Introduction

“Instinct leads mothers to keep their infants warm,” (1) and this instinct surely prevailed during the millennia that preceded recorded history. Organized institutional programs for the care of preterm infants did not appear until the last quarter of the 19th century. Tarnier in Paris and Budin, his intern and successor, were largely responsible for the first protocols for in-hospital global care of preterm infants. (2) Previously, “foundling asylums” cared for the unwanted infants who were “dropped off” by their parents. (2) Provision of “warmth, breastmilk, and tender nurture” by mothers (1) were the very fabric of infant care at home, and because preterm infants were “weaklings,” it followed that their postnatal care should be a continuation of the nurture that began in utero. Physicians cared for neonates at birth only if survival was in question or if the infant was obviously ill. Care at home by mothers was the rule. (1)(3)

The idea of providing warmth for newborns, and for preterm infants in particular, was not always without challenge. Considerable controversy surrounded the overall care of neonates until the first quarter of the 19th century. This was based on a popular belief that newborns were as robust as adults, requiring only Spartan-like “hardening” after birth that could be accomplished best by repeated baths in very cold water. This practice disappeared during the second quarter of the 19th century. The return to traditional warmth went virtually unchallenged over the decades that followed, but there were a few exceptions. A review by Oliver (4) indicates that as late as the middle of the 20th century, some notably knowledgeable physicians advocated immersion of depressed babies in cold water to stimulate the onset of uninitiated breathing. Silverman stated that in the middle 1950s, Virginia Apgar was convinced that ice-water immersion was effective in resuscitation of asphyxiated babies. (5) During the 1930s, a large study in Boston concluded that somewhat lower environmental temperatures were beneficial to preterm infants. (6) This concept pervaded until 1958, when a higher environmental temperature was shown to be associated with lower mortality. (7)

The Evolution of Apparatus

Incubators

In any historic account of thermoregulation, even an encapsulated version such as this one, the story of incubators must not be overlooked, many previous publications notwithstanding. The first provision of warmth in an incubator probably occurred in 1835 at the Imperial Foundling Hospital in St. Petersburg, Russia. (8) This incubator was a metal double-walled tub with an open top. It was conceived by von Ruehl, a physician to the wife of Czar Paul I. Approximately 15 years later, 40 such incubators were in place at the Moscow Foundling Hospital. These incubators also were double-walled, with warm water repeatedly replaced to provide environmental heat. The Moscow version differed from the von Ruehl device only by virtue of a wire-supported sheet of muslin that covered the top of the “warming tub.” (8)

Tarnier originated the earliest version of a heated-air incubator in 1880. Etienne Stéphane Tarnier was an eminent, innovative Parisian obstetrician who was adulated even before he conceived of the warm air incubator. He introduced gastric tube feedings (gavage), invented a new dilator to induce premature labor, and successfully applied a methodology to reduce high rates of maternal mortality due to puerperal sepsis. (1) Tarnier’s incubator, constructed by Odile Martin, a zookeeper in Paris, generally is acknowledged to be the earliest of modern incubators because it was first to use circulating heated air as a source of warmth. (9) Water in a chamber beneath the infant was warmed...
by an externally placed alcohol lamp. Air that was warmed by water wafted upward to provide heat for the infant’s compartment. (9) This large incubator provided heat by convection and housed two infants. Simplified models subsequently were developed by Tarnier’s interns Auvard and Budin. (1) These incubators housed a single infant, and convective warmth was maintained by the passage of air over frequently changed hot water bottles located in a compartment beneath the infant. In 1883, the German obstetrician Crede located in a compartment beneath the infant. In 1883, the German obstetrician Crede published an article in which he questioned the originality of the French incubator. He argued that double-walled “open tubes” had been in use all over Europe for at least 20 years and that the difference between the French incubators and their predecessors was simply the closed design of the former. Nevertheless, Tarnier’s incubator became widely accepted, particularly after Auvard (1) reported that mortality among infants whose birthweights were 1,200 to 2,000 g was reduced from 66% to 38% by use of the incubators. Denucé described 16 days of care during which he did not perceive any loss of body warmth, although the infant died from an apparent need for nutrition. In use, 0.5 L of hot water replaced existing water every 6 hours. The cradle itself was wrapped in a woollen cover to minimize heat loss.

