Historical Perspective

The Incubator and the Medical Discovery of the Premature Infant

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The invention of the incubator in 1880 ignited a dramatic outpouring of popular and professional excitement over the prospect of reducing premature infant mortality. Yet the technology itself progressed slowly and fitfully over the next 50 years. The story is worth examining not so much from the standpoint of technological progress, but from the perspective of how responsibility for the newborn shifted from mothers to obstetricians and eventually pediatricians. It also illustrates how the history of technology involves more than invention. The invention of the incubator itself was less significant than the development of a system to support the device.

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The history of neonatology before the mechanical ventilator may be likened to that of the American frontier before the railroad. On one level, it was an era of exploration and colonization dominated by a small but colorful cast of characters who saw their task as taming an uncharted wilderness. But on another, the frontier metaphor reminds us that the "unclaimed" territory in question was in fact neither empty nor uncontested. The care of newborns had traditionally been regarded as the province of mothers. The first physicians who attempted to treat premature babies following the invention of the incubator in 1880 found the task of gaining the mother's confidence and cooperation to be at least as challenging as that of applying the new technology. Further complicating their efforts was the fact that doctors themselves were divided. Both obstetricians and pediatricians at the turn of the century claimed that their specialty was better situated to deal with the problems of prematurity. The incubator thus set into motion a three-way contest between mothers, obstetricians, and pediatricians regarding who should care for the premature infant.

This essay will examine the first 50 years following the incubator's invention in 1880 to ask how responsibility for the premature newborn shifted from mother to physician, and eventually from obstetrician to pediatrician, by the Second World War. In doing so, I will be building on the foundations built by earlier clinician-historians. Much of this work, thanks particularly to the efforts of L. Joseph Butterfield and William A. Silverman, has centered on one of the most fascinating phenomena of the premature nursery area, the popularity of incubator baby side-shows in fairs and amusement parks before the Second World War.[1,2] Other writers have dealt with various other aspects of neonatal technology, public health, and particular controversies, such as the retrolental fibroplasia epidemic.[3–5] The main thrust of my own work has been to integrate these various stories into a social context, with as much attention given to who controls a technology as to who invented it.[6] In doing so, I hope to illuminate some points about technological innovation that are obscured by the traditional narrative of linear progress.

Premature Birth in the 19th Century

Finding the starting point for this story—the state of premature infant care before the incubator—is more difficult than might be apparent. To begin with, the word "premature" in the 19th century was not equivalent to what we mean by "preterm." Medical writers instead grouped together all tiny newborns under the category of "premature and weak infants," or congenital "weaklings" for short. Such babies were conceptualized as suffering from a lack of energy or vitality, and those dying from respiratory distress were diagnosed as having congenital atelectasis secondary to feeble breathing. There was further uncertainty regarding whether this state of weakness reflected immature development or some kind of hereditary taint. Many physicians pointed to the example of congenital syphilis to suggest premature birth to be nature's way of expelling a defective fetus.[7]

The premature infant occupied an ambiguous position between physician and mother as well as between fetus and newborn. These infants, like other newborns, were almost always born at home, unless the mother was so destitute to turn to the resources of a lying-in hospital. Although obstetricians were increasingly likely to be present at the birth of these infants over the course of the 19th century, their focus on the mother rarely allowed attention to the infant beyond initial resuscitation.[8] Mothers, however, were accustomed to providing considerable medical care for infants themselves. They were aided in this regard by a substantial body of domestic medical guides popular since the late 18th century.[9,10]

The mortality of these infants was further hidden by the high overall mortality of infancy. In the late 19th century, some 15–20% of all infants in American cities never lived to see their first birthday. The newborn period doubtless accounted for a substantial fraction of this high mortality, yet was not analyzed separately in United States vital statistics until the 1910 census.[11] The fate of premature infants born earlier can only be sketched in general terms. Those born >2 months

