



Case Study

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Efficacy of Kangaroo Mother Care on Thermoregulation in Preterm Neonates

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Abstract

Preterm and low-birth-weight neonates face a disproportionate risk of hypothermia due to a high surface-area-to-mass ratio, minimal subcutaneous fat, and immature nonshivering thermogenesis, and hypothermia remains an independent, mechanistically well-characterized contributor to neonatal mortality worldwide. Kangaroo mother care (KMC) -- continuous or near-continuous skin-to-skin contact between an infant and a parent's bare chest -- was developed in Bogota, Colombia as a response to incubator scarcity and has since become one of the most extensively trialed interventions in neonatal medicine. This article synthesizes the literature on KMC's specific efficacy for thermoregulation, from the physiology of neonatal heat loss through the foundational Cochrane and Pediatrics meta-analyses, which report hypothermia risk ratios of roughly 0.28 to 0.48 favoring KMC over conventional incubator or crib care, to large recent randomized trials of immediate KMC initiated before full clinical stabilization. We give particular attention to a genuine open question the recent trial literature has surfaced: whether immediate KMC confers uniform benefit across the full range of clinical stability at birth, or whether its optimal timing differs for the most acutely unstable neonates. Read together, the evidence supports KMC as a thermally efficacious, physiologically well-grounded practice, while leaving implementation coverage, transport-phase protocols, and population-specific timing guidance as an active research and health-systems agenda.

Keywords: kangaroo mother care; neonatal thermoregulation; preterm infant; skin-to-skin contact; neonatal hypothermia

1. Introduction

Every year, an estimated 20 million infants are born preterm or with low birth weight, and for a very large share of them the first hours after delivery are also the most thermally dangerous hours of their lives. A newborn weighing 1500 grams has a body-surface-area-to-mass ratio roughly three times that of a term infant, almost no subcutaneous fat to insulate against heat loss, and a stratum corneum too thin to meaningfully slow evaporative cooling — a combination that lets skin temperature fall by 2-4°C within minutes of exposure to a delivery-room environment that a term infant would tolerate without difficulty. The global burden this imposes is not a minor operational nuisance; a systematic review of the topic estimated that in some low-resource neonatal units more than half of admitted low-birth-weight infants are hypothermic on arrival, and identified hypothermia as an independent contributor to neonatal mortality across virtually every setting it was measured in, rich and poor alike [1]. Climate change is, if anything, sharpening this problem rather than easing it: a recent modeling study attributed a measurable share of neonatal deaths in 29 low- and middle-income countries directly to temperature extremes, with cold-attributable risk concentrated in exactly the populations — small, preterm, resource-poor — least able to compensate physiologically [2].

Kangaroo mother care (KMC) — continuous or near-continuous skin-to-skin contact between an infant, clad only in a diaper and cap, and a parent's (usually the mother's) bare chest, typically under a wrap or gown — was developed in Bogotá, Colombia in the early 1980s as a low-cost response to a very concrete shortage: too many low-birth-weight infants and not enough functioning incubators. What began as a stopgap has become one of the most extensively studied interventions in neonatal medicine, and thermoregulation was, from the outset, one of its central claims: a mother's chest, it turns out, is a strikingly effective thermal environment for a small infant, one that adapts its own temperature in response to the infant's needs in a way no static incubator setting can. This article synthesizes what the literature — spanning early physiological trials, large multi-country randomized controlled trials, and recent meta-analyses — has established about the efficacy of KMC specifically for thermoregulation in preterm neonates, and what

remains genuinely open about how, when, and for whom it should be implemented.

