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# The implementation of infant pain practice change resource to improve infant procedural pain practices: a hybrid type 1 effectiveness-implementation study

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**Abstract**

Implementation of infant pain practice change (ImPaC) is a multifaceted web-based resource to support pain practice change in neonatal intensive care unit (NICU). We evaluated the (1) intervention effectiveness and (2) implementation effectiveness of ImPaC using a hybrid type 1 effectiveness-implementation study (ie, cluster randomized controlled trial and longitudinal descriptive study). Eligible level 2 and 3 Canadian NICUs were randomized to intervention (INT) or waitlisted to usual care (UC) for 6 months. We assessed the number of painful procedures, proportion of procedures accompanied by valid assessment and evidence-based treatment, and pain intensity to determine intervention effectiveness using intention-to-treat (ITT) and wait-list (WL) analyses. Implementation feasibility and fidelity were explored. Twenty-three NICUs participated (12 INT, 11 UC). Thirty infants/NICU were included in the ITT (INT = 354, UC = 325) and the WL (INT = 678, UC = 325) analyses. In the ITT analysis, the average number of painful procedures/infant/day was lower in the INT group [2.62 (±3.47) vs 3.85 (±4.13), $P < 0.001$] than in the UC group. Pain assessment was greater in the INT group (34.7% vs 25.5%, $P < 0.001$) and pain intensity scores were lower [1.47 (1.25) vs 1.86 (1.97); $P = 0.029$]. Similarly, in the WL analysis, there were fewer painful procedures/infant/day [3.11 (±3.98) vs 3.85 (±4.13), $P = 0.003$] and increased pain assessment (30.4% vs 25.5%, $P = 0.0001$) and treatment (31.2% vs 24.0%, $P < 0.001$) in the INT group. Feasibility and implementation fidelity were associated with improved clinical outcomes.

**Keywords:** Pain, Pain in infants, Implementation science

## 1. Introduction

Since the adverse effects of untreated pain in preterm infants were first identified,[1] considerable effort has been dedicated to reducing pain exposure and optimizing treatment. Unfortunately, infants continue to undergo multiple painful procedures in level 2 (intensive care for sick and preterm infants) and level 3 (comprehensive care for more seriously ill infants) neonatal intensive care units (NICUs), where pain relief is inconsistent.[5,8] Repeated exposure to pain may result in increased pain sensitivity, psychological disorders in childhood, learning difficulties, and poor academic achievements.[34]

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Evidence supports skin-to-skin care,[19] breastfeeding,[31] sweet-tasting solutions,[13,35] nonnutritive sucking, holding, and swaddling[25] to mitigate procedural pain in infants. Yet, ~70% of painful procedures are not accompanied by these treatments.[5]

Implementation science (IS) and quality improvement (QI) provide critical pathways for implementing evidence into practice. Using QI, Sawleshwarkar et al.[30] increased sucrose administration from 0% to 96.27% during the study and at >80% for the subsequent 4 years in a level 3 NICU in India.

In a QI project, Lyngstad et al.[24] implemented pain guidelines, pain-assessment certification of NICU staff and pain management flow charts encouraging parental involvement in a level 2 NICU in Norway. After 1 year, 88.8% of pain assessments were conducted as per the guidelines.

Anne et al.[2] implemented QI Plan-Do-Study-Act (PDSA) cycles in a level 3 NICU in India to reduce procedural pain intensity. Mean pain scores decreased, and use of analgesia and automated heel lances (spring-loaded devices to control for the depth of the incision) increased. The mean number of painful procedures/infant/day decreased from 6.5 (±1.8) to 2.7 (±0.9). In a follow-up study,[28] procedural analgesia increased from 11.5% to 75% over 6 months; 40% of infants received analgesia after 1 PDSA cycle, and 81% after 3 cycles.

In a multifaceted QI study in one level 3 NICU,[20] there was a 26.8% decrease in laboratory tests, representing significant reductions in test frequency and cost savings.

Recently, Balice-Bourgois et al.[3] developed an intervention for procedural pain management in neonates in Switzerland, involving clinicians' education and training, parents' education, and a clinical care plan (bundle procedure). However, effectiveness and implementation evaluations have not been conducted.

Studies focused on developing interventions or improving pain practices in single NICUs. In this study, we aimed to determine the effectiveness and implementation of a web-based intervention across settings. Local national and international knowledge users, researchers, and policymakers contributed to the iterative development of infant pain practice change (ImPaC; **Table 1**), a 7-step multifaceted tool for ImPaC.[6,7]

## 2. Aim

The primary aim was to evaluate ImPaC's effectiveness. The primary outcomes were the (1) frequency of painful procedures/infant/day, and (2) probability that an infant had procedural pain assessed with a validated pain measure and treated with an evidence-based intervention. We also examined differences in ImPaC's effectiveness between level 2 and 3 NICUs. The secondary aim was to explore ImPaC's implementation through feasibility and fidelity. We hypothesized that NICUs that implemented ImPaC would have improved clinical outcomes compared with usual care.