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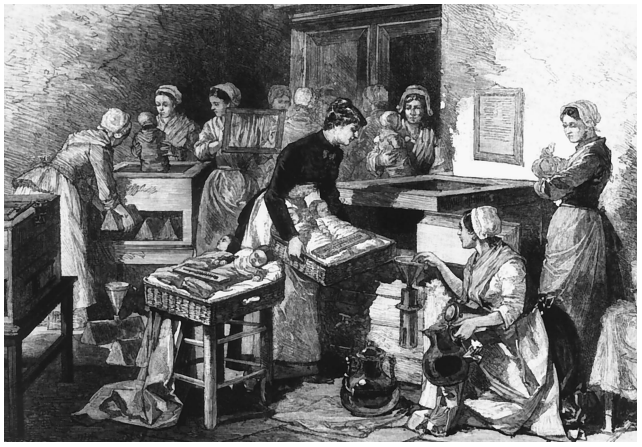


Figure 1 Tarnier's incubators in the Maternité Hospital, Paris, 1884. Source: *Illustrated London News*, 8 March 1884, p. 228.

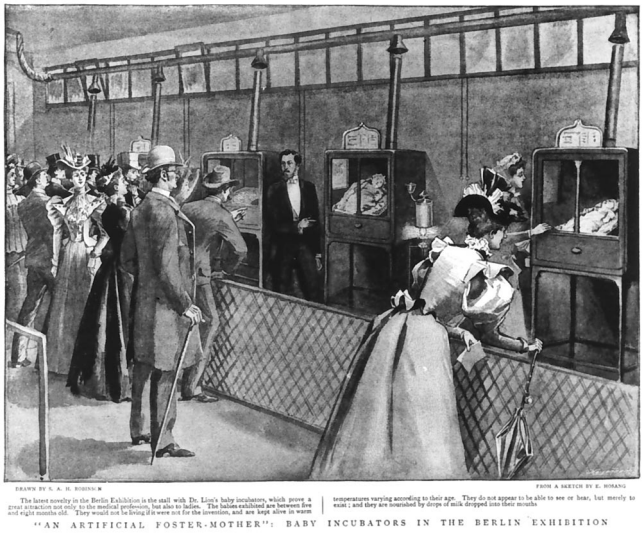
Figure 2 Incubator baby "graduate" reunion organized by Alexandre Lion, 1894. Source: Reference 30.

early with severe hyaline membrane disease likely died at home within a matter of hours. There nonetheless remained a much larger group of infants of 7 to 8 months' gestation whose existence remained precarious and yet not a foregone conclusion. Many died in the first days of life from hypothermia, infection, or weight loss. Mothers might well attempt to rear such infants according to the principles of infant hygiene gleaned from medical guides emphasizing cleanliness, breast-feeding, and the provision of warmth. The latter might be accomplished through such simple means as wrapping the infant in a padded basket heated by hot-water bottles.[12] Regardless of whether or not such techniques succeeded, doctors generally remained out of the picture.

Paris: The Catalyst of Change

The first significant challenge to this equilibrium between doctor and mother was the invention in Paris of a medical technology directed at premature infants, the incubator. Its invention was associated with the French obstetrician Stéphane Tarnier, who in the 1870s sought to find a means to warm the numerous premature infants who routinely succumbed to hypothermia on the wards of Paris's Maternité hospital. A visit to the chicken incubator display in the Paris zoo inspired him to have the zoo's instrument-maker install a similar device for the care of infants in 1880. Tarnier's first incubator housed several infants (befitting its derivation from chicken incubators) who were warmed over a hot-water reservoir attached to an external heating source (Figure 1). He quickly simplified the apparatus to a single-infant model heated by hot-water bottles replaced manually by the nurse every 3 hours. Ventilation relied on simple convection, with air entering at the base and circulating upward around the infant.[13]

Tarnier's invention, it should be noted, hardly represented a quantum leap over other available means of warming premature infants. Aside from the domestic expedient of laundry baskets stuffed with blankets and hot-water bottles, metal warming tubs known as *warmwännen* heated by means of a double-walled jacket of warm water had been in use in some European maternity hospitals for >20