Two things are worth flagging about scope before proceeding. First, thermoregulation is only one of KMC's reported benefits — the practice has also been linked to reduced mortality, lower rates of severe infection, improved breastfeeding rates, and better neurodevelopmental outcomes — but this article deliberately keeps its focus on the thermal evidence base specifically, drawing on the wider mortality and morbidity literature only where it bears directly on thermal mechanisms or on how thermal benefit is thought to translate into survival benefit. Second, we distinguish throughout between facility-based KMC, initiated after some degree of clinical stabilization, and immediate KMC (iKMC), initiated within minutes of birth regardless of stabilization status, because the trial evidence for these two implementation models — and, as later sections describe, their apparent risk profiles in the most unstable infants — is not identical.

2. The Physiology of Neonatal Thermoregulation and Hypothermia Risk

Thermoregulation in a healthy term newborn already strains the limits of the neonatal physiological toolkit; in a preterm infant, several of the mechanisms a term infant relies on are simply less developed or entirely absent. Nonshivering thermogenesis, the principal heat-generating mechanism available to a newborn (shivering itself is a comparatively minor contributor), depends on brown adipose tissue, which accumulates mainly in the third trimester; an infant born at 28-32 weeks has substantially less of it than one born at term, and what tissue is present is metabolically immature. Brown fat generates heat through uncoupling protein 1, which short-circuits the normal mitochondrial proton gradient so that the energy that would otherwise produce ATP is released as heat instead — a mechanism that is metabolically expensive and that a compromised, hypoglycemic, or hypoxic preterm infant may simply not be able to sustain at the rate needed to offset ongoing heat loss.

Heat loss itself operates through the four familiar physical routes — evaporation, convection, conduction, and radiation — but each is disproportionately severe in a preterm infant. Evaporative loss from wet skin immediately after birth can be extreme in an infant whose stratum corneum is not yet fully keratinized;

convective loss is amplified by delivery-room air currents and the infant's high surface-area-to-mass ratio; radiative loss to cold incubator walls or nearby equipment can proceed even when ambient air temperature seems adequate; and conductive loss to any cold surface the infant contacts is immediate. A recent clinical review of thermoregulation in preterm infants catalogs these mechanisms in detail and makes a point that is easy to lose in a purely mechanistic account: because a preterm infant's compensatory range is narrow, the clinically relevant question is rarely whether heat loss occurs (it always does, to some degree) but how quickly and reliably a caregiving strategy can offset it before core temperature drifts into a range associated with worse metabolic and hemodynamic outcomes [3]. Hypothermia is not a benign, easily-reversed cosmetic finding; it is mechanistically linked to increased oxygen consumption (as the infant attempts metabolic compensation), worsened acidosis, impaired surfactant production, coagulopathy, and, at the population level, a measurably higher risk of death, a relationship the systematic review by Lunze and colleagues documents across a wide range of health-system contexts, from well-resourced neonatal intensive care units to community-based newborn care programs in low-income settings [1].

This physiological fragility is precisely what makes the choice of thermal care strategy for a preterm infant clinically consequential rather than a matter of comfort or convenience, and it is the backdrop against which KMC's specific thermal claims need to be evaluated: not "does skin contact feel warm" but "does it reliably offset a genuinely dangerous physiological deficit, across the range of gestational ages and clinical states preterm infants present in."

The cold-stress cascade

It is worth being explicit about why clinicians treat mild hypothermia in a preterm infant as more than a monitoring nuisance, because the downstream cascade is what actually links a temperature reading to survival outcomes. A falling core temperature triggers peripheral vasoconstriction, which reduces heat loss at the cost of reduced peripheral perfusion; sustained vasoconstriction under hypoxic or already-compromised circulatory conditions can worsen tissue acidosis. The metabolic cost of nonshivering thermogenesis itself increases oxygen and

glucose consumption at precisely the moment a stressed, possibly already hypoglycemic infant can least afford it, which is why cold stress and hypoglycemia are so frequently observed together clinically rather than as coincidental, independently occurring findings. Surfactant production and function can also be impaired by cold stress, compounding respiratory difficulty in an infant whose lungs may already be immature, and the clotting cascade itself is temperature-sensitive, meaning a hypothermic infant is also a more coagulopathy-prone infant. None of these individual mechanistic links is, on its own, a large effect; the reason hypothermia shows up so consistently as a mortality risk factor across the epidemiological literature is that these effects compound rather than operate in isolation [3,1].

