Creating the Optimal Environment for Babies’ Brains

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I have no conflicts of interest to disclose

I will not discuss any off-label, experimental, or investigational use of a product, drug, or device

NICU Design – Why it Matters

The NICU Experience – A Defining “Moment”

• For babies
  – Crucial period of brain growth & development
• For families
  – Defining moment for relationships – with their baby, each other, healthcare system, spiritual
• For staff
  – The NICU and what we do there largely defines who we are and how we feel about ourselves

Working Premises

• Babies deserve the best available treatment
• Babies and parents should not be separated because of inadequate space or restrictive policies
• The commitment of a mission-oriented hospital to babies and their families should be as great or greater than to any other program, because the stakes are higher
• The NICU environment should meet the needs of all those who inhabit it

Developmentally-appropriate design and care: why does it matter?

• Brain weight increases 400% from 26 weeks to term (in 3 months!)
• Brain weight increases 400% from term to adulthood (in 18 years)

"The neonatal synaptic big bang", by Jean-Pierre Bourgeois

From The Newborn Brain, 2nd Ed, edited by Hugo Lagercrantz, MK Honore, Laura Ment, and Donald Peebles, Cambridge University Press, 2010
**Cortical Hubs in Infants vs. Adults**

<table>
<thead>
<tr>
<th>Adults (association, information processing)</th>
<th>Infants (visual, auditory, and sensorimotor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pancuneus</td>
<td>1. SMA/cingulate cortex</td>
</tr>
<tr>
<td>2. Dorsomedial PFC</td>
<td>2. Left temporal cortex</td>
</tr>
<tr>
<td>3. Medial PFC</td>
<td>3. Left sensorimotor cortex</td>
</tr>
<tr>
<td>4. Posterior cingulate cortex</td>
<td>4. Superior right sensorimotor cx</td>
</tr>
<tr>
<td>5. Ventromedial PFC</td>
<td>5. Visual cortex</td>
</tr>
<tr>
<td>7. Left temporal cortex</td>
<td>7. Right inferior sensorimotor cx</td>
</tr>
<tr>
<td>8. Left visual cortex</td>
<td>8. Left parietal lobe</td>
</tr>
<tr>
<td>9. Right insula region</td>
<td>9. Dorsolateral PFC</td>
</tr>
<tr>
<td>10. Left insula region</td>
<td>10. Right sensorimotor</td>
</tr>
</tbody>
</table>

“The pruning of synapses in the developing brain might be compared to the creation of a statue by removing material from the raw stone.”

- Sensory experience we provide is the sculptor for newborn brains.
- Normal development of the brain requires normal stimuli and normal activity — even in utero, but especially ex utero.

**Common Myths about the preterm infant brain**
- A blank slate
- Extraordinarily resilient
- “At rest” during sleep
- Too young for memory, sensitization, habituation, or conditioning in response to external stimuli

**The Preterm Newborn as an Altricial Mammal**
- Altricial vs. Precocial
- Altricial newborns
  - Rely on mother for food, temp control, circadian cues
  - Receive valuable gut flora, immune factors, trophic substances, hormones, and circadian cues via mother’s milk
  - Receive critical kinetic, tactile, thermal, auditory, gustatory, olfactory, and circadian stimuli from mother

**Stimulus**  | **In utero** | **Skin-to-skin with mother** | **Incubator or warmer** |
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound</td>
<td>Primarily mother’s voice and body sounds, transmitted through liquid and solid media</td>
<td>Primarily mother’s voice and body sounds, transmitted through air and solid media</td>
<td>White noise and a cacaphony of unfamiliar sounds, transmitted through an air medium</td>
</tr>
<tr>
<td>Odor/taste</td>
<td>Mother’s, through a liquid medium</td>
<td>Mother’s, through air and touch</td>
<td>Unfamiliar smells and tastes, many of them noxious</td>
</tr>
<tr>
<td>Touch/kinesthetic</td>
<td>Mother’s movement; liquid/muscular interface</td>
<td>Mother’s movement; skin-to-skin interface</td>
<td>Flat, non-human surface with no natural movement</td>
</tr>
<tr>
<td>Circadian</td>
<td>Hormonal, activity, chemical, temperature, heart rate</td>
<td>Temperature, activity, and chemical/hormonal (via breast milk)</td>
<td>None</td>
</tr>
</tbody>
</table>
“That kangaroo care idea is nice for moms, but does it really matter to the baby?”