Pierre Budin published his first articles in 1880. A pupil of Tarnier, he achieved international prominence largely by virtue of his book The Nursling, published in 1900. The historic significance of Budin’s work in two large Parisian maternity centers was his formulation of programs specifically designed for research and care of preterm infants. With a global approach to care that exceeded pre-existing practices, Budin promulgated sensitivity to key problems intrinsic to the care of preterm infants. He emphasized maintenance of normal body temperature, but of equal importance were appropriate feedings and attention to the infants’ vulnerability to special disorders, particularly infection. (9) He prescribed the precautions necessary for the prevention of infection as part of his protocol for care in a unique unit that was specifically designed for the care of preterm infants. Budin’s noteworthy place in history is based on his concept of research and his insistence on personnel specially educated in the care of preterm infants. Like Tarnier before him, Budin documented a low mortality rate among infants whose birthweights were less than 2,000 g by maintaining normal body temperatures. Mortality was 98% when rectal temperatures were at 32°C, 90% at 32° to 34°C, and 23% at normal rectal temperatures. (10)

Alexandre Lion’s incubator was patented in 1889. He was a physician in Nice, France, whose father was an inventor. (3)(11) Similar to the cost-driven motivation that permeates today’s medical practices, the overriding attraction of this incubator was the reduced attention needed to operate it. With fewer trained personnel needed, cost was reduced. The Lion incubator was a high point in technology at the end of the 19th century. An automatically regulated heating system was housed in an attractive cabinet. The incubator pulled outside air into its system, adding ventilation to the traditional function of warming. (11) A commentary in Lancet (1897) pointed out that “the main feature of this new incubator is the fact that it requires no constant and skilled care. It works automatically; both ventilation and heat are maintained without any fluctuations whatsoever . . . the only attendance necessary is that needed for feeding and washing the infants.” The Lion incubator was expensive, which limited its availability. Charities and municipal government were early sources of support. Because Lion was probably as much an entrepreneur as a physician, he improvised revenue-producing “incubator charities,” storefront facilities usually located on busy boulevards throughout France. He charged spectator admission, and he advertised his product widely. He did, however, receive professional endorsement from a study by the physician-general of the City of Nice in which a 72% survival rate among 185 infants was reported.

The Lion incubator probably was used by Martin Couney in the 1896 Berlin Exposition and in 1897 at the Victorian Era Exhibition in London. (12) At both of these international exhibitions, Couney exhibited preterm infants in incubators and charged admission fees. Descriptions of the relationship between Lion and Couney are not consistent. (1)(3)(9). In one version, Lion was involved with the sideshow in Berlin for which Couney usually is credited. The Lion incubator was used by Couney, and Lion’s business funded the exhibit. (1) The Berlin Exposition also is described as the high point in Lion’s career, and Couney is described as “one of Lion’s associates.” (3) In another version, there is no mention of Lion. (9) Rather, it indicates that Budin asked his “young associate” Martin Couney to exhibit the “newly modified Tarnier incubator” at the World Exposition in Berlin. “Couney hit on the idea of placing live preterm infants in the exhibit incubators. . . .” (9)
Was this incubator the Lion incubator, and was Couney influenced by Lion’s storefronts?

The first exhibit of preterm infants in incubators at an international fair took place at the Berlin Exposition. In the next few decades, many more exhibitions were to come, virtually all conducted by Martin Couney. Berlin was a howling success. Newspapers published feature stories, and songs were sung in beer halls about babies in incubators. (3)(9) The next year (1897), Couney staged a second incubator show in London at the Victorian Era Exhibition, another shrieking success. An editorial in *Lancet* was laudatory. The British public was enamored of the “weaklings” in incubators. All this theatrical exploitation seems to have begun with the Lion storefronts in Nice, which ultimately evolved into sideshows at international expositions.

