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A Medical Transport System for the Neonate

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THE REGIONAL CARE of critically ill newborn infants is a concept that has gained rapid acceptance.[1,2] Development of highly sophisticated neonatal intensive care units with improved ability to manage the sick infant has caused physicians to realize that many infants who previously might not have lived can now be successfully treated.[3,4] Usher, in Montreal, has demonstrated increased survival of critically ill neonates transferred to a regional care center from community hospitals without newborn intensive care units.[5] Schneider and Graven have shown a significant impact of regional perinatal care in Wisconsin in accelerating the decline in neonatal mortality.[6] Brann reports similar positive results in Mississippi.[7]

The treatment of the critically ill neonate begins in the delivery room and continues into the intensive care unit. Since most community hospitals with maternal services do not have the personnel, space, or facilities for adequate newborn critical care, transfer of the sick infant to a regional care center is frequently necessary. The provision of intensive care during the transport process may present formidable problems. The transport program must be well organized and staffed with knowledgeable personnel if complications and risks are to be minimized.[8] Segal,[9] Cunningham,[10] and Fanaroff and Klaus[11] have discussed the requirements of newborn transport systems.

The rapid transport of the critically ill patient to treatment centers received strong impetus from the military experiences of the Second World War, the Korean War, and most dramatically, the Vietnam War, where air transport of American wounded servicemen to hospitals equipped to handle major trauma again was shown to reduce mortality markedly. European countries have applied the lessons of this experience to their civilian populations, with considerable success.[12–15] It is notable that the leadership for this movement in Europe has come from anesthesiologists, particularly those interested in critical care medicine. Not surprisingly, neonatologists and pediatric anesthesiologists concerned with newborn intensive care have been in the forefront of similar movements in the United States.

The role of the anesthesiologist in the delivery room and the intensive care unit is discussed elsewhere in this Symposium Issue. It is my belief that the American anesthesiologist, like his European counterpart, can and should play an important role in the transportation of critically ill patients from primary care hospitals to intermediate care and regional medical centers. These patients are frequently in shock, with respiratory failure. Their medical management in a mobile intensive care facility is an extension of the therapy they receive in the hospital critical care unit. Anesthesiologists, because of their experience in the management of critically ill patients, are a logical group of physicians to be leaders in this area of medical care. The programs for transport of newborn infants can serve as models for programs for older pediatric patients and adults.

Transport programs for newborn infants are not an innovation in the United States. Large cities, such as New York City, have had infant transport services for many years. The utilization of skilled personnel and sophisticated monitoring and resuscitation equipment is, however, a recent advance. Various transport programs exist in the United States. Each program is an outgrowth of the particular needs of the community or regions served. The characteristics of the transport system vary according to local requirements, *i.e.*, the terrain of the area, the population density, weather patterns, and availability of

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special surface or air carriers. For example, New York City has a transport service with specially equipped ambulances and medical teams. This service transported 1,042 infants from 70 hospitals to 16 centers in 1973.[16] By contrast, the Arizona Premature Transport Project utilizes special medical teams, portable equipment, and chartered aircraft to transport infants to four centers in Phoenix and Tucson over relatively flat terrain.[17] In Colorado and Utah, sick infants are transferred over mountainous terrain by specialized medical teams to centers in Denver and Salt Lake City by specially equipped helicopters as well as ambulances and fixed-wing aircraft.† In Maryland, critically ill infants are transferred with the aid of the Highway Patrol through the State Trauma program.[19] In California, 3,678 infants were transferred by a variety of vehicles over varied terrain to 20 specialized centers in 1973.[20]

The most important component of any transport system for the critically ill patient is the medical transport team. A basic concept in regionalization of neonatal care is the early treatment of distressed infants. Preferably, early treatment is begun by the primary care team, but frequently therapy must await the attendance of a physician/nursing team experienced in newborn intensive care. The makeup of the medical transport team is thus of utmost importance. Guidelines for composition of the medical transport team vary, but generally are similar to those proposed by the Conference on Newborn Transport sponsored by the Bureau of Maternal and Child Health of the California Department of Health in 1971, and recently published by the California Medical Association.[21] A medical team must be available on a 24-hour basis, seven days a week. There should be at least two members, a physician and a nurse, both skilled in techniques of neonatal intensive care. Of particular importance is the need for the medical team to be experienced in assisted ventilation, as approximately 75 per cent of these infants suffer from respiratory failure as the primary or secondary component of their disease. Utilization of the regional care center's own personnel furthers a basic tenet of the regional care program, *i.e.*, establishing a close working and teaching relationship between the medical and nursing staffs of the center and the primary and intermediate care nurseries.

The fastest and safest means of transport available should be utilized to transport the specialized medical team to the infant's bedside. After arrival at the referral hospital, the medical team must first stabilize the infant's clinical condition. Many of these infants are in shock and require emergency treatment prior to transport. Stabilization may require a number of hours; and the team must be prepared to spend whatever time is necessary at the primary hospital to improve the infant's clinical condition before transport is begun. Special equipment and drugs for newborn intensive care must be carried by the transport team. Special procedures will frequently be necessary, for example, catheterization of umbilical artery or vein or endotracheal intubation with assisted ventilation. Medications for treatment of hypovolemia, hypoglycemia, acid–base derangements, cardiogenic shock, and electrolyte abnormalities are carried by the medical