3. Origins and Global Adoption of Kangaroo Mother Care

KMC's origin story is worth recounting briefly because it shapes how the intervention is still described in the literature: a response to scarcity that turned out, on closer physiological and clinical examination, to outperform some of what it was meant to substitute for. Edgar Rey Sanabria and colleagues introduced continuous skin-to-skin contact at the Instituto Materno Infantil in Bogotá in response to overcrowding, a shortage of incubators, and high rates of nosocomial infection and abandonment among hospitalized low-birth-weight infants. The subsequent decades of follow-up from that same Bogotá cohort, led largely by Nathalie Charpak and colleagues, have produced some of the longest-running outcome data available for any neonatal intervention, tracking children from birth through to young adulthood and reporting effects on growth, cognitive and motor development, and even brain structure that persist decades after the intervention itself ended in infancy [4,5].

A widely cited retrospective by Charpak and colleagues, published on the 25th anniversary of the program's founding, traces this evolution explicitly: from a resource-scarcity improvisation, through a period of skepticism in which KMC was viewed mainly as a way to shorten incubator time, to a practice with an independently documented physiological and clinical rationale that the World Health Organization and national ministries of health across dozens of countries have since incorporated into formal newborn-care

guidelines [6]. That the same intervention now appears in both a 1994 Colombian cohort study and a 2024 multi-hospital randomized trial in Uganda [7] is itself a marker of how far the evidence base has traveled, and how much weight now rests on getting the details of implementation right rather than on establishing the basic concept.

A useful review by Nyqvist and colleagues, prepared as part of an international expert consensus effort, is worth flagging here because it addresses a question practitioners in well-resourced settings often ask first: does KMC's rationale survive contact with a modern, technologically intensive neonatal intensive care unit, where ventilators, monitors, and intravenous lines complicate — but do not preclude — skin-to-skin positioning? The review's answer, synthesizing observational and small trial data from high-technology NICUs, is that it does: KMC can be implemented safely alongside most forms of respiratory and hemodynamic support with appropriate protocols, and the thermal and physiological stabilization benefits documented in lower-resource settings are not simply an artifact of KMC's original scarcity-driven context [8].

4. Quantifying Thermal and Survival Effects: Trials and Meta-Analyses

The single most heavily cited quantitative summary of KMC's effects remains the Cochrane systematic review by Conde-Agudelo and Diaz-Rossello, most recently updated in 2016, which pooled data from randomized and quasi-randomized trials comparing KMC to conventional (incubator or open-crib) care for low-birth-weight infants. Its thermal finding is close to unambiguous: infants who received KMC had a hypothermia rate of 7.6% at discharge or at 40-41 weeks' postmenstrual age, compared with 27.1% among infants receiving conventional care, a risk ratio of 0.28 (95% CI 0.16-0.49) — meaning KMC infants experienced roughly a quarter of the hypothermia risk of the comparison group [9]. The same review found a mortality benefit at latest follow-up (4.0% versus 6.0%, RR 0.67, 95% CI 0.48-0.95), and while mortality is a composite outcome shaped by far more than thermal status alone, the size and consistency of the effect is broadly in line with what would be expected if a meaningful share of the excess mortality among low-birth-weight infants in conventional care is thermally mediated, whether directly (hypothermia-associated metabolic

derangement) or indirectly (hypothermic infants being more vulnerable to sepsis, feeding intolerance, and other complications).