"AN ARTIFICIAL FOSTER-MOTHER": BABY INCUBATORS IN THE BERLIN EXHIBITION

Figure 3 "An Artificial Foster Mother: Baby Incubators at the Berlin Exposition," display of Lion incubators in 1896. Source: Reference 35.

years.[14] The renowned German obstetrician Carl Credé of the Leipzig maternity hospital quickly pointed this out in an 1883 article challenging the originality of Tarnier's accomplishment.[15] Credé in one sense was right: there was little fundamentally novel about the French incubator beyond its use of a closed rather than open design. Many contemporaries believed that any advantage such an arrangement might offer for temperature control was more than countered by the problems it created for ventilation.

But such criticisms missed Tarnier's most important contribution, which was to convince his colleagues that incubators (of whatever design) really made a difference. Reflecting the French predilection for statistical argument in clinical medicine, he compared premature infant mortality before and after the introduction of the device in a large case series that eventually comprised >500 infants.[16] The results appeared impressive: mortality of infants in the

1200- to 2000-gm range fell, he claimed, from 66% to 38%, a decrease of nearly half.[17] In retrospect, it is far from clear that the incubator itself deserved such credit. The simple act of placing the spotlight on premature infant mortality may in itself have improved nursing care or feeding techniques; gavage feeding, in fact, was introduced at the same time. And Tarnier no doubt included many infants that today would be classified as "small for gestational age." But contemporaries rarely appreciated these points. The Paris municipal board moved rapidly to set up incubators in all of its maternity hospitals.

The incubator, as it turned out, was invented at an especially propitious moment in history. French politicians of the time were obsessed by the implications of their country's falling birth rate, which in 1870 was only half of that of rival Germany's. At the core of the debate was the question of whether women were failing to carry out their patriotic "duty" of bearing and raising sufficient children. Practices such as the prevalence of wet-nursing (more common in France than any other European country) and foundling hospitals for abandoned infants came under particular fire. By the 1890s, however, reformers increasingly shifted their focus from moral exhortation to urging that the state play an active role in assisting mothers to raise healthy infants. Infant mortality in this context became a political rather than a mere humanitarian concern, a problem that robbed the nation of future workers and soldiers. The context of widespread anxiety over the prospect of "depopulation" thus helped generate a powerful infant mortality crusade, and to center that campaign on the role of the mother. This maternal emphasis encouraged the involvement of obstetricians in infant mortality efforts. Obstetricians, in turn, naturally concentrated upon newborns.[18,19]

The growing French infant mortality campaign propelled the incubator further, but ironically charged it with an expanded mission that would soon derail it. Hospital-based care had to move beyond treating the relatively small number of infants born in the hospital to have an impact on overall infant mortality. The Maternité responded by developing the first of several *services des débiles* ("hospital services for weaklings") attached to Paris maternity hospitals. These were incubator wards charged with the mission of admitting and treating premature babies brought from home. A dormitory for wet-nurses made breast milk available apart from the mother. Thanks to a donation of 40,000 francs from the Paris municipal council, the Maternité's service opened its doors in 1893 amidst high expectations.[20]

Back to the Mother

These first premature infant nurseries proved to be a disaster. Mortality rates rebounded to >75%, without even counting those babies who had died within 2 days of admission. The increased mortality in large part reflected the condition of the "outborn" infants, babies born at home who frequently arrived at the hospital highly compromised. Nearly one-third of the service's admissions arrived with rectal temperatures of <33.5° C; a total of two-thirds suffered from infection or some other complication.[13] The condition of these outborn infants, it should be emphasized, did not simply represent morbidity sustained in the course of transport from home to the hospital. Most arrived not in a matter of hours, but of 2 or 3 *days*.[21] The service for weaklings had created an open system in which the motivations of the mother had to be taken into account.