The historic significance of this strange combination of showmanship, entrepreneurship, and infant care was that it would dominate preterm care and set its standards for decades to come. Through these years, the technological attraction of the incubators actually was testimony that these “weaklings” could indeed survive if proper care were rendered. Couney’s protocol impressed the few experts who were preoccupied with neonatal care during the early decades of the 20th century. Hospitals had not yet committed to organized programs for the care of preterm infants, and Couney’s protocol at sideshows was apparently of benefit to those infants who were not ill. In 1914, Julius Hess was assigned by the Chicago Medical Society to oversee an exhibit that Martin Couney sought to activate at an amusement park. (3) Hess was impressed with Couney’s expertise, stating that the showman knew more about preterm infants than most physicians. The two men became good friends. Hess later recognized Couney’s expertise in two of his world-famous books. Couney’s methodology withstood critical scrutiny and received praise in more than one editorial in the *Lancet*. Couney also drew praise from Hess’ head nurse Evelyn Lundeen. She took exception to the carnival-like environment in which infants were managed, but she praised the quality of care and the skill of Couney’s nurses. (9)

The sideshow saga continued until 1939, when the exhibit was installed at the New York World’s Fair. After the Fair closed, Couney spent most of his time at Coney Island where he had an ongoing summertime exhibit. He terminated this last show when the New York Hospital (Cornell University) established a preterm infant facility, the first such unit in New York City. His inappropriate showmanship through the decades notwithstanding, Couney’s contribution was nevertheless positive. A bronze tablet in Atlantic City marks the site of his shows in that city. It reads: “Dr Couney was the first person in the United States to offer specialized care for preterm infants.” (9)

In 1900, Joseph DeLee was the first to install an area of incubators in a hospital of full function at the Chicago Lying-In Hospital. (3) For approximately 10 years, DeLee managed preterm infants in modified Lion incubators. He was primarily an authoritative obstetrician whose textbook was used widely. He also established a transport service in which doctors and nurses used portable incubators to transfer babies from other hospitals in Chicago. In time, DeLee increased his interest in the obstetrics for which he was trained. Increasingly, he relied on Isaac Abt, a local pediatrician of national prominence.

Julius Hess became interested in incubators and preterm infants through his associations with Couney and Abt. He established a noteworthy incubator station at the Michael Reese Hospital in Chicago. It gained worldwide recognition largely because Hess operated a functional system of care in which the incubator was but one in an array of devices and procedures that were used for the care of preterm infants. Hess refined and expanded the approach taken by Tarnier and Budin decades earlier and invented his own version of an incubator that was known widely as the Hess Bed. The bed provided a thermal environment that was easily stabilized. It had no windows. The small opening in its hood for ventilation precluded adequate visibility. (13) This incubator used circulating warm water within double walls for warmth. Water was heated by electrical power. Hess also provided a system in which free-flow oxygen was administered in the incubator. (1)(2) For transport, he designed a box that was heated electrically when plugged into the cigarette lighter receptacles in Chicago taxis. (2)

In 1933, Blackfan and Yaglou (6) converted their entire nursery in Boston into an incubator, which they maintained at 27° to 30°C and 60% to 70% humidity. Personnel and babies alike were, thus, in the same environment. This nursery was the “conditioned” one. Temperature, humidity, and ventilation were adjustable. After analyzing data collected over almost 7 years (1923 to 1929), they concluded that infant mortality was reduced significantly in conditions of high humidity and somewhat lowered temperature. They advocated maintaining “subnormal” body temperature because it was “characteristic of prematurity” and low birthweight, suggesting that attempts to elevate body temperature to 36.6°C may result in overheating and its serious consequences. This practice prevailed for a number of years.
(14) until Silverman and colleagues (7) published their pivotal study in 1958, demonstrating that environmental temperatures were associated with higher mortality, particularly in smaller babies. This study virtually eliminated the widespread practice of maintaining subnormal body temperature. The Boston study is the only one that attempted to control environment using the entire nursery as a “walk-in” incubator rather than the microenvironment of an individual baby in an incubator.