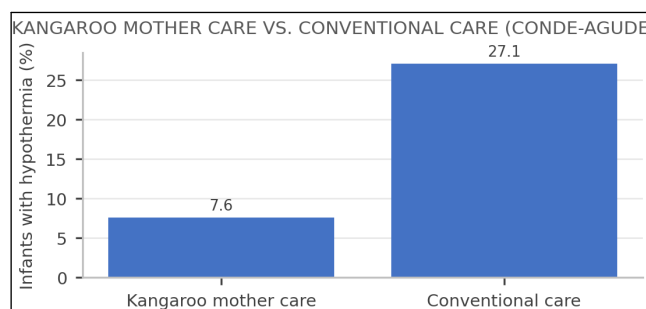


Figure 1: Hypothermia at discharge or at 40-41 weeks' postmenstrual age among low-birth-weight infants receiving kangaroo mother care versus conventional incubator/crib care, pooled across randomized and quasi-randomized trials (risk ratio 0.28, 95% CI 0.16-0.49) [9].

Boundy and colleagues' independent meta-analysis, published the same year in *Pediatrics* and drawing on a substantially overlapping but not identical set of trials, reported a comparable mortality effect: KMC was associated with a 36% relative reduction in mortality at latest follow-up among infants weighing less than 2000 grams at enrollment (RR 0.64, 95% CI 0.46-0.89) [10]. That two independent meta-analytic efforts, drawing on overlapping but not identical trial sets and using somewhat different inclusion criteria, converge on mortality risk ratios in the same general range (0.64-0.67) is itself a form of evidence: it suggests the effect is not an artifact of one review team's particular set of methodological choices.

More recent work has extended this evidence base with updated pooled estimates and formal statistical safeguards against false-positive findings from repeated meta-analysis. A 2025 meta-analysis with trial sequential analysis — a technique designed to assess whether the cumulative evidence has crossed a threshold of statistical reliability, rather than relying on a single pooled p-value that might reflect an underpowered or heterogeneous evidence base — reported an in-hospital mortality risk ratio of 0.791 (95% CI 0.696-0.899) and a 28-day mortality risk ratio of 0.810 (95% CI 0.709-0.926) for KMC versus conventional care [11]. Its thermal-specific findings are, for the purposes of this article, the more directly relevant numbers: a hypothermia risk ratio of 0.482 (95% CI 0.363-0.638), and — a finding earlier reviews addressed less consistently — a hyperthermia risk ratio of 0.689 (95% CI 0.535-0.886), indicating that KMC does not simply trade one thermal derangement for another by overheating infants, a

concern that is sometimes raised informally given the intervention's reliance on direct maternal body heat. The same analysis reported that the hypothermia-reduction effect was, if anything, larger in lower-middle-income-country settings specifically (RR 0.303), which is a clinically important finding given that these are exactly the settings in which incubator access is most constrained and thermal protection strategies matter most acutely [11].

5. Immediate Kangaroo Mother Care and Facility-Based Trials

A distinction that has become central to the recent literature, and that earlier reviews sometimes blurred, is between KMC initiated after an infant has achieved some baseline clinical stability — the model most of the foundational trials tested — and immediate KMC (iKMC), initiated within minutes of birth, before formal clinical stabilization, and continued nearly continuously thereafter. The WHO Immediate KMC Study Group's large multi-country randomized trial, published in the *New England Journal of Medicine* in 2021, tested exactly this immediate model in infants weighing 1.0-1.799 kg across hospitals in Ghana, India, Malawi, Nigeria, and Tanzania, comparing iKMC (started as soon as the infant's condition allowed, targeting within hours of birth) against a strategy of stabilizing infants first, in a conventional warmer or incubator, before introducing KMC [12]. The trial found a significant survival benefit for the immediate strategy and helped catalyze a shift in WHO and national guidance toward earlier initiation wherever feasible, and its scale — enrolling low-birth-weight infants across five countries with substantially different baseline neonatal mortality rates and health-system capacities — gave the finding a generalizability that single-site trials cannot offer.