## 3. Methods

### 3.1. Theoretical framework

The Consolidated Framework for Implementation Research (CFIR)[10] guided data collection and analysis. This determinant IS framework outlines constructs/subconstructs that act as implementation barriers or facilitators in 5 domains, including the innovation (eg, ImPaC Resource), inner setting (eg, level of NICU), outer setting, implementation process, and individual implementers. Selected implementation outcomes (eg, feasibility [extent to which an innovation can be successfully implemented in a given setting] and fidelity [degree to which an innovation can be implemented as it was originally designed]) were adapted from Proctor's[27] taxonomy.

### 3.2. Study design

A hybrid type 1 effectiveness-implementation study[9] was used to determine intervention effectiveness, while exploring implementation effectiveness. A cluster randomized controlled trial (cRCT) was undertaken to evaluate the intervention effectiveness of ImPaC in level 2 and level 3 NICUs across Canada. A longitudinal descriptive design was used to explore the implementation effectiveness of ImPaC. Ethics approval was received from The Hospital for Sick Children (SickKids) Research Ethics Board (REB), as the Board of Record for the Clinical Trials Ontario Streamlined Research Ethics Review System (CTO project ID: 1863, Toronto, Canada). All participating NICUs obtained ethics approval locally. The study protocol was published[6] and registered at ClinicalTrials.gov before data collection commencement (NCT03825822).

#### 3.2.1. Cluster randomized controlled trial

Canadian NICUs (clusters) were eligible if they (1) had a minimum of 15 designated NICU beds and (2) agreed to be engaged in the study for up to 24 months (across 4 data collection points). After baseline data collection, eligible NICUs were computer randomized to either the intervention (INT) or the usual care (UC) groups.

#### 3.2.2. Intervention group

For NICUs randomized to the INT group, eligible health care professionals were recruited to a Change Team, to lead the pain practice change using the 7 Steps of ImPaC. In step 1, 3 to 5 Change Team members were recruited. They were eligible to participate if they were English speaking, had ≥3 years of NICU experience, had flexibility and time within their role, and clinical leadership experience. The Change Team determined NICU readiness for change (step 2), conducted audits of existing pain practices (step 3), identified pain practices to target and developed aims (step 4), selected, instigated (step 5), and evaluated (step 6) implementation strategies, and planned for next steps (step 7). Before ImPaC implementation, Change Teams completed a standardized 1-hour online training session delivered by the lead site covering study expectations, how to implement the 7 ImPaC steps and sources of support. After training, Change Team members were granted unlimited access to and encouraged to use of ImPaC for a 6-month period.

#### 3.2.3. Usual care group

Neonatal intensive care units randomized to the UC group continued with their unit or institutional pain practices as usual for 6 months. After completing the wait-list period, the UC group was offered ImPaC in an equivalent manner and interval to the INT group.

### 3.3. Intervention effectiveness

#### 3.3.1. Primary clinical outcomes

Clinical outcome data to determine ImPaC effectiveness were collected at: T1—baseline, T2—intention-to-treat (ITT) analyses, T3—wait-list (WL) analyses, and T4 sustainability (T4 will be reported

**Table 1**

**Implementation of infant pain practice change resource steps.**

| Step | Description of ImPaC* steps | Estimated time to complete |
|---|---|---|
| 1 | Complete a checklist on the characteristics and strengths of a small team of 3-5 healthcare professionals responsible for implementing a practice change on the unit | 4 wk |
| 2 | Complete the ImPaC readiness for change survey and review your individual or team results | |
| 3 | Using the brief audit tool, perform about 10 infant chart audits to identify the unit's current pain assessment and management practices | |
| 4 | 1. Based on the audit results, select a pain assessment measure or pain management intervention that will be the focus for practice change<br>2. Review the evidence briefs. Consider measures or interventions that are the most feasible, relevant, and important for the infants, staff, and organization at this time<br>3. Create an aim statement and specify the percentage of change the team is aiming to achieve, and the time frame to achieve it. For example: We aim to increase pain assessment with the NIPs tool from 20% to 40% over the next 8 wk | 2-3 mo per cycle |
| 5 | 1. Select the knowledge translation (implementation) tools (eg, mini presentations, stickers, screen savers) to help implement the pain assessment or management change into practice<br>2. Complete the activity planner to develop a detailed implementation plan | |
| 6 | As in step 3, use the audit tool to perform at least 10 infant charts audits after the practice change implementation period; compare the audit results with the results generated in step 3 to see if there is improvement | |
| 7 | Evaluate the pain practice change and the implementation process; repeat steps 4-7 (cycle) until the desired practice change is achieved | |

*ImPaC is a multifaceted web-based tool involving several implementation strategies,[26] such as identifying and preparing the change team (champions) (step 1), assessing for readiness and identifying barriers and facilitators (step 2), auditing and feedback (steps 3 and 6), distributing educational materials, making training dynamic, reminding clinicians (steps 4 and 5), and re-examining the implementation (step 7).
ImPaC, infant pain practice change; NIPS, Neonatal Infant Pain Scale.

at a later time). In all participating NICUs, a trained local research coordinator collected data from ~30 infants who had been hospitalized for a minimum of 24 hours at each data collection point. Data included the frequency of (1) painful procedures/infant/day; (2) painful procedures with accompanying pain assessment and the pain intensity score using a valid pain measure [eg, Premature Infant Pain Profile—Revised (PIPP-R);[33] Neonatal Infant Pain Scale (NIPS),[23] Behavioral Indicators of Infant Pain (BIIP)[16]]; and (3) pharmacological and nonpharmacological pain treatment interventions accompanying the procedure.