<table>
<thead>
<tr>
<th>Environment of care</th>
<th>Mother’s Arms</th>
<th>Incubator/Warmer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate sound</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Familiar odors</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Circadian stimuli</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Kinesthetic</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Caress/massage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hormonal/immunologic/neural communication</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Protection</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

**Myths about the incubator**

- Optimal for temperature control?
  - Incubator/warmer temp control is precise, but...
    - Should the temperature that minimizes BMR be the set point?
    - Circadian rhythmicity is obliterated
    - Temp control is not a problem if STS done properly
- Optimal for infection control?
  - Pathogens are as/more likely to be found in/on incubator as on mother’s skin, whereas benign flora are more likely to be found with the mother
  - Infection rates lowered by kangaroo care (Cochrane 2011)
- And perhaps other dangers?
  - e.g., electromagnetic fields (Bellieni et al. Early Hum Dev 2012)

In fact, incubators were never shown to be better than STS care – comparison groups were babies in cribs.

**Benefits of Maternal Care in the NICU: Recent Evidence in Humans**

- Scher et al. – STS (1.5 hrs/day x 4 days/week x 8 weeks) accelerated EEG signs of brain maturation (Clin Neurophysiol 2009;120:1812-8)
- Karolinska – 24/7 presence of the family -> decreased LOS and BPD (Pediatrics 2010;125:e278-85)
- Milgrom et al. - Training parents about neurosensory needs of babies improved white matter development (Ped Research 2010; 67:330-5).
- Infant massage by parents -> improved weight gain (Cochrane 2010)
- Caskey et al – Exposure to parental talk increased infant vocalization (Pediatrics 2011;128:910-6)
- Kangaroo care reduces mortality, sepsis, and LOS (Cochrane 2011)
- Confirming a large body of work in animals and humans showing how crucial mother-infant interaction is in the neonatal period.

**This is not a new concept...**

“It must never be forgotten that, ultimately, the care of even very sick newborns is the responsibility of the parents and that medical and nursing staff exist to assist them in doing what needs to be done while not usurping the parents’ role.”

-1978

**NICU – Locus of Care**

Revisiting an old concept for the 21st Century

- Pre-NICU (from prehistoric times):
  - Baby/Mother ← Family ← Community (friends, spiritual)
- Early NICU (1970s – 1980s):
  - Baby ← Technology ← Staff ← Family, Community
- "Family-Centered" NICU (1990s – present):
  - Baby ← Technology ← Staff, Family ← Community
- NICU of the Future?
  - Baby/Mother/Family ← Staff, Technology ← Community

**We have a long way to go...**

% of time in contact with mother

![Graph showing % of time in contact with mother across different settings](image)
Examples of Data Supporting Developmentally-Appropriate Sensory Environments

Fetal Auditory Development

- *In utero* – lots of sound, mostly low frequency, transmitted in a liquid or solid medium
- Auditory cortex is in an active and critical phase of development in the third trimester
- Fetus learns to recognize certain sounds from the mother *in utero*, and rapidly after birth

Auditory Development in the Preterm Infant

- Occurs in an environment vastly different from the womb
  - Unfamiliar, inconsistent voices and sounds
  - Acquired through an air medium
  - Multisensory input, often unpleasant
  - Sleep often disrupted

How would our care practices change if we had a real-time window into the brain?

Lighting – Circadian Rhythm

- Multiple circadian rhythms established by the third trimester – heart rate, temperature, activity, and several hormones
  - Governed by maternal cues
- Neuronal connections (RHT and SCN) are responsive by 28-32 weeks
  - In the absence of maternal cues, is light the best *zeitgeber* for preterm infants?
Circadian Rhythms - Babies

- Biological mechanisms to respond to light as a circadian stimulus are present by ~32 weeks
- Babies are exposed and entrain to circadian stimuli in utero
- Day-night cycling shown superior to continuous bright or continuous dim lighting
- No evidence that exposure to moderate amounts of light is harmful to premies
- So day-night lighting is important, at least for premature infants >28-32 weeks gestation

But what about infants at <28 weeks? And why do premies in a cycled-light NICU fail to entrain to light?
- Are there additional zeitgebers? – e.g., temp, feedings, activity, melatonin in mother’s milk

What We Know Today...