Following Tarnier's retirement, the future of premature infant care fell to a new generation of obstetricians. On one side was Adolph Pinard, widely known as both a champion of maternal education classes *(púericulture)* and a French eugenics leader fearful that the French race would continue in a state of decline and degeneration unless vigorous public action was taken.[22] In testimony before the French Senate Commission of Depopulation in March 1902, Pinard condemned the project of trying to rescue the lives of premature babies. After recounting the depressingly high mortality rate encountered in the Maternité's *service des débiles*, he expressed his belief that even the few surviving infants, "for whom so many sacrifices have been made," were likely to "remain for the duration of their lives weak or infirm."[23] Instead, Pinard urged that the government shift its resources from treatment to prevention. Citing his own 1895 study demonstrating that working-class women who spent the last part of their pregnancy resting in a municipal shelter were half as likely to deliver prematurely as were their working counterparts, Pinard became an early advocate of maternity leave as the best strategy to assure a "strong and vigorous population" in the future.[24,25]

The incubator might have been abandoned were it not for the advocacy of Pinard's rival obstetrician in the infant mortality movement, Pierre Constant Budin. Having inherited Tarnier's position overseeing the Maternité's service for weaklings, Budin struggled with understanding why babies arrived in such deplorable condition. "Too often," he wrote, "the *service des débiles* served only as a mortuary depot . . . a place where one transported his little infant when it was going to succumb."[26] He noted that mothers of surviving infants tended to visit less and less over time, sometimes eventually abandoning the baby. To Budin, the implication of these observations was to underline the need to recruit the mother into the infant's care. Mothers were apparently only willing to part with their infants as a last resort after all resources at home had failed.

Budin's response was to condemn the project of hospitalizing premature infants apart from their mothers. Leaving the Maternité for a new position as obstetric chief of the newer maternity hospital, the Clinique Tarnier, he retreated to the simpler task of treating premature infants born within the hospital. He now emphasized breast-feeding more than the incubator, going so far as allowing mothers and wet-nurses to temporarily switch infants until the mother's milk appeared. Budin made a virtue of simple glass incubators at the bedside in this approach. "The glass permits the mother to watch every movement of the poor, fragile little being," noted one observer; "And thus by watching him, almost minute by minute, the mother becomes attached to her baby."[27] Budin continued to assist the mother even after discharge via supervision of the infant in weekly "consultations for nurslings," a remarkable innovation that became an important model for well child care.[28]

Through the publication of his textbook *Le Nourrisson* ("The

Nursling") in 1900, Budin became recognized as an international authority on the care of premature infants. Yet his relationship to the future of neonatology remains complex. His uncompromising insistence upon breast-feeding and maternal involvement anticipated similar movements in our own day. At the same time, it must be admitted that he sounded a partial retreat in terms of treating prematurity. He produced admirable statistics, but quietly shifted his focus to relatively mature infants in the 2000- to 2500-gm range while discarding deaths in the first 48 hours. Nonetheless, it could be argued that this approach made sense in his context, and that his warnings have lost none of their relevance: "First, save the infant, the essential point; second, save it in such a way that when it leaves the hospital it does so with a mother able to suckle it."[13]

Budin died unexpectedly from influenza in 1907, and was eulogized as having saved a "battalion of infants" for France.[3] Obstetric leadership in the infant welfare movement passed on to Pinard, who continued to focus on maternity leave while retaining a secondary role for incubator care. In hindsight, the similarities between the approaches of the two men stand out more than their differences. Both centered their efforts not on technology but on efforts to educate and support the mother. Although the incubator was never abandoned, it retained a decidedly secondary role. This maternal approach resonated well with the broader aims of the French infant welfare movement. It contrasted with a radically different style that emerged outside of Paris.