Table 1: Pooled risk-ratio estimates for thermal and survival outcomes of kangaroo mother care versus conventional care, as reported by independent systematic reviews and meta-analyses. [9,10,11].			
Outcome	Source	KMC vs. Control	Effect Estimate (95% CI)
Hypothermia at discharge / 40-41 wk PMA	Conde-Agudelo & Diaz-Rossello [9]	7.6% vs 27.1%	RR 0.28 (0.16-0.49)
Mortality at latest follow-up	Conde-Agudelo & Diaz-Rossello [9]	4.0% vs 6.0%	RR 0.67 (0.48-0.95)
Mortality at latest follow-up, infants <2000 g	Boundy et al. [10]	36% relative reduction	RR 0.64 (0.46-0.89)

Outcome	Source	KMC vs. Control	Effect Estimate (95% CI)
Hypothermia (updated pooled estimate)	2025 meta-analysis with trial sequential analysis [11]	Pooled across trials	RR 0.482 (0.363-0.638)
Hyperthermia (overheating)	2025 meta-analysis with trial sequential analysis [11]	Pooled across trials	RR 0.689 (0.535-0.886)
28-day all-cause mortality	2025 meta-analysis with trial sequential analysis [11]	Pooled across trials	RR 0.810 (0.709-0.926)

That generalizability, however, does not extend uniformly to every clinical subgroup, and the most recent large trial in this space illustrates why the distinction between "low birth weight and reasonably stable" and "low birth weight and clinically unstable" matters. The OMWaNA trial, conducted across five hospitals in Uganda and published in *The Lancet* in 2024, specifically tested KMC initiated *before* clinical stabilization — including in infants who were, by the trial's own enrollment criteria, more acutely unwell than the population the WHO iKMC trial's protocol effectively selected for — against standard care with KMC introduced only after stabilization [7]. The trial's overall findings did not replicate a clear survival advantage for pre-stabilization KMC in this more clinically fragile population, a result that prompted considerable discussion in the field about whether "immediate" KMC needs a narrower and more precisely specified target population than the phrase alone suggests. An accompanying commentary in the same issue of *The Lancet* framed this directly as an open implementation question rather than a refutation of KMC's underlying rationale: the physiological logic for thermal and cardiorespiratory benefit from skin-to-skin contact remains intact, but translating that logic into "start KMC as early as possible, in as many infants as possible, in resource-constrained health systems" requires more precise guidance than a single trial result on either side of the question can provide, particularly for the subset of neonates who are hemodynamically unstable at the moment KMC would otherwise begin [13].

This tension — strong, consistent thermal and survival benefit in the pooled trial literature broadly, alongside a genuine open question about optimal timing in the most acutely unstable infants — is, in our reading, one of the

more important nuances the current evidence supports, and one that a purely aggregate meta-analytic summary can obscure if read uncritically.

Thermal benefit as one strand within a broader stabilization effect

It is also worth resisting the temptation to treat thermal stabilization and the other physiological benefits reported alongside it as fully separable phenomena, because the trial literature generally does not measure them separately either. Infants in the WHO iKMC trial and in OMWaNA were assessed for composite outcomes — survival, sepsis, hypothermia, and related morbidities together — precisely because the underlying physiological rationale treats thermal, cardiorespiratory, and metabolic stability as an interlocking set of effects rather than independent endpoints that happen to be measured in the same infant [12,7]. A mother's chest provides not only a heat source but also a source of tactile and vestibular stimulation, a relatively constant and predictable sensory environment compared to an open ward, and — for breastfeeding-capable mother-infant pairs — earlier and more frequent access to colostrum and breast milk, itself a source of both calories (supporting thermogenesis) and passive immune protection. Disentangling how much of KMC's mortality benefit specifically runs through the thermal pathway, as opposed to these adjacent pathways, is methodologically difficult with the trial designs available to date, and is part of why this article has been careful to describe thermal efficacy as one well-evidenced strand within a broader physiological effect rather than claiming it as the sole causal mechanism behind KMC's documented survival benefit.