At the end of World War II, little more than 10 years following the publication of the Boston study, the Isolette® was produced by the Airshields Company. It was adapted from an incubator designed by Chapple. At this stage of development, an incubator that provided maximum visibility was a high priority. This was feasible through a clear plastic hood. The maximum visibility became a more urgent requirement as management of preterm infants became more active. Babies could be naked in the warmth of an incubator, and now that they were so exposed, their breathing, color, and behavior could be observed continuously. Their newly imposed nudity placed a responsibility on caregivers to provide a painstakingly proper thermal environment. These incubators drew large volumes of air from the nursery through a filter or from outside the hospital. (15) The modern convectively heated incubator had arrived. Heat changes were servocontrolled from sensors placed on abdominal skin or from sensors in air within the incubator. In these convective incubators, the major modality of heat loss was radiation, (16) which bore little relationship to incubator air temperature. In 1966, Hey and Mount proposed that a radiant heat shield be placed within the incubator to minimize radiant heat loss. (17) Six years later, Fanaroff and associates reported use of a similar shield to minimize evaporative heat loss. (18) To minimize these radiant losses, double-walled incubators also became available, but although they diminished radiant losses, they increased convective loss, (19) thus negating the effect on total heat loss.

Radiant Warmers

The use of servocontrolled radiant heat in incubators was reported initially by Agate and Silverman in 1963. (20) They used a “simulated infant” (a black box) with thermistors attached to its inner and outer surfaces. Radiant heat emanated from an electroconductive glass plate assembly (Electropane by Libby, Owens and Ford Company), which was the ceiling of the incubator. When this incubator was studied later by others, survival improved significantly when abdominal skin temperature was maintained at 36°C. (21)(22) However, commercial production was apparently impossible because of technical obstacles that could not be overcome. These are described by one author as occasional shattering of the glass ceiling. (13)

The Sierracin Cradle Warmer® was one of the earliest commercially produced radiant heaters to be applied safely to infant care. (23)(24) This was a transparent plastic hemicylinder from which servocontrolled radiant heat emanated in response to an abdominal sensor. Both ends of the cylinder were open, but overall accessibility was limited. The device soon was replaced by other warmers that allowed complete accessibility.

Today’s radiant warmer bed evolved from the original idea of Agate and Silverman. (20) The first practical application of radiant energy as the sole source of heat from an overhead panel was described in 1969 by Du and Oliver. (25) Theirs was an open bed used for resuscitation in the delivery room. Overhead radiant heating elements were placed 60 to 65 cm above the baby. Heat loss was minimized, and accessibility to the open bed was unlimited, representing an overwhelming advantage. Ordinarily in the delivery room, dried-off babies can be kept warm in a blanket, but if resuscitation is indicated, the radiant warmer becomes an indispensable device. This particular model (Merco Infant Warmer®) was tilted easily and had no safety alarms. (19) It soon was replaced by others with safer designs. The authors correctly indicated that a servocontrolled mechanism would not be necessary for the usual short stay of an infant in the delivery room. (25)

Contemporary versions of incubators and radiant warmers became available at the end of the “hands-off” era of preterm care. Intensive care had begun. The “hands-off” policy was appropriate in its time. There was, after all, little available scientific rationale for aggressiveness. As data accumulated, care became more intensive; sometimes too intensive and sometimes still without scientific rationale. The demonstrated usefulness of a warmer in the delivery room soon led to its widespread use in the neonatal intensive care unit. As intensive care became more active, accessibility to infants became increasingly urgent.