Another Path: Technological Enthusiasm

The late 19th century is remembered as the era of the professional inventor, particularly in the United States. Yet the French were hardly immune to the lure of technology. In Nice, France, Alexandre Lion, a physician and son of an inventor, developed in the 1890s a much more sophisticated incubator that that of Tarnier. A large metal apparatus equipped with a thermostat and an independent forced ventilation system, the Lion incubator was designed to compensate for less-than-optimal nursing or environment. Unfortunately, none of its features came cheaply, limiting its appeals to charity- or government-supported hospitals.[29]

Lion reasoned, however, more like an entrepreneur than a physician, and struck upon the ingenious solution of charging admission. He created so-called "incubator charities" throughout France supported by spectator admission fees. For 50 *centimes* onlookers could watch the workings of a functional premature infant nursery with complex incubators, situated in a storefront facing a busy boulevard. Lion further promoted his activities through publications in the popular press. Photographs of chubby incubator "graduates" no doubt awakened many members of the public to the potential of the new technology—and reassured them about the prospects of treating the patients inside (Figure 2).[30]

The high point of Lion's career was his opening of the *Kinderbrutenstalt* ("child hatchery"), an elaborate incubator baby show that became the surprise sensation of the Berlin Exposition of 1896. Medical professionals might have scoffed, but so great was the show's popularity that similar (or still larger) shows became a regular feature of World Fairs at the turn of the century. International interest in the incubator, as measured by journal articles, surged far more dramatically than it had at the time of Tarnier's invention. Such "incubator baby" exhibits became an important medium for technological transfer.[1,2]

Thanks to the efforts of one of Lion's associates, the physician-showman Martin Couney, incubator shows came to the United States. Despite having attracted more interest than any other figure in early American neonatology, Couney remains an enigmatic figure.[31] A physician who had apparently worked with Lion at the Berlin Exposition of 1896, Couney set up his own incubator shows in London and the Pan-American Exposition of 1901 in Buffalo, NY, before becoming an American citizen. Throughout his career, Couney protested that he was making "propaganda for the proper care of preemies" in contrast to being a mere showman.[32] Indeed, the early 20th century incubator baby shows offered a standard of technological care not matched in any hospital of the time, featuring entire arrays of Lion incubators staffed by rotating shifts of physicians and nurses.[33] The shows were first and foremost celebrations of technology and its future promise in rescuing the lives of premature infants. They fulfilled a role in generating public expectations for medical technology analogous to that played by television in a later day.

Yet it should be noted parenthetically that it was far from clear that the message Couney intended to transmit was the message crowds received. Although he wanted to display in the technology sections of the fairs, he was invariably assigned the Midway—a context than placed him in the company of exploitative exhibits such as ethnic villages and freak shows. Indeed, one of the infants displayed in the Buffalo exhibit was born to none other than Chief Many Tales of the Midway's "Indian Village," and suitably christened with a staged "birth dance" of costumed native Americans chanting the name of the incubator's manufacturer, "QBATA! QBATA! QBATA!"[34] Such contrasts became still more audacious after Couney agreed to set up a permanent show at Coney Island, where he in fact remained until the early 1940s. Although whether or not the showman actually had any training under Budin is unclear, he certainly departed from Budin in philosophy. One popular magazine captured the shift of emphasis in a caption to its illustration of incubators in the Berlin show titled "An Artificial Foster Mother" (Figure 3).[35] The incubator was changing from an extension of the mother to a substitute for her.

Nonetheless, the technological enthusiasts broke new territory, going well beyond the accomplishments of the French obstetric tradition. This can particularly be seen in the work of the physician who made the most sustained attempt to incorporate a Lion-style incubator station into an actual hospital, the Chicago obstetrician Joseph B. DeLee. The son of a eastern European immigrants who rose to become one of the founding leaders of 20th century obstetrics, DeLee argued that childbirth itself was a pathological process that required systematic intervention.[36] A similar philosophy of early, standardized technological intervention can be seen in his approach to prematurity. While many of his contemporaries tried to set up incubators in

open pediatric wards, DeLee recognized that the incubator was not self-contained but required a supportive system analogous to that developed within the incubator shows. In 1900, he opened such an incubator station at the Chicago Lying-in Hospital. DeLee's technical mastery is perhaps most immediately striking; he was able to intubate and inflate the lungs of premature infants, and created his own thermostats for his incubator. But other innovations were ultimately more important. He set up a transport service whereby a portable incubator could be dispensed with a doctor and nurse to pick up premature newborns in the midst of the Chicago winter. And he recognized the central role of standardized expert nursing care as still more important to the operation of complex incubators than simple ones.[37,38]