6. Mechanisms of Heat Transfer and Comparative Physiological Studies

Beyond the clinical trial literature, a smaller body of work has examined the physiological mechanics of maternal-infant heat transfer directly, using continuous temperature monitoring rather than binary hypothermia/normothermia classification at a single discharge timepoint. Ludington-Hoe and colleagues' early comparative study measured infant temperature continuously during kangaroo care versus incubator care in preterm infants and found that skin-to-skin contact maintained infant temperature at least as effectively as a closed incubator across the monitoring period, with the added observation that maternal chest

temperature appeared to rise modestly in response to a cooler infant being placed against it — a phenomenon since described elsewhere in the literature as maternal thermal synchrony, in which a mother's chest skin temperature adjusts, apparently reflexively, to the thermal needs of the infant in contact with it [14]. Bergman and colleagues' randomized trial comparing skin-to-skin contact from birth against a conventional incubator for physiological stabilization in 1200- to 2199-gram newborns similarly tracked continuous physiological measures rather than relying solely on discharge-timepoint classification, and reported that skin-to-skin infants achieved stable physiological status, including thermal stability, at least as reliably as incubator-cared infants, while also showing differences in heart-rate stability during the stabilization period that the authors interpreted as evidence of a broader autonomic stabilization effect beyond temperature alone [15].

Two more recent studies extend this mechanistic picture to the most vulnerable end of the preterm spectrum: extremely preterm and very preterm infants, for whom clinicians have historically been more cautious about skin-to-skin contact given concerns about physiological fragility. Maastrup and Greisen's study of extremely preterm infants found that skin-to-skin contact was generally well tolerated during the first weeks of life, without the systematic destabilization some clinicians had anticipated, when appropriately monitored [16]. Lode-Kolz and colleagues, studying immediate skin-to-skin contact after birth specifically in very preterm infants in high-resource neonatal units — precisely the population for whom the thermal case might seem least obvious, given ready incubator availability — found that immediate skin-to-skin contact was associated with stable thermoregulation from birth, suggesting that the thermal rationale for early skin-to-skin contact is not solely a resource-scarcity argument but reflects a genuine physiological advantage that persists even when a technologically superior alternative (a modern closed incubator) is readily available [17]. Cochrane's parallel review of early skin-to-skin contact specifically for healthy newborns — a broader population than the low-birth-weight infants most KMC trials target — reaches a structurally similar conclusion about thermal and cardiorespiratory stability benefits, reinforcing that the underlying mechanism is not specific to any one gestational-age band but reflects

a more general physiological response to maternal contact [18].

A separate, more pragmatic line of physiological evidence concerns KMC's use outside the neonatal unit itself: during transport. Sontheimer and colleagues' study of kangaroo-position transport, comparing it against conventional incubator transport for low-birth-weight infants being moved between care settings, found favorable thermal outcomes for the kangaroo-position group, a finding with direct relevance for referral systems in which infants must be moved between facilities of varying thermal-support capability, and one that extends the thermal argument for KMC beyond the static hospital-ward setting most trials are conducted in [19].

7. Implementation Barriers and Health-System Considerations

A well-documented efficacy signal does not automatically translate into population-level effectiveness, and a substantial applied-research literature has examined why KMC coverage remains uneven even in settings where it is formally recommended in national guidelines. Vesel and colleagues' multi-country analysis of KMC implementation, conducted across several low- and middle-income countries as part of a broader effort to understand why documented efficacy has not consistently translated into high coverage, identified bottlenecks spanning health worker training and confidence, facility space and privacy constraints for mothers expected to provide near-continuous skin contact, family and community support structures (or their absence), and health-system financing and supply-chain issues that affect whether KMC is offered as a genuine standard of care or as an occasional, under-resourced afterthought [20]. These findings matter directly for the thermal-efficacy question this article has focused on: a trial-demonstrated risk ratio of 0.28 for hypothermia is a ceiling on achievable benefit under close-to-ideal implementation conditions, and the gap between that ceiling and what a health system with limited maternal accompaniment, minimal staff coaching, and no formal KMC space actually achieves is a live, largely unresolved operational question rather than a footnote to the efficacy literature.