The complications of using the radiant warmer were largely concerned with avoiding manually controlled output of heat (overheating) and monitoring for disruption of skin temperature probe contact (overheating). More gradual in its development, but hazardous nevertheless, was the failure to perceive dehydration due to the excessive insensible water loss that occurs under radiant heat. It soon became apparent that babies managed in these warmers could become severely dehydrated as a
result of the increased transepidermal water loss that was associated with radiant heaters. (26) Presumably this was the consequence of a higher skin-ambient vapor pressure gradient. Increased convective air current around a totally exposed baby also increases evaporative losses, and enhanced blood flow to the skin results from heat-stimulated vasodilatation. Hyponatremia, hypovolemia, and heightened urinary osmolality were noted as water loss progressed to the extreme. The more immature the baby, the more rapid and severe the dehydration. This was a major objection to the use of radiant warmers. I was serving on a United States Food and Drug Administration Panel when several of my colleagues appeared to petition for disapproval of radiant warmers, largely because of their concern for dehydration. Needless to say, the petition was not granted, even though the concern for dehydration was valid. Dehydration is easily avoided by increasing water intake and by use of an appropriate heat shield.

**Heat Shields**

Water loss in the neonate was minimized by the introduction of various types of heat shields. Early studies of heat shields indicated that insensible water loss in radiant heat could be decreased with the use of a Plexiglas® shield, but later studies did not confirm these findings. (27)(28) More important, however, was the fact that Plexiglas® is virtually impervious to infrared energy, absorbing the radiation and blocking passage to the baby. (27) Bell and associates (28) noted that increased radiant output and diminished abdominal skin temperature were associated with the use of such shields and advised against their use. In contrast, polyethylene sheets (blankets) transmit virtually all infrared energy. Baumgart and colleagues (29)(30) reported reduction of evaporative and convective losses with the use of polyethylene blankets. Fitch and Korones (31) reported effective reduction of water loss with the use of an easily manipulated rigid plastic shield consisting of polycarbonate walls and a covering of removable sheets of polyvinyl chloride. That study also demonstrated an 85% reduction in infrared transmission through a Plexiglas® shield. In an incubator, the Plexiglas® shield was appropriate. It reduced insensible water loss by 25% (18) and also reduced heat loss by radiation. (17)

**Servocontrol and Proportionate Response**

A stable thermal environment using either an incubator or radiant warmer generally is maintained by means of a thermistor placed on the anterior abdominal wall. Set points usually are kept between 36°C and 37°C. This practice is based on a 1966 study by Silverman and associates (32) in which oxygen consumption (and, therefore, metabolic rate) was lowest at abdominal skin temperatures of 36°C. Thermal neutrality occurs at this lowest metabolic rate. Oxygen consumption in this study was determined at set points of 35°C, 36°C, and 37°C for 15 to 24 hours. This was the first time that abdominal skin temperature was suggested as the modality of choice for “routine thermometry” in clinical practice.

With general use of servocontrolled mechanisms, wide fluctuations in temperature could occur within the incubator, particularly when port openings were entered for infant care. Perlstein and colleagues (33) correlated increased apneic episodes with the wide fluctuations. Until then, servocontrolled mechanisms turned heat completely on or completely off, but the new observations regarding apneic episodes necessitated installation of proportional (partial) heat control. Perhaps the ultimate attainment of nonfluctuating environmental temperatures was the later description of a mechanism for computer-assisted control of environmental incubator temperatures around the clock. (34) Investigators demonstrated reduced metabolic rates in 105 infants who were managed in a computer-controlled environment compared with 105 infants whose environment was managed in a standard setting without computer control. The equipment demanded detailed attention, and its complicated maintenance seemed to have precluded widespread application. (13)

**The Evolution of Concepts and the Clinical Application of Experimental Data**

The overall benefits of incubators far exceeded their original physical purpose to provide warmth for preterm infants. The apparent success of incubators demonstrated that survival was feasible with appropriate care. The need to provide more than warmth attracted talented workers because with enhanced infant survival, it became mandatory to provide nutrition, to prevent and manage infection, and to resuscitate with supplemental oxygen. Like most other medical efforts, neonatal clinicians have grasped the technology that surrounded care and applied it to sick babies whose improved survival became a source of new information. Today’s apparently effective management of the neonate’s thermal environment is a clear example of this type of “building block” progress.