- Infants of all mammalian species studied suffer in the absence of extensive, intimate contact with their mothers
- STS care has been shown to be efficacious in all cultures studied – Africa, Latin America, Sweden, and Cleveland (even 6 hours/week!)
- Most current NICUs were built without much consideration of these findings
- Neonatal caregivers have done a poor job of recognizing and responding to this science

Sensory Environment of the NICU for Staff

- Staff benefit from:
  – Daylight
  – Bright light at night
  – Reduced noise
  – Ability to collaborate and socialize
  – Ability to control their environment

Circadian Rhythms - Staff

- Bright light exposure at night increases body temperature, alertness, performance, but
- Night-shift workers are more prone to breast and colon cancer and lymphoma, SO
- Although there are other possible causes for this finding (stress, poor nutrition, etc.), since melatonin has antineoplastic effects, the optimal night-time lighting environment for staff is not yet determined.
Light and activity for seven days (Data from Rea, et al – RPI)

- Day shift nurse
- Rotating shift nurse

Sleep – the Most Crucial Time for Babies

- We learn everything when we are awake, and consolidate learning into long-term memory during REM sleep
- Babies learn during both wake and sleep from exogenous stimuli
- Babies’ brains also receive endogenous stimuli during sleep that prepares the cortex for learning
- In all likelihood, babies consolidate long-term neuronal linkages during sleep

Sleep Deprivation is Endemic in the NICU

<table>
<thead>
<tr>
<th>Causes</th>
<th>Cures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babies</td>
<td>Noxious stimuli (lights, noise, resp. support)</td>
</tr>
<tr>
<td></td>
<td>Caregiving</td>
</tr>
<tr>
<td></td>
<td>Displacement from normal environment</td>
</tr>
<tr>
<td>Families</td>
<td>Stress</td>
</tr>
<tr>
<td></td>
<td>Displacement from normal environment</td>
</tr>
<tr>
<td></td>
<td>Travel</td>
</tr>
<tr>
<td>Caregivers</td>
<td>Shift work</td>
</tr>
</tbody>
</table>

Working Premises

- Babies deserve the best available treatment
- Babies and parents should not be separated because of inadequate space or restrictive policies
- The commitment of a mission-oriented hospital to babies and families should be as great or greater than to any other program, because the stakes are higher
- The NICU environment should meet the needs of all those who inhabit it

Therefore, good NICU design requires space specifically designed for the needs of babies and their families, as well as separate spaces for the needs of caregivers

A full understanding of good NICU design requires knowledge of neonatal biology and
- Sociology
- Anthropology
- Psychology
- Occupational Health
- And Much More

Which brings us to...

Individualized environments for the NICU

SFR = Single Family Room

- Private rooms are now the standard in every other area of US hospitals for new construction, and the growing trend in NICUs
- Are they a good idea for NICU? What are the hazards? What are the pitfalls?
SFR – The Rationale

- Optimal environment for the baby
  - Individualized lighting and sound control
  - Infection control
  - Skin-to-skin contact has substantive biological impact, and most closely approximates the in utero sensory environment
- Optimal environment for the family
  - Privacy for interaction with baby
  - Privacy for interaction with med staff
  - A sense of control, belonging, family

Caregivers also benefit from appropriate lighting and noise control.

SFR design permits some nursing functions to be separated from direct patient care areas and provided with lighting and sound that is suitable for adult workers.

SFR – The Current Database

- Adult and Pediatric units proved that the concept was feasible
- Pioneering NICUs demonstrated that the concept was practical
- Pitfalls do exist – a bad SFR design can be worse than current NICUs

SFR Experience

- France – Brest, Angers, Reims
- Belgium – Brussels
- Sweden - Stockholm
- Switzerland – Lucerne
- Netherlands – Nijmegen
- Canada - Toronto
- Australia - Melbourne
- US – nearly 100 units are predominantly or totally SFR design, and many more coming each year

Extended parental presence in SFR improves preterm infant outcomes

<table>
<thead>
<tr>
<th>&lt;30 weeks gestation</th>
<th>Standard Care</th>
<th>FCC (rooming-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS, ICU</td>
<td>43.1 days</td>
<td>32.4 days</td>
</tr>
<tr>
<td>p=.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS, total</td>
<td>66.7 days</td>
<td>56.6 days</td>
</tr>
<tr>
<td>p=.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mod/severe BPD</td>
<td>6.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>OR 0.18 (0.4-0.8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Cabell Huntington NICU

<table>
<thead>
<tr>
<th></th>
<th>OPEN</th>
<th>SFR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS</td>
<td>17.9</td>
<td>15.7</td>
<td>NS</td>
</tr>
<tr>
<td>Vent days</td>
<td>7.3</td>
<td>5.0</td>
<td>NS</td>
</tr>
<tr>
<td>CPAP days</td>
<td>7.4</td>
<td>7.1</td>
<td>NS</td>
</tr>
<tr>
<td>Apnea events</td>
<td>29.3</td>
<td>12.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caffeine days</td>
<td>10.3</td>
<td>7.5</td>
<td>NS</td>
</tr>
<tr>
<td>TPN days</td>
<td>7.3</td>
<td>5.1</td>
<td>0.048</td>
</tr>
<tr>
<td>MBM days</td>
<td>23.2</td>
<td>34.4</td>
<td>0.031</td>
</tr>
<tr>
<td>Late sepsis</td>
<td>11%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Leq</td>
<td>46-53</td>
<td>32-34</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Domanico R, Davis DR, Coleman F, Davis BO / Perinatal 2011;31:281-8.
Subsequent data from this unit has demonstrated no change in staffing levels and a **15% reduction in costs**, when adjusted for acuity and inflation.