The scale-up implications are not merely administrative. If the thermal and survival benefits documented in

controlled trial settings depend on genuinely continuous or near-continuous skin contact — most protocols specify at least several hours per day, ideally approaching 24 hours — then partial or intermittent implementation, which is what resource and staffing constraints often produce in practice, may deliver meaningfully less benefit than the trial literature would predict, a dose-response relationship that Vesel and colleagues' analysis and the broader implementation literature it draws on flag as a priority for further applied research rather than a settled matter [20].

Transport and referral present a related but distinct implementation gap. Low-birth-weight infants in many health systems are not born in the facility where they will ultimately receive definitive care, and the interval between birth and arrival at a capable neonatal unit is disproportionately represented in thermal-risk statistics precisely because ambulances, referral vehicles, and informal transport arrangements are among the least thermally controlled environments an infant passes through. The transport-specific evidence, while smaller in volume than the facility-based trial literature, points in the same direction as the facility-based findings: kangaroo-position transport compares favorably to conventional incubator transport on thermal outcomes, and does so using no equipment beyond a wrap and a caregiver's body heat, which makes it a plausible default recommendation precisely in the lower-resource referral systems where incubator-equipped ambulances are least likely to be available [19]. Embedding this transport-phase guidance into routine referral protocols, rather than treating KMC as a practice that begins and ends at the bedside, is a comparatively low-cost extension of the existing evidence base that health systems have been slow to formalize.

8. Open Challenges

Several gaps recur across the literature synthesized here and are worth naming plainly. First, and most consequentially given the discussion above, the field lacks a precise, empirically validated answer to the question the OMWaNA trial raised: exactly which degree of clinical instability should delay KMC initiation, and for how long, given that the WHO iKMC trial's positive result and OMWaNA's more equivocal one were obtained in populations that differed in ways the field has not yet fully characterized [12,7,13]. A single global recommendation to "start KMC immediately" may be

appropriate for the population the iKMC trial enrolled while requiring meaningful qualification for more acutely unstable neonates, and resolving this will likely require prospectively designed trials that stratify by baseline clinical status rather than treating "low birth weight" as a sufficiently homogeneous enrollment criterion on its own.

Second, most of the mechanistic, continuous-monitoring studies of maternal-infant heat transfer — the Ludington-Hoe, Bergman, Maastrup, and Lode-Kolz studies discussed above — are relatively small, single- or few-site investigations, and the field would benefit from larger, multi-site continuous-monitoring studies that could characterize maternal thermal synchrony and its limits (does it hold across maternal fever, maternal hypothermia, or maternal fatigue-driven reduced positioning vigilance?) with more statistical power than any individual study to date has offered [14,15]. Third, the coverage and implementation-science literature, exemplified by Vesel and colleagues' multi-country bottleneck analysis, has identified barriers more thoroughly than it has tested solutions; there is comparatively little randomized evidence on which specific implementation strategies (task-shifted counseling, dedicated KMC wards and furniture, peer-mother support models, financial support for accompanying mothers) most reliably close the gap between trial-demonstrated efficacy and real-world coverage [20]. Fourth, as the modeling work on climate-attributable neonatal mortality makes clear, ambient thermal stress on newborns is not a static background condition but one that is measurably worsening in exactly the low- and middle-income settings where KMC coverage is often lowest and where incubator-based alternatives are least available — a convergence of rising thermal risk and uneven protective coverage that deserves more explicit attention in KMC scale-up planning than it has so far received [2].