For all of its promise, DeLee's station lasted <10 years. It was a case of expectations far out of line of economic realities. Before middle-class women began entering the hospital in large numbers, maternity hospitals remained heavily reliant on philanthropy for support. DeLee attempted mightily to obtain such support, donating his own money and writing publicity articles for local newspapers. He never succeeded.[39] The main thrust of his career, moreover, was moving into interventionistic obstetrics and leaving little time for the newborn. He did rely upon a prominent Chicago pediatrician, Isaac Abt, to supervise the station, but Abt did not sustain interest on his own.[40] DeLee's departure and aborted transfer of power to Abt embodied a larger story overtaking the incubator at this time: the shift from obstetricians to pediatricians as advocates for the premature infant. The transition did not take place smoothly.

No Man's Land

The 10-year period (1910–20) following the closure of DeLee's incubator station represent a hiatus in the incubator story that is difficult to explain. Incubator shows went on the defensive following a gastroenteritis epidemic at the Louisiana Purchase Exposition in 1904, as well as a fire that destroyed the Coney Island show (from which the infants were narrowly rescued) in 1911.[41] Couney persevered with shows at Coney Island and Atlantic City in considerable isolation. The medical profession was remarkably unanimous that its previous enthusiasm for the incubator had been misplaced. One physician asserted in 1917 that "incubators are passé, except at country fairs and sideshows."[42] A 1919 review article noted that "the use of the incubator is becoming more and more unpopular.[43] And the United States Children's Bureau advised mothers in 1920 that "incubators are not now generally used even in hospital cases."[44] This eclipse of the incubator is all the more puzzling given that American public health leaders began a new emphasis on the newborn period after its significance was demonstrated by the 1910 census.[11]

The explanation for the stalemate involves three factors that impeded the successful use of the incubator in the hospital setting (as opposed to the artificial context of a world fair). The first hurdle, the traditional preponderance of home birth, was actually diminishing during the years around the First World War. Hospital birth was well on its way to becoming the norm by 1920, particularly in cities.[8] But two other obstacles remained.

One factor was the rise of an organized eugenics movement. There had always been a certain ambivalence regarding the value of the lives of premature infants in the United States. Immigration, moreover, countered the falling birth rate of the American middle class. American infant mortality reformers tended to speak of "race suicide" rather than depopulation, and called attention to improving not so much the quantity but the quality of the population. These tendencies reached a climax during the First World War and its aftermath. A complex but powerful eugenics movement arose that would have great success in measures such as sterilization of the mentally handicapped and restriction of immigration.[45] Premature infants, who some thought bore the mark of heredity taint and certainly were more concentrated among the poor, were suspect on both counts. Their vague designation as "weaklings" did not help. Mary Mills West, the author of the phenomenally successful Children's Bureau manual "Infant Care", gave little attention in her book to prematurity. The reasons why came forth in a 1915 public address: "These puny, ill-conditioned babies crowd out our welfare stations and hospitals; many of them die in later infancy . . . still others live on dragging out enfeebled existences, possibly becoming finally the progenitors of weaklings like themselves."[46] There had always been ambivalence about saving prematures; now there was rising fear that surviving "weaklings" might beget more of the same.