As the unit of analysis was the NICU and not individual infants, the local REBs approved an opt-out approach to consent for infants whose parents did not wish to participate. Data were collected electronically within a 1- to 4-week period in a site-specific REDCap[11,12] form hosted at the lead site. Database monitoring for each NICU was performed weekly during data collection by the lead site. Local research coordinators were prompted to address any conflicting or missing data issues before data collection was completed. **Figure 1** summarizes the outcomes, and data collection and analyses processes for the INT and UC groups.

#### *3.3.2. Sample size calculation*

Sample size was calculated based on the most conservative scenario of a binary outcome (eg, pain assessed with a validated measure) measured at the infant level. Data were collected from 30 medical records of eligible infants randomly selected in each NICU. Assuming an interclass correlation coefficient of 0.2, the variance inflation factor because of the cluster design is 6.8. With 16 NICUs, there was an 80% power to achieve statistical significance at the 5% level, 2-sided if the treatment arms differ by 0.67 SD (between-patient, within cluster), representing a moderate effect size. Using estimates from previous studies,[33] this would yield detectable differences of 0.33 for the binary outcome pain assessed with a valid instrument and 0.27 for the binary outcome any pain treatment. A dropout rate of 10% of the sites was anticipated; therefore, 18 units were targeted to be enrolled. However, because several sites included associated units (eg, level 2 and 3 NICUs in the same setting), all partnered units were invited to participate resulting in 23 participating NICUs. Statistical power would be greater for continuous outcomes and outcomes examined at the procedure level.

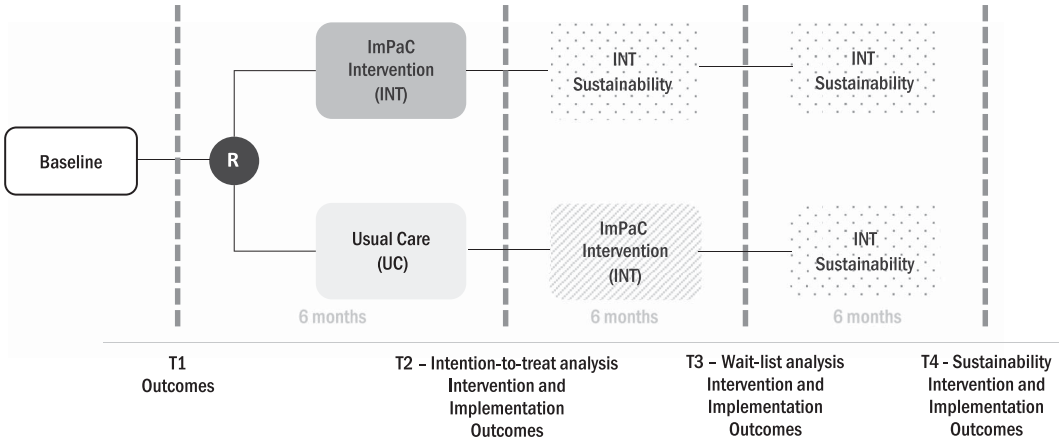


**Figure 1.** Study design, data collection, outcomes, and analyses.

### *3.4. Randomization*

Enrolled NICUs were randomized upon completion of baseline data collection (T1). Using a computer-generated random allocation sequence (www.randomize.net), the lead site randomized clusters to INT or UC groups. Randomization was stratified by NICU care level (level 2 and level 3) in blocks of 4. Neonatal intensive care units at the same site that shared a common governance model (eg, had the same manager) were randomized together. The lead site informed the NICUs of their allocation and provided guidance on the next steps in a standardized manner. Blinding was not possible because of the visible nature of the intervention.

### *3.5. Statistical analyses*

Intention-to-treat statistical analyses were undertaken to determine intervention effectiveness after the 6-month ImPaC intervention period (time 2). Descriptive statistics were used to summarize characteristics of infants and NICUs enrolled. Given the lack of independence in outcomes because of sampling of multiple patients from the same NICU, inferential statistical methods that accounted for this clustering were used. A separate WL analysis was conducted comparing the UC 6-month outcomes from T2 with the combined INT outcomes at T2 and T3 (after UC units had 6-month access to the Resource). Parameter estimation was facilitated by generalized estimating equation (GEE) models accounting for clustering of patients within NICUs, and of procedures within patients within NICUs as necessary. Generalized estimating equation models for binary outcomes (ie, logit link) modeled implementation outcomes in both groups while including contextual covariates (ie, levels of care). All models were assessed for goodness-of-fit. Generalized linear models were used to model continuous outcomes (eg, number of painful procedures per day). For pain intensity scores, values were recorded according to the measure implemented in each site (eg, PIPP-R, NIPS, BIIP, and others) and rescaled to range from 0 (no pain) to 10 (severe pain).

## 4. Descriptive longitudinal study

### *4.1. Implementation effectiveness*

#### *4.1.1. Secondary outcomes*

A descriptive longitudinal design was used to explore implementation effectiveness (ie, feasibility, fidelity). We assessed feasibility by determining the number of hours the change team spent implementing the steps of the Resource in the NICU, and fidelity as the number of the 7-step cycles that were completed. Intervention feasibility and fidelity data were analyzed at T2 (INT) and at T3 (UC) after the 6-month use of ImPaC. These data were captured within the Resource (back-end data). These back-end data were objective because they were calculated through the automatic capture of time spent in the Resource as users signed in/out.