We do not think any of these gaps undermine the core finding that KMC is thermally efficacious for preterm and low-birth-weight infants under a wide range of conditions tested to date; the consistency of the hypothermia risk-ratio estimates across the Cochrane review, the Boundy meta-analysis, and the more recent trial-sequential-analysis update, obtained from substantially different trial samples and analytic teams, is about as strong a form of convergent evidence as a

non-experimental research synthesis can offer [9,10,11]. What remains open is less "does KMC work thermally" than "under exactly which clinical and implementation conditions does it work as well as the trial literature suggests it can."

Practical implications for clinical and health-system practice

Translating this evidence base into bedside and policy guidance involves a handful of recurring, practically oriented judgment calls that the literature synthesized above helps inform even where it does not settle them outright. For a clinically stable low-birth-weight infant, the aggregate trial evidence supports initiating skin-to-skin contact as early as feasible and sustaining it for as many hours per day as the mother's and infant's circumstances allow, with the hypothermia risk-ratio reductions reported by Conde-Agudelo and colleagues and by the more recent trial-sequential-analysis update representing a realistic target for what well-implemented KMC can achieve [9,11]. For an infant who is not yet clinically stable, the OMWaNA trial's more equivocal finding counsels a more individualized approach, weighting the severity and nature of instability rather than treating "low birth weight" alone as sufficient justification for immediate, unmodified KMC initiation [7]. For health systems planning scale-up, the implementation-science literature is arguably as important as the efficacy literature: a program that achieves high nominal coverage but only a few intermittent hours of skin contact per day, because staff have not been trained to support mothers through a demanding practice or because ward space does not accommodate it, should not be expected to reproduce trial-level risk reductions, and monitoring actual hours of skin contact delivered, not merely whether KMC was "offered," is a modest but achievable step toward closing that gap [20].

9. Conclusion

The literature reviewed here supports a fairly specific and well-evidenced claim: kangaroo mother care meaningfully reduces the risk of hypothermia in preterm and low-birth-weight neonates, with pooled risk ratios in the range of 0.28 to 0.48 across independent systematic reviews spanning nearly two decades of trial evidence, and this thermal benefit sits alongside a consistent, independently replicated mortality benefit whose magnitude (relative risk reductions in the general

range of 20-40% depending on the specific population and outcome window) is broadly compatible with thermal protection being one, though certainly not the only, mechanistic pathway involved [9,10,11]. Mechanistic studies using continuous temperature monitoring, rather than single-timepoint classification, reinforce that this benefit reflects a genuine physiological phenomenon — maternal thermal responsiveness to a cooler infant, sustained stable thermal contact across hours of skin-to-skin positioning — rather than an artifact of how hypothermia happens to be measured or defined in the largest trials [14,15,17].

At the same time, the evidence base has matured enough to surface real, unresolved questions rather than simply accumulating more studies that confirm the basic finding. The contrast between the WHO iKMC trial's clear survival benefit and OMWaNA's more equivocal result in a more acutely unstable population is the most consequential of these open questions, because it bears directly on how confidently "start immediately, regardless of clinical status" can be recommended as universal guidance rather than as a recommendation that needs population-specific qualification [12,7]. Implementation-science findings on coverage bottlenecks, and the newly documented interaction between climate-driven ambient thermal stress and neonatal vulnerability, add a further layer: efficacy demonstrated under trial conditions is a necessary but not sufficient basis for confidence that the same benefit is being realized at scale, in the health systems and climatic conditions where low-birth-weight infants are, in absolute numbers, most concentrated [20,2]. None of these open questions diminish the strength of the underlying thermal-efficacy finding; they define, instead, the next decade's research and implementation agenda for a genuinely deployment-grounded practice, in contrast to a purely simulated or small-trial evidence base that KMC research left behind some time ago.

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Ethical Approval

Not applicable. As a synthesis of previously published literature, this work did not involve the recruitment of human or animal subjects or the collection of primary clinical data.

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