**Heat Loss**

Modern concepts of neonatal thermoregulation probably began with the report by Day and associates in 1943
in which they demonstrated the limited capacity of preterm infants to adjust to environmental temperature changes. The investigators cited the earlier work of Mordhorst in 1932, who observed increased heat production in cool air, and even earlier work by Eckstein in 1926, who concluded that preterm infants had no important deficiency in physiologic responses to variations in environmental temperature.

Day and coworkers described several basic attributes of the preterm infant’s response to changes in thermal environment that would be confirmed by Brück (36) and Hill (37) approximately 2 decades later. The attributes described are as follows:

1. Preterm infants can maintain core temperature, but only in a narrow range of environmental temperature change.
2. Vasodilatation occurs in warm air, but sweat glands are not functional.
3. The thermoconductivity of preterm tissue is greater than that of adults, increasing the propensity of the preterm infant to lose heat.
4. The ratio of surface area to body mass in preterm infants is considerably higher than in adults.
5. Subcutaneous fat insulation is negligible in preterm infants.
6. The muscular activity of preterm infants is minimal.
7. Measurement of metabolic rate and heat loss by radiation, evaporation, convection, and conduction demonstrates responses known to be characteristic of homeotherms in varying environmental temperatures.

At this point in history, there was every reason to question the pervasive bias of poikilothermy in preterm neonates, but no one did so until 1958. (7) Furthermore, Day’s observations have maintained validity for 60 years when applied repeatedly to a variety of ramifications that are a substantial basis of today’s clinical care.

In comments on clinical experimentation in neonatal medicine, (5) Silverman described Day’s actual presentation of these data to the group in Boston whose subneutral thermal management then was the established protocol in nurseries throughout the country. After his talk, they showed him the charts of currently hospitalized babies in which satisfactory progress and growth were recorded, even though body temperatures were maintained at subnormal levels. Furthermore, they believed that Day’s data were not clinically significant because his observations were made on larger infants who were past 1 week of postnatal age. The homeothermic characteristics of the preterm infant, as shown by Day in 1943, were neglected, and infants all over the world were kept cool for years, as recommended by Blackfan and Yaglou in Boston in 1933. (6)

In the early 1950s, Silverman and his group began a series of controlled clinical trials in the preterm nursery that evaluated a number of their current practices. The fourth trial in this sequence studied the effect of two different incubator temperatures and associated 5-day survival rates, (7) a study that would change the thermal management of preterm infants throughout the world thereafter. The investigators demonstrated an increased 5-day survival among the babies in warmer (31.7°C) incubator ambiance compared with the cooler traditional ambience of 28.9°C. This study was precipitated by the findings of preceding studies in the sequence in which two different humidities were compared in the same environmental temperature. (38) Increased survival was demonstrated in the more humid environment. Detailed examination of the data led to the hypothesis that the increased survival among babies who were maintained in higher humidities was due to the slightly higher body temperatures, which in turn were the result of decreased evaporative heat loss in higher humidities. The pivotal report that followed in 1958 (confirmed later by others) (21)(22) turned the thermal management of the preceding 25 years sharply away from the maintenance of subneutral temperatures. Previously, normothermia was considered to be unnecessary, and it was believed to place the baby at risk for life-threatening overheating. In a later publication, Day and associates (21) stated that even mild cold stress was associated with increased mortality.