### *4.2. Statistical analysis*

Frequencies and proportions were used to summarize categorical measures of feasibility and fidelity (eg, use of tool) and mean values and SDs were used to summarize continuous measures (eg, hours spent using tool). Differences were determined in clinical outcomes between units completing 1 or more cycles of change (ie, fidelity) and units completing less than 1 cycle of change using GEE techniques, as above, to account for the lack of independence of outcomes reported within units.

### *4.3. Differences from the study protocol*

Wait-list analyses were not originally included in the published study protocol[5] or trial registration. We expanded the analyses given all NICUs randomized to the UC group chose to have the intervention after being wait-listed. This allowed us to collect implementation and intervention data from twice as many units and conduct the waitlist analyses in addition to the intention-to-treat analyses.

## 5. Results

### *5.1. Description of neonatal intensive care units*

Twenty-three NICUs (12 INT; 11 UC) from across Canada, stratified by level 2 or 3 care, participated in the study (**Fig. 2**). The average number of occupied beds per NICU was 31 (range 10-75). Data from ~30 infants per site (T2: INT = 354, UC = 325; T3: INT = 358, UC = 324) were collected. As there were significant differences in gestational age (GA) at baseline (T1), all analyses were adjusted for GA (**Table 2**).

### *5.2. Intervention effectiveness*

#### *5.2.1. Intention-to-treat analysis*

At T2, the average number of painful procedures/infant/day was less in the INT group [INT 2.62 (±3.47) vs UC 3.85 (±4.13), $P <$