The third complicating factor was, ironically, the increasing differentiation of obstetrics and pediatrics characterizing the time period. Put more simply, the problems of the newborn infant fell between the two specialties—occupying, to use a phrase contemporaries often borrowed from the First World War, a "no-man's land."[47] A kind of stalemate analogous to the Western front had indeed fallen upon the hospital nursery. Obstetricians tended to retain control of their growing nurseries as hospital birth became routine, but found the challenges of managing childbirth so consuming so as to preclude direct involvement with the newborn. Pediatricians had more interest but rarely had early access to newborns. More often than not they saw premature infants in the setting of infant hospitals, where babies commonly arrived in the same moribund condition that had confounded Paris's services for weaklings. On the rhetorical front, pediatricians sometimes portrayed their obstetric colleagues as fatalistic, and indeed there were well-documented cases of prominent obstetricians writing off newborn infant deaths within the first 2 weeks as stillbirths.[48,49] Obstetricians tended to see prenatal care as their more valuable contribution and deprecated pediatricians for promotion of artificial formula over breast milk.[50] The division seemed especially rigid in the venerated academic institutions of the east coast.

It is not hard to understand how the isolated Martin Couney at Coney Island could portray himself as the last remaining advocate for the premature infant. It was in fact through Couney's example that American pediatrics would finally find its professional champion of the newborn. In 1914, Couney sought to set up a show at Chicago's White City amusement park. The city's medical society objected unless he would consent to supervision by a local pediatrician. The physician thus assigned, Julius H. Hess, was quickly impressed that the incuba-

tor showman knew more about premature infants than did most physicians, and the two eventually became friends.[2] Hess's entry into the field proved to be permanent, and marked the turning point in the incubator saga.

Creating a Technological System

Julius Hess shared with DeLee the distinction of having arisen from Chicago's Jewish community, a legacy that may have had great portent for their interest in premature infants. He was chief of Michael Reese Hospital, an institution founded by the city's more established and relatively wealthy German Jewish population directed at the far less privileged Polish and Eastern European Jewish community that had arrived more recently.[51] There he presumably acquired an early interest in premature infants derived partly from Chicago colleague Isaac Abt (the pediatrician who had assisted DeLee) and reinforced by his meeting Couney. Hess developed his own version of the incubator in 1914, an electrical "heated bed" reminiscent of Credé's design that surrounded the infant in a metal jacket containing hot water.[52] Of more importance was his success in raising financial support to move beyond single incubators to an organized incubator station. Here he had the fortune of living in the only American city that had an infant welfare society advocating specifically for premature infants: Chicago's Infants' Aid Society, founded in 1914 by another prominent member of the Jewish community, Mrs. Hortense Shoen Joseph. It will be recalled that mainstream infant mortality campaigners and public health officials, motivated in part by eugenic concerns, preferred to invest in prenatal care rather than in treatment of the premature infant. One wonders if the Jewish origins of this one exception were more than coincidental given the fact that so much eugenic rhetoric was directed specifically against eastern European immigrants, the kinds of patients who filled Michael Reese Hospital. At any rate, Joseph's unexpected death in 1922 left Hess an endowment of over $65,000 that placed Hess's efforts on behalf of premature infants on secure financial footing.[53]

Largely as a result of the superb incubator station he had developed by the early 1920s, Hess emerged as the leading American authority on the premature infant before the Second World War. To some extent, he tied together the varied strands characterizing the earlier years of American neonatology. Like DeLee, he was a system builder. While many of his contemporaries had rejected incubators, Hess realized that they were in fact useful but had to be incorporated into a supportive context. He expanded the function of the incubator itself into an oxygen chamber, and developed a automobile-based transport system to address the problem of treating outborn infants. Most importantly, Hess worked with his head nurse Evelyn Lundeen to develop a staff of trained nurses following specific protocols.[54,55]

The neonatal nurse, in fact, inherited a position somewhat analogous to that held by the mother in the French obstetric tradition. Nurses were responsible for all day-to-day operations of Hess' nursery, operating much like nurse practitioners or residents today. One physician recalled head nurse Lundeen as "an autocrat who knew more about the care of the premature than the doctors did, and woe unto them that dared to write orders."[56] It is a remarkable statement for a time when hospital nurses typically had little autonomy. Although the mother had been replaced by the nurse, there remained a sense that the premature nursery remained a woman's world—a "no-man's land" in a literal sense. The nurse was the critical mediator in the transfer of responsibility for the premature infant from mothers to doctors.

