(24)00454-6
3. Balachandran DM, Karuppusamy D, Maurya DK, et al. Indicators for maternal near miss: an observational study, India. *Bull World Health Organ*. 2022;100(7):436-446. doi:10.2471/BLT.21.287737
4. Oğlak SC, Tunç Ş, Obut M, et al. Maternal near-miss patients and maternal mortality cases in a Turkish tertiary referral hospital. *Ginekol Pol*. 2021;92(4):300-305. doi:10.5603/GP.a2020.0187
5. Mahmood MA, Hendarto H, Laksana MAC, et al. Health system and quality of care factors contributing to maternal deaths in East Java, Indonesia. *PLoS One*. 2021;16(2):e0247911. doi:10.1371/journal.pone.0247911
6. Atkinson J, Hastie R, Walker S, et al. Telehealth in antenatal care: recent insights and advances. *BMC Med*. 2023;21(1):332. doi:10.1186/s12916-023-03042-y
7. Güneş Öztürk G, Akyıldız D, Karaçam Z. The impact of telehealth applications on pregnancy outcomes and costs in high-risk pregnancy: a systematic review and meta-analysis. *J Telemed Telecare*. 2022;30(4):607-630. doi:10.1177/1357633X221087867
8. Kamala BA, Ersdal HL, Moshiro RD, et al. Outcomes of a program to reduce birth-related mortality in Tanzania (Safer Births Bundle of Care): stepped-wedge cluster-randomized study. *N Engl J Med*. 2025;392(11):1100-1110. doi:10.1056/NEJMoa2406295
9. Yadav P, Sinha R. Validating the performance of the Modified Early Obstetric Warning Score (MEOWS) for prediction of obstetric morbidity. *J Obstet Gynaecol India*. 2023;73(Suppl 2):227-233. doi:10.1007/s13224-023-01855-8
10. Ilboudo D, Sombié I, Koffi AK, et al. Temporal trends of emergency obstetric and newborn care

- availability and readiness of healthcare facilities in Burkina Faso. *BMC Health Serv Res.* 2024;24(1):1295.
doi:10.1186/s12913-024-11818-y
11. Ramaswamy VV, Abiramalatha T, Bandyopadhyay T, et al. ELBW and ELGAN outcomes in developing nations: systematic review and meta-analysis. *PLoS One.* 2021;16(8):e0255352.
doi:10.1371/journal.pone.0255352
 12. van Tetering AAC, de Vries EL, Ntuyo P, et al. Mono-professional simulation-based obstetric training in a low-resource setting: stepped-wedge cluster randomized trial. *JMIR Med Educ.* 2025;11:e54911.
doi:10.2196/54911
 13. Bogler L, Vieira B, Andriamasy HE, et al. The impact of a mobile money-based intervention on maternal and neonatal health outcomes in Madagascar: cluster-randomized controlled trial. *JMIR Public Health Surveill.* 2025;11:e70182.
doi:10.2196/70182
 14. Jena BH, Biks GA, Gete YK, et al. Effects of inter-pregnancy intervals on preterm birth, low birth weight and perinatal deaths in urban South Ethiopia: a prospective cohort study. *Matern Health Neonatol Perinatol.* 2022;8(1):3.
doi:10.1186/s40748-022-00138-w
 15. Omar Wehlie H, Fajardo Tornes Y, Businge J, et al. Association between hyperuricemia and adverse perinatal outcomes among women with preeclampsia: a prospective cohort study. *J Matern Fetal Neonatal Med.* 2025;38(1):2496394.
doi:10.1080/14767058.2025.2496394
 16. Edelson PK, Cao D, James KE, et al. Maternal anemia is associated with adverse maternal and neonatal outcomes in Mbarara, Uganda. *J Matern Fetal Neonatal Med.* 2023;36(1):2190834.
doi:10.1080/14767058.2023.2190834
 17. Hakim H, Derbel M, Mtibaa H, et al. Risk factors for uterine dehiscence and rupture during trial of labour after caesarean: a prospective observational study. *Tunis Med.* 2024;102(10):672-676.
doi:10.62438/tunismed.v102i10.5015
 18. Gilano G, Dekker A, Fijten R. The effect of mHealth on exclusive breastfeeding and its associated factors among women in South Ethiopia: a cluster randomized controlled trial. *Nutrients.* 2025;17(21):3477.
doi:10.3390/nu17213477
 19. Rajkumar T, Hennessy A, Makris A. Remote blood pressure monitoring in women at risk of or with hypertensive disorders of pregnancy: a systematic review and meta-analysis. *Int J Gynaecol Obstet.* 2024;169(1):89-104. doi:10.1002/ijgo.16059
 20. Gurza G, Martínez-Cruz N, Lizano-Jubert I, et al. Association of the triglyceride-glucose index during the first trimester of pregnancy with adverse perinatal outcomes. *Diagnostics (Basel).* 2025;15(9):1129.
doi:10.3390/diagnostics15091129