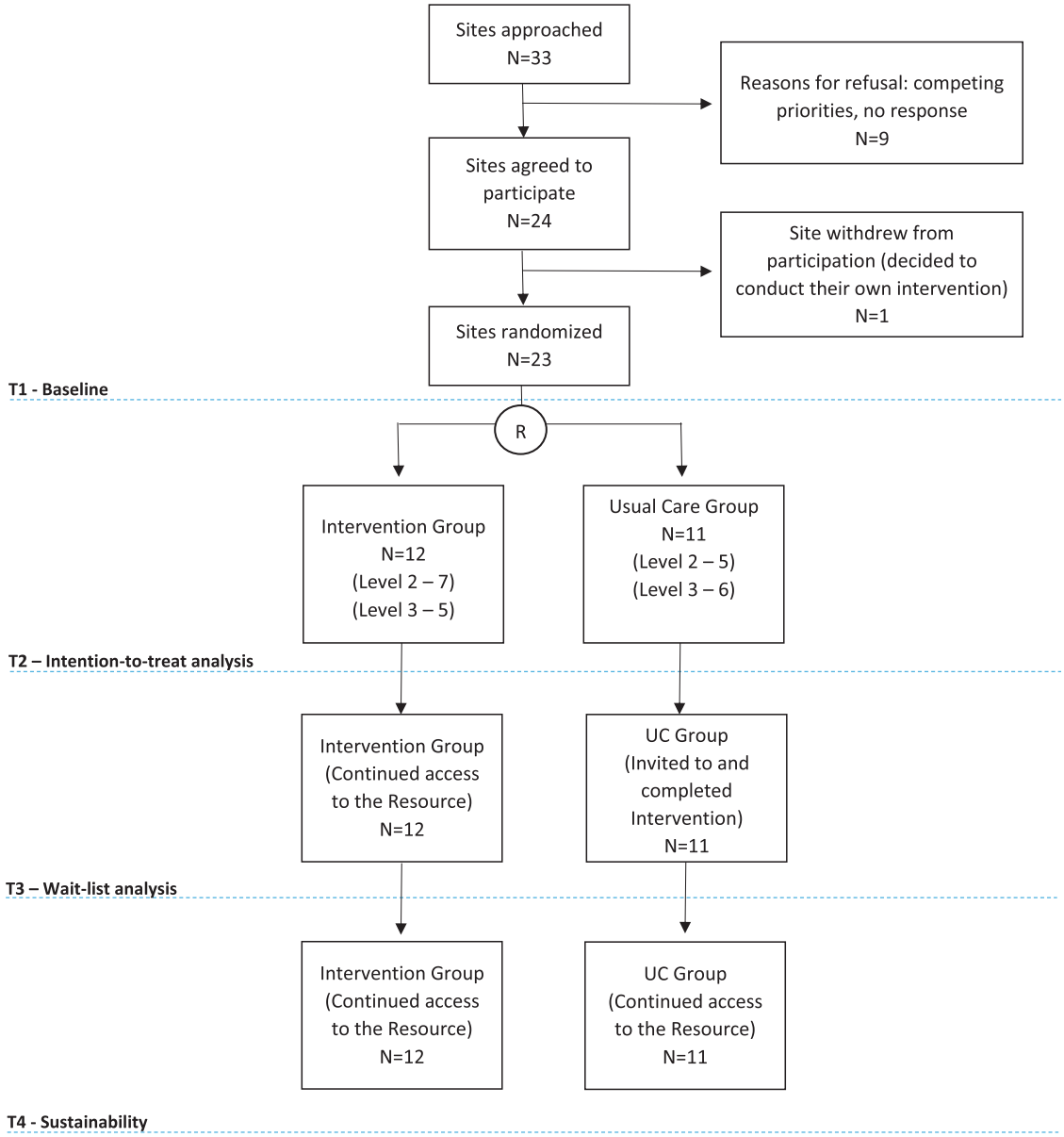


**Figure 2.** Consort flow diagram.

0.001]. The proportion of procedures associated with a validated pain assessment measure was greater in the INT group (INT 34.7% vs UC 25.5%, $P < 0.001$). Pain intensity scores were lower in the INT group [INT 1.47 (±1.25) vs UC 1.86 (±1.97), $P = 0.029$]. There was no significant difference in the proportion of procedures associated with pain treatment, although the use of nonpharmacologic pain treatment was significantly higher in the INT group (**Table 3**).

#### *5.2.1.1. Differences between level 2 and 3 neonatal intensive care units*

In level 2 NICUs, there was no difference in the number of painful procedures/infant/day between INT and UC units. There were significant differences favouring INT units in the proportion of painful procedures associated with validated pain assessment (INT 39.4% vs UC 16.6%, $P < 0.001$), and the proportion of pain treatment strategies associated with painful procedures (INT 39.7% vs UC 23.1%; $P < 0.001$). There was no difference in pain intensity between INT and UC groups (**Table 4**).

In level 3 NICUs, there were significantly fewer painful procedures/infant/day in the INT group (INT 3.16 [±4.14] vs UC 5.32 [±4.45], $P < 0.001$); however, there were no differences in the proportion of validated pain assessment measures accompanying painful procedures or pain intensity. There were significant increases in the UC group in pain treatment but no differences in nonpharmacological pain treatment strategies (**Table 5**).

### *5.2.2. Waitlist analysis*

Waitlisted UC NICUs completed ImPaC and were assessed at time 3. The combined INT data from T2 and T3 were compared to the UC group data at T2. The average number of painful procedures/infant/day was less in the INT group (INT 3.11 [±3.98] vs UC 3.85 [±4.13], $P = 0.003$). The proportion of procedures associated with a validated pain assessment was greater in the INT group (INT 30.4% vs UC 25.5%, $P = 0.001$) and pain intensity was lower in the INT group (INT 1.54 [±1.83] vs UC 1.86 [±1.97], $P = 0.028$). There were significant differences in the

**Table 2**

**Characteristics of infants in participating neonatal intensive care units.**

| | T1—Baseline | | | T2—ITT analyses (6 mo) | | | T3—WL analyses (12 mo) | | |
|---|---|---|---|---|---|---|---|---|---|
| | UC (n = 330) | INT (n = 365) | *P* | UC (n = 325) | INT (n = 354) | *P* | UC (n = 324) | INT (n = 358) | *P* |
| Female* | 145 (43.9) | 174 (47.7) | 0.38 | 146 (44.9) | 164 (46.3) | 0.71 | 192 (59.3) | 193 (53.9) | 0.16 |
| Gestational age (wk)† | 33.6 (4.5) | 32.5 (4.5) | <0.001 | 33.5 (6.1) | 31.6 (4.5) | <0.001 | 33.34 (4.58) | 31.33 (4.60) | <0.001 |
| Chronological age (d)† | 19.6 (26.7) | 19.9 (28.5) | 0.87 | 20.9 (30.1) | 21.5 (30.0) | 0.78 | 19.54 (22.54) | 25.52 (36.87) | 0.015 |
| Birth weight (g)† | 2448.1 (880.2) | 2268.2 (1016.4) | 0.078 | 2530.8 (1221.8) | 2223.4 (1084.6) | <0.001 | 2453.0 (909.5) | 2193.6 (968.5) | <0.001 |

* Values are presented as number (%).
† Values are presented as mean (SD).
INT, intervention; ITT, intention to treat; T1, time 1; T2, time 2; T3, time 3; UC, usual care; WL, wait list.

proportion of procedures with any pain treatment (INT 31.2% vs UC 24%, $P < 0.001$) and more nonpharmacologic pain treatment was associated with the INT group (INT 29.2% vs UC 19.9%, $P = 0.001$) (**Table 3**).

#### *5.2.2.1. Differences between level 2 and 3 neonatal intensive care units*

In level 2 NICUs, there was no significant differences in the frequency of painful procedures/infant/day or pain intensity between INT and UC groups. There were significant differences favouring the INT group in terms of pain assessment (INT 39.4% vs UC 16.6%, $P < 0.001$) and in pain treatment practices overall (INT 43.8% vs UC 23.1%; $P < 0.001$) (**Table 3**). In level 3 NICUs, the average number of painful procedures/infant/day was less in the INT group (INT 4.07 [±4.70] vs UC 5.32 [±4.45], $P = 0.002$). There was no significant difference in pain assessment or treatment associated with painful procedures although more nonpharmacological pain treatment was used in the INT group (**Table 5**).

### *5.3. Implementation effectiveness*

Change Teams spent, on average, 10.18 (±4.36) hours interacting with ImPaC during their 6-month intervention period. In NICUs, where Change Teams spent more time implementing ImPaC, positive change was demonstrated in reducing the number of painful procedures and increasing pain assessment and treatment practices (**Table 6**).