### Overall Assessment

<table>
<thead>
<tr>
<th>Category</th>
<th>Old NICU</th>
<th>New NICU</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family Friendly</td>
<td>38.2</td>
<td>65.1</td>
<td>+26.9</td>
</tr>
<tr>
<td>Staff Work Together</td>
<td>60.7</td>
<td>71.8</td>
<td>+11.1</td>
</tr>
<tr>
<td>Care Given to Baby</td>
<td>69.1</td>
<td>81.2</td>
<td>+12.1</td>
</tr>
<tr>
<td>Care to Family</td>
<td>55.4</td>
<td>68.6</td>
<td>+13.2</td>
</tr>
<tr>
<td>Likely to Recommend</td>
<td>71.4</td>
<td>82.6</td>
<td>+11.2</td>
</tr>
</tbody>
</table>

Vanderbilt Family Study (Cont)

- Although physicians continued to round in the usual fashion, presence and participation of families became normal in the private rooms
- No changes in nursing ratios occurred

### Two Sides of the Same Coin...

- **Privacy**
  - Families need it, and we are mandated to provide it
- **Isolation**
  - An inevitable by-product of privacy
  - Perception varies according to culture (of community as well as NICU), individual, situation
  - Addressed by good design (e.g., welcoming, easily accessible gathering areas), programs (e.g., MoD Family Support), and high level of awareness by staff
**St. Paul Children’s – Conclusions**
Smith, Schoenbeck, Clayton (Work 2009;33:211-27)
- Staff perceive the private room environment to be consistently better than open bay in relation to:
  - Work environment quality
  - Patient care quality
  - Job quality
  - Interaction with NICU patient care technology
  - Interaction with NICU patients and parents
  - Quality of life off-the-job
- Staff perceive open bay to be substantially better than private room for interaction with other members of the NICU patient care team

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**Key studies on infant outcomes in SFR**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Controls</th>
<th>(+) Findings</th>
<th>(-) Findings</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortenstrand et al Pediatrics 2010</td>
<td>Stockholm</td>
<td>RCT</td>
<td>decreased LOS, BPD</td>
<td></td>
<td>70% STS</td>
</tr>
<tr>
<td>Domanico et al J Perinatol 2011</td>
<td>West Virginia</td>
<td>historical</td>
<td>decreased apnea, TPN; increased breast milk use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stevens D et al J Perinatol 2010</td>
<td>Sioux Falls</td>
<td>historical</td>
<td>Reduced cost, noise; increased staff and parental satisfaction</td>
<td>increased support staff needed</td>
<td></td>
</tr>
<tr>
<td>Pineda RG et al J Perinatol 2011 and unpublished</td>
<td>St. Louis</td>
<td>historical</td>
<td>increased parental presence</td>
<td>increased parental stress; delayed language devt.</td>
<td>Limited STS; no overnight</td>
</tr>
</tbody>
</table>

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**Oklahoma Children’s “Neonatal Village”**

**Newborn Intensive Care, Blank Children’s Hospital, Des Moines, IA**

Informal destinations at the end of hallways

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**Staff Lounge**
Meriter Hospital Madison, WI
Good Samaritan Hospital, Legacy Health System
Adult ICU Garden, Portland, OR

Good Samaritan Hospital, Legacy Health System
Adult ICU Garden, Portland, OR

Small space captured for critical care on an upper floor in a vertical building.

Design that Lifts the Spirit

• A well-recognized concept, but of particular importance in healthcare facilities
• Important elements include
  — Access to daylight and nature
  — Scale
  — Color
  — Form (angular is not natural!)

A design that is optimal from a functional standpoint but does not nourish the spirit treats patients, families, and caregivers as less than fully human.

Nurturing Environments — 21st Century Style

WIHRI – not so long ago
WIHRI NICU - 2010

Neuroprotective Elements of the Newborn Environment

• Normal flora
• Mother’s milk
• Appropriate sensory stimuli
• Extended maternal contact
  — Important in its own right, but also promotes all of the others, thus reinforcing a virtuous cycle
  — If we understand that all the baby’s senses are engaged even when asleep, where is the best environment for them?