Another step toward improved thermal management evolved from the suggestion that temperature in the incubator was better servocontrolled by abdominal skin sensors set at temperatures of 36° to 37°C. (5)(32) This proposal was based on a study by Agate and Silverman (20) in which the use of radiant energy in an incubator was servocontrolled by sensors placed on the abdominal skin. They demonstrated minimal oxygen consumption at these settings in well babies. (32) The use of abdominal skin sensors was based on the earlier findings of Brück (36) and Hill (39) in which skin temperature was shown to have a major influence on metabolic rate, independent of core temperature. The sensitivity of thermoreceptors in the skin to changes in ambient temperature largely governed fluctuations in heat production, as indicated by measured levels of oxygen consumption.

**Heat Production**

The balance of body temperature depends on heat production to replenish heat loss. Therefore, one or more mechanisms must be called into play when the homeo-
thermic neonate, particularly the preterm infant, loses heat to the environment. Exposed to a cold environment, the newborn was shown in the 1960s and before to increase heat production to twice or three times basal level. (40) A series of experiments clearly demonstrated the impact of environmental temperature on neonatal metabolism. (4)(19)(36) In the coldest environments, oxygen consumption rose abruptly in an effort to maintain core temperature. However, this was a losing battle in such a cold environment because the excessive heat loss that was replenished incompletely caused a fall in core temperature. At a somewhat higher 28°C ambience, less heat was lost and core temperature was undisturbed because heat production compensated for losses. When the environmental temperature was raised further (to the neutral zone), oxygen consumption abruptly decreased to neutral levels, even when the core temperature was initially low. These data clearly indicated the role of skin thermoreceptors in initiating a metabolic response to environmental temperature changes. Oliver and Karlberg (41) emphasized that the increase in metabolism provided nonshivering thermogenesis (also known as “chemical heat production”). Shivering was seen rarely in the neonate. Most investigators have surmised that muscle activity contributes little to heat production. (4)

Thermogenesis is largely the consequence of a generalized enhancement of oxidative metabolism and a specific enhancement of metabolic activity in brown fat. The role of brown fat in heat production was described first in the rat by Smith in 1961, (42) and soon thereafter in other newborn animals. (43)(44) In 1964, Silverman and coworkers (45) used Smith’s description of the anatomic distribution of brown fat to measure skin temperatures over 12 body sites in preterm infants exposed to cool air for 1 hour. Skin temperature of the extremities and trunk fell sharply when infants were in the cool environment. The fall in skin temperature over the nape was significantly less than in the other measured sites, and the nape remained relatively warmer throughout the cooling period. On three occasions, skin temperature over the nape was higher at the end of 1 hour in a cool environment than at the onset of the experiment. The authors concluded that the warmer skin temperature corresponded to areas containing the subcutaneous deposits of brown fat described by Smith. In 1966, Aherne and Hull (46) published a remarkably detailed study of human neonates describing the distribution of brown fat and its cytologic appearance in varying conditions. They concluded that brown fat was a major source of nonshivering thermogenesis. The chemical mechanism involves hydrolysis of triglyceride, followed by the oxidation of some fatty acid molecules and the resynthesis of other such molecules to triglyceride. This heat-producing enhancement by brown fat metabolism increases significantly during periods of cold stress and with the infusion of norepinephrine. (37)

Summary

Thermoregulation has been a major underpinning of neonatal care from its earliest involvement with primitive Russian incubators in St. Petersburg to the provision of contemporary care wherever babies are born. Its scientific origins are complex, yet hands-on management of the thermal environment entails simple acts such as placement of heat shields, covering with plastic blankets, drying skin after delivery, or ascertaining proper probe positions. Both the benefits of scientifically based thermal care and the hazards of its mismanagement vary inversely in magnitude with birthweight and gestational age.

There also is some irony in the history of thermoregulation. When Silverman demonstrated in 1958 that warmer babies were more likely to survive, we had come full circle from Tarnier and Budin in the 1880s, who also saved preterm infants by keeping them warmer. The overall benefit of Martin Couney’s entrepreneurial showmanship also was ironic. For one more dose of irony, I point to the report of Miller and associates describing the salutary effect of deep hypothermia on the outcomes of experimentally asphyxiated newborn animals published in 1964. (47)

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