Change Teams in 14 of 23 NICUs (60.9%) used ImPaC as intended (ie, followed all 7 steps to complete 1 or more cycles of change). The remaining 9 of 23 (39.1%) Change Teams did not complete all the 7 steps (most completed 5 or 6 steps). Using the Resource as intended (intervention fidelity) was associated with fewer painful procedures/infant/day as well as with improved use of pain assessment and pain treatment strategies (**Table 6**).

## 6. Discussion

In this hybrid type 1 effectiveness-implementation study, we evaluated ImPaC, a multifaceted web-based resource, designed to change pain practices of healthcare professionals caring for neonates in the NICU. ImPaC (intervention) effectiveness was evidenced by reductions in procedural pain, observed at both the infant level (eg, fewer procedures/infant/day) and the procedural level (eg, greater number of procedures associated with pain assessment and treatment; lower pain intensity scores). These results were generally observed in the primary ITT and the WL analyses. Level 2 NICUs exhibited more significant change in pain

**Table 3**

**Intervention effectiveness outcomes.**

| | T2—ITT analyses | | | T3—WL analyses | | |
|---|---|---|---|---|---|---|
| | UC No. of infants = 325 # procedures = 1252 | INT No. of infants = 354 No. of procedures = 928 | *P** | UC No. of infants = 325 No. of procedures = 1252 | INT No. of infants = 678 No. of procedures = 2110 | *P** |
| Painful procedures/infant/24 h† | 3.85 (4.13) | 2.62 (3.47) | <0.001 | 3.85 (4.13) | 3.11 (3.98) | 0.003 |
| Any validated pain measure used with procedure‡ | 319 (25.5) | 322 (34.7) | <0.001 | 319 (25.5) | 642 (30.4) | 0.001 |
| Average pain intensity/procedure† | 1.86 (1.97) | 1.47 (1.25) | 0.029 | 1.86 (1.97) | 1.54 (1.83) | 0.028 |
| Any pain management associated with procedure‡ | 301 (24.0) | 252 (27.2) | 0.053 | 301 (24.0) | 649 (31.2) | <0.001 |
| Pain management strategies/procedure† | 0.39 (0.84) | 0.40 (0.74) | 0.78 | 0.39 (0.84) | 0.50 (0.85) | 0.002 |
| Any nonpharmacological§ pain management associated with procedure‡ | 249 (19.9) | 241 (26.0) | <0.001 | 249 (19.9) | 615 (29.2) | 0.001 |
| Nonpharmacological§ pain management strategies/procedure† | 0.30 (0.70) | 0.38 (0.72) | <0.001 | 0.30 (0.70) | 0.46 (0.83) | 0.001 |

* All analyses were adjusted for GA.
† Values are presented as mean (SD).
‡ Values are presented as number (%).
§ Includes breastfeeding, facilitated tucking, nonnutritive sucking, skin to skin care, sucrose, and swaddling.
GA, gestational age; INT, intervention; ITT, intention to treat; UC, usual care; WL, wait list.

**Table 4**

**Intervention effectiveness outcomes in level 2 neonatal intensive care units.**

| | Intention-to-treat analyses (T2) | | | Wait-list analyses (T3) | | |
|---|---|---|---|---|---|---|
| | UC No. of infants = 145 # procedures = 295 | INT No. of infants = 174 No. of procedures = 360 | P* | UC No. of infants = 145 No. of procedures = 295 | INT No. of infants = 318 No. of procedures = 644 | P* |
| Painful procedures/infant/24 h† | 2.03 (2.79) | 2.07 (2.50) | 0.70 | 2.03 (2.79) | 2.03 (2.58) | 0.99 |
| Any validated pain measure used with procedure‡ | 49 (16.6) | 142 (39.4) | <0.001 | 49 (16.6) | 254 (39.4) | <0.001 |
| Average pain intensity/procedure† | 1.22 (1.56) | 1.32 (2.07) | 0.74 | 1.22 (1.56) | 1.22 (1.81) | 0.99 |
| Any pain management associated with procedure‡ | 68 (23.1) | 143 (39.7) | <0.001 | 68 (23.1) | 282 (43.8) | <0.001 |
| Pain management strategies/procedure† | 0.36 (0.77) | 0.60 (0.83) | <0.001 | 0.36 (0.77) | 0.79 (1.02) | <0.001 |
| Any nonpharmacological§ pain management associated with procedure‡ | 68 (23.1) | 142 (39.4) | <0.001 | 68 (23.1) | 279 (43.3) | <0.001 |
| Nonpharmacological§ pain management strategies/procedure† | 0.34 (0.70) | 0.60 (0.82) | <0.001 | 0.34 (0.70) | 0.77 (1.00) | <0.001 |

* All analyses were adjusted for GA.
† Values are presented as mean (SD).
‡ Values are presented as number (%).
§ Includes breastfeeding, facilitated tucking, nonnutritive sucking, skin to skin care, sucrose, and swaddling.
GA, gestational age; INT, intervention; UC, usual care.

assessment and treatment interventions than level 3 NICUs. Implementation effectiveness was demonstrated by a positive relationship between feasibility, intervention fidelity, and the clinical outcomes.