Hess's research agenda addressed another great factor inhibiting medical interest in the premature newborn: the fear that premature infants were somehow damaged. He conducted long-term follow-up studies of the physical and intellectual development of his premature graduates, whose results reassured many contemporaries.[57] Of great importance in this respect were his efforts to separate premature infants from those born small or early from an identifiable disease such as syphilis. The distinction made by the title of his first textbook, "Premature and Congenitally Diseased Infants," is of great significance in this regard.[58] The older notion of the "weakling" was finally dropping out of usage.

Advocacy thus linked many of Hess's accomplishments. He shared this trait with Martin Couney (to whom he dedicated his first textbook), and in fact the two jointly sponsored a premature infant display at the Chicago Century of Progress Exposition in 1933. This collaboration brought Couney a new measure of respect as the unheeded pioneer of early neonatology. To honor his last show at the New York World's Fair of 1939, the city's medical establishment provided the showman with a special banquet while the *New Yorker* made him the subject of a feature article.[32] Couney closed down his operation at Coney Island soon thereafter, asserting that improved hospital care had rendered it unnecessary.

The country's dramatic rise of prosperity during the 1940s provided the final push to disseminate premature infant technology around the country. This story carries us into a phase of neonatology going beyond this paper, one that centered on rising pediatric research and the consequences of high oxygen therapy.[4] The ascent of ventilator support, "micromethod" blood sampling technologies, and the intensive care nursery lay still further in the future. Yet much of the critical organizational groundwork for these developments was already laid. Premature infants were now largely born in the hospital, with their care provided by specialized nurses supervised by pediatricians rather than obstetricians. Mothers gained access to far more powerful technologies capable of assisting their infants, but lost a certain degree of control. And the division of responsibility between obstetrics and pediatrics frequently meant that continuity of care was disrupted at a time when it was needed the most. The working out of boundaries between physicians, nurses, and parents has thus continued to be a major theme of the expansion of neonatology to the present day.

Conclusion

The most obvious point of this essay is to underline that the history of technology cannot be reduced to a sequence of inventions or discoveries. Invention is but one stage in the development of technology, and

rarely the most important. Inventions, in fact, are frequently modifications of existing devices in search of a new function. It is often surprising how early a mechanical device may appear before it transforms patient care. The example of the mechanical ventilator comes to mind: infant respirators modeled on polio "iron lungs" as well as operating room positive pressure systems were developed as early as the 1950s. Yet as with the incubator, they did not succeed until an individual "champion" incorporated them into a system. Ventilator care did not become routine until a variety of supportive technologies came into being, both within the nursery (intravenous lines, monitors, and micromethod blood sampling) and outside (transport systems and referral networks).[59]

As is the case with many other 20th century technologies, neonatal technology can be most profitably analyzed as a system. Invention is but one step in a process by which a new technology becomes successful. Successful innovators must not only develop a device, but demonstrate that it works—a task that often assumes some kind of supportive context. Attempts to apply the technology in other settings often lead to setbacks that make the role of social context explicit. In some cases, this phase can lead to such chaos that the technology is actually abandoned, as was almost the case with the incubator. But in other cases, these obstacles are countered by "system builders" who consciously seek to incorporate the technology into a new framework. This phase of innovation requires the talents less of a scientist than an entrepreneur, a pragmatic spirit capable of crossing traditional boundaries. It requires that economic barriers be addressed as well as scientific barriers. But if successful, the technology may enter a new phase of growth and even momentum. Newborn intensive care reached this stage in the 1970s.

Finally, the story as told here highlights that neonatology has not evolved along a single line of progress. Its history more resembles a river with many contributing streams, although this analogy suggests more harmony than the historical record indicates. Diversity always has the potential for conflict as well as creativity. It is for this reason that the stories of the many disparate characters who together forged neonatology, only a portion of which have been told here, need to be remembered and retold.

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