Single-family rooms are a means to an end — they are a better environment, but do not replace the mother’s arms as the optimal environment for all newborns.

Natural Neonatal Neuroprotection
(courtesy of Dr. Nils Bergman)

Feeding choices | 1970 | 2010
---|---|---
Formula | Preferred — convenient, sterile, varied “recipes”, cheap | Used in only a few ELBW babies, formulated to be as much like breast milk as possible
Breast milk | Rarely used, and then only with precautionary measures | Used preferentially; considered the gold standard
Environment of Care -> Incubator/ Warmer Mother’s Arms
Today Warm, secure Hassle, risky
NICU of the Future Devoid of human contact and normal stimuli; used sparingly Natural extension of fetal environment; rich source of natural stimuli

The “Elevator Speech”:
• **Nowhere** in the hospital is the need greater:
  — Crucial period of brain development
  — No patient needs their family more — emotionally and biologically.
  — Potentially just as life-changing for the family
• Important, profound things are also happening elsewhere in the hospital, but not with the frequency or long-term impact of the NICU — for better or worse, brains and families are being formed for a lifetime every day in the NICU.

If you can remember only one thing...
The incubator will never be more than a meager alternative to intimate and extended contact between a baby and its family.

The best 21st Century NICU designs begin with this premise and does not sacrifice it for convenience, lack of imagination, or false economies.

We shape our buildings and afterwards our buildings shape us.”

-Winston Churchill

Resources
• Recommended Standards for Newborn ICU Design –
  www.nd.edu/~nicudes/
  – Also published in supplements to the Journal of Perinatology in 2007 and 2012, with several accompanying articles of interest
• Clinics in Perinatology – June ‘04 and December ‘11
• Gravens/March of Dimes Conference – Clearwater Beach, FL – Feb 28 – March 2, 2013
  www.cme.hsc.usf.edu and on Facebook

Summary of Arguments For/Against Individualized Environments in NICU
• **FOR**
  — Science – Neurodevelopment of prematures
  — Business Case – Family satisfaction surveys
  — Patient Rights – Privacy, HIPAA
• **AGAINST**
  — Staff - Concern for the well-being of the babies
    • But dozens of units have demonstrated safety
  — Administration - Cost/space concerns
    • If LOS and outcomes improved, major cost savings
    • Since charges and needs are similar to adults, space should be also, except for the size of the bed (~2 sq m)
The 90% Concept

• Build enough rooms to meet 90% of census needs
• ~300 sq ft with dual headwalls
• At least one larger room for higher-order multiples or unrelated infants/families who prefer community setting
  * Families get choice - private or community setting
  * Unit can flex to 150% or more of anticipated need

Paying homage to the wrong god?

• Moving into a beautiful new unit where babies spend little time in the arms of their parents pays homage to the wrong god
  – We did this once before (in the 80s), when high technology was our epitome
• Like building a beautiful new house but making your kids live in the basement
  A well-designed NICU is only a means to an end – which is optimal health - and neurodevelopmental health in particular - for our babies and their families!

Some Additional Elements of Future NICU Design – Seeing 2020

• Sustainable design
  – Greater use of daylight, natural materials
  – Reduced use of electricity, water
• Electronic communications
  – Continuous monitoring of many infant functions
  – Continuous connectivity of staff with other staff, data sources, families
• Parents as partners
• Staff as an invaluable resource to be treasured, pampered, and facilitated
• Specialized staff/units
  – Stepdown, tiny babies, surgical, neurocritical care

Practical Considerations for NICU Design

• The “dragons” of SFR design:
  – “We’ll have to walk too far to care for our babies”
  – “We won’t know when our babies are in trouble”
  – “We’ll need more staff”
• The “lions and tigers and bears” of SFR design:
  – Difficulty in hearing non-networked equipment alarms
  – Requires more space and therefore cost to construct
  – “We will be isolated from our colleagues and the parents”
• The “porcupines” of SFR design:
  – Nursing station design
  – Adequate natural lighting for all adult spaces
  – Less control over parent behavior

As you create your design, ask yourself....

• What is your strongest motivation in designing a new unit?
• Is this an inviting place for families?
• Do we give them choices?
• Can we give our patients and their families the assurance that we will continually seek to make their experience the best we can provide?
• Does this design allow you to be at your best, all the time?

What improvements can be expected with a new, well-designed NICU?

• Reduced infection rate
• Sensory environment more closely approximating in utero
• Enhanced family participation, preparation, and satisfaction
• Increased staff health, satisfaction, productivity, and retention
• Reduced environmental impact