Prevention and treatment of procedural pain in hospitalized infants continues to be an ongoing issue despite evidence that pain is deleterious to cognitive and behavioural development[1] and sensitivity to pain, learning and academic achievement.[34] Although the question of whether healthcare professionals have improved their procedural pain assessment and administration of pain-relieving treatments has been frequently posed,[18,29] practice changes remain inconsistent, yet unequivocal in their importance. Cruz et al.[8] conducted a systematic review, revealing that hospitalized infants undergo 7.5 to 17.3 painful procedures/neonate/day with insufficient pain treatment. A recent scoping review, building on the results of Cruz, found that there was not a significant change over time in the daily number of painful procedures experienced by neonates in the NICU ($P = 0.16$). However, the frequency has declined from 9.16 procedures/infant/day in studies published in 2012 or earlier to 6.48 in studies published from 2013 to date.[5] Despite this downward trend, procedural pain treatment was inconsistent and frequently low (24%-31%) compared with results previously reported (~46%).[18] Realization that effective pain treatment is insufficient for practice

**Table 5**

**Intervention effectiveness outcomes in level 3 neonatal intensive care units.**

| | Intention-to-treat analyses (T2) | | | Wait-list analyses (T3) | | |
|---|---|---|---|---|---|---|
| | UC No. of infants = 180 No. of procedures = 957 | INT No. of infants = 180 No. of procedures = 568 | P* | UC No. of infants = 180 No. of procedures = 957 | INT No. of infants = 360 No. of procedures = 1466 | P* |
| Painful procedures/infant/24 h† | 5.32 (4.45) | 3.16 (4.14) | <0.001 | 5.32 (4.45) | 4.07 (4.70) | 0.002 |
| Any validated pain measure used with procedure‡ | 270 (28.2) | 180 (31.7) | 0.12 | 270 (28.2) | 388 (26.5) | 0.34 |
| Average pain intensity/procedure† | 1.98 (1.74) | 1.60 (1.99) | 0.065 | 1.98 (2.02) | 1.74 (1.81) | 0.12 |
| Any pain management associated with procedure‡ | 233 (24.4) | 109 (19.2) | 0.015 | 233 (24.4) | 377 (25.7) | 0.39 |
| Pain management strategies/procedure† | 0.40 (0.86) | 0.27 (0.64) | <0.001 | 0.40 (0.86) | 0.37 (0.73) | 0.32 |
| Any nonpharmacological§ pain management associated with procedure‡ | 181 (18.9) | 99 (17.4) | 0.28 | 181 (18.9) | 336 (22.9) | 0.010 |
| Nonpharmacological§ pain management strategies/procedure† | 0.29 (0.69) | 0.25 (0.61) | 0.19 | 0.29 (0.69) | 0.33 (0.71) | 0.17 |

* All analyses were adjusted for GA.
† Values are presented as mean (SD).
‡ Values are presented as number (%).
§ Includes breastfeeding, facilitated tucking, nonnutritive sucking, skin to skin care, sucrose, and swaddling.
GA, gestational age; INT, intervention; UC, usual care.

**Table 6**

**Relationship between implementation effectiveness outcomes and clinical effectiveness outcomes.**

| | Relationship between completing at least 1 cycle of change (fidelity) and clinical outcomes | | | Relationship between time spent on tool (feasibility) and clinical outcomes | |
|---|---|---|---|---|---|
| | Completed 1 cycle or more No. of infants = 420 No. of procedures = 1190 | Did not complete a cycle No. of infants = 258 No. of procedures = 919 | *P* | Effect size and 95% CI* | *P* |
| Painful procedures/infant/24 h† | 2.83 (3.75) | 3.57 (4.30) | 0.020 | −0.09 (−0.15 to −0.02) | 0.013 |
| Any validated pain measure used with procedure‡ | 443 (37.2) | 199 (21.6) | <0.001 | 1.06 (1.03 to 1.08) | <0.001 |
| Average pain intensity/procedure† | 1.48 (1.72) | 1.67 (2.04) | 0.22 | −0.0001 (−0.05 to 0.05) | 0.99 |
| Any pain management associated with procedure‡ | 466 (39.2) | 193 (21.0) | <0.001 | 1.10 (1.07 to 1.13) | <0.001 |
| Pain management strategies/procedure† | 0.64 (0.94) | 0.31 (0.66) | <0.001 | 0.04 (0.01 to 0.07) | 0.003 |
| Any nonpharmacological§ pain management associated with procedure‡ | 442 (37.1) | 173 (18.8) | <0.001 | 1.09 (1.06 to 1.12) | <0.001 |
| Nonpharmacological§ pain management strategies/procedure† | 0.61 (0.92) | 0.28 (0.64) | <0.001 | 0.03 (0.003 to 0.06) | 0.027 |

* Slope for continuous outcomes and odds ratio for binary outcomes.
† Values are presented as mean (SD).
‡ Values are presented as number (%).
§ Includes breastfeeding, facilitated tucking, nonnutritive sucking, skin to skin care, sucrose, and swaddling.
95% CI, 95% confidence interval.

change mandates us to consider the importance of evidence-based implementation approaches and strategies that may assist in improving infant pain and developmental outcomes.

The level of care provided in the NICU (level 2 or level 3) also influenced pain practices after ImPaC implementation (**Tables 3 and 4**). There was increased pain assessment and treatment of procedural pain in level 2 vs in level 3 NICUs. However, the average number of daily painful procedures was greater in level 3 NICUs. We speculate that this finding may be because of the presence of infants of lesser gestational age and higher acuity of illness requiring more intensive diagnostic and treatment in level 3 NICUs. Similarly, level 2 NICUs may have had less exposure to painful procedures; thus, ImPaC may have introduced new pain assessment and treatment evidence and novel learning opportunities. A key goal moving forward is to further explore the difference in outcomes in level 2 and level 3 NICUs in relation to pain exposure and treatment.

These results demonstrating intervention and implementation effectiveness of ImPaC are promising. To our knowledge, we are the first group to report on a comprehensive intervention involving a web-based resource for improving procedural pain practices across a broad spectrum of clinical sites. Other researchers have reported on the implementation of single site interventions[2,20,24,28,30] but none have considered the generalizability of an intervention across multiple sites with limited support from a researcher. As ImPaC was only implemented in English-speaking NICUs in a high-income country, we would also want to consider accessibility to ImPaC across a broad and diverse array of users in different contexts (eg, in different income countries, languages, and cultures).

The implementation process is complex, and we need to know more about why ImPaC is not being implemented fully in all settings when users stated that they found ImPaC feasible. Specifically, we need to know which of the 7 ImPaC steps are being underused and why. We need to build on the positive association between clinical outcomes with feasibility and intervention fidelity, especially considering suboptimal pain assessment and treatment practices reported across reviews (ie, 30%-45% of procedures).[5,8] Researchers could implement other IS hybrid designs that focus more on implementation effectiveness and less on intervention effectiveness (eg, IS type 3 hybrid design), given that the effectiveness of the innovation had already been established.

Discussion with users about the intervention (ImPaC), setting, implementation process and users may help to unravel some of this mystery. Attention to potential implementation barriers (eg, time, infrastructure, competing priorities) and facilitators (eg, leadership support, beliefs in the benefits of the intervention)[15] and how best to tailor interventions to address these determinants needs to be addressed.

### *6.1. Research implications*

In this study, the use of a hybrid type 1 implementation effectiveness design[9] allowed us to determine intervention effectiveness while at the same time, to explore implementation. This approach contrasts with the paradigm where research is characterized as a pipeline[4] with the progression of studies moving from efficacy to effectiveness to implementation. This traditional trajectory does not promote tailoring the implementation approach early on and may limit determining the implementation effectiveness (eg, acceptability, reach, cost, sustainability) of web-based resources such as ImPaC, as technology will outpace research performance effectiveness. Attention to site-specific implementation barriers and facilitators for effective implementation and tailoring to the setting in both research and clinical practice is paramount. Given the diversity of infants and clinical scenarios presenting in the NICU, a "one-size-fits-all" approach to implementation of ImPaC is not ideal or realistic. It is important to understand the individual needs of the infants to best select pain assessment and treatment; we can then consider the context where each infant is being cared for to select appropriate implementation strategies. For example, in low-income settings where staffing levels and resources are extremely stretched, it is not surprising that there is little to no pain treatment or education of staff.[21,22] However, when the distribution of pain guidelines is associated with receiving pain-related education and determining competence and compliance with guidelines, pain assessment

and treatment improves.[17] Investigating effective procedural pain prevention and pain management strategies in different economic, geographical, and competency contexts is paramount.

### 6.2. Clinical implications

Considerable evidence has been generated over the past few decades and national guidelines[32] and a pediatric pain standard to enhance competency[14] have been developed. Yet, such a pain standard has not yet been implemented and procedural pain assessment and treatment is not an accepted standard in many NICU settings. We have learned over time that evidence on prevention and treatment strategies is simply not enough—there needs to be a concerted effort to implement this evidence in practice. ImPaC is a resource that focuses on changing pain behaviors of stakeholders using the most up-to-date evidence, validated implementation strategies, support by champions, and engaging health care professionals in practice change using quality improvement principles. The importance of demonstrating the effectiveness of such strategies and the unwavering energy of champions to making resources such as ImPaC available to targeted audiences is crucial if we are to see the statistics change. Support from leadership at the system level including priority of the practice change, available resources, and protected time to supersede individual efforts is required. To improve patient outcomes, the care paradigm must shift from responsibilities of individuals to those of the organization. Thus, the organization will take more responsibility for the quality of pain prevention and treatment.

## 7. Conclusion

Prevention of procedural pain and provision of effective pain-relieving treatment is not solely the result of determining the ideal combination of evidence-based interventions. Rather, we must focus on how to best implement this evidence taking contextual factors (what will work best for whom in what setting), and implementation barriers and facilitators into consideration. The ImPaC Resource provides the basis for a change of healthcare professional pain practice across settings. Intervention effectiveness was demonstrated in that NICUs who implemented ImPaC had improved clinical outcomes; beginning evidence on implementation success was also demonstrated. Given the relative provision of pain assessment and treatment was still relatively low, at the infant and procedural level, future research must look more carefully at the implementation process, mechanisms, and strategies and how these can be adapted to enhance clinical outcomes for infants and their families.

## Conflict of interest statement

The authors have no conflict of interest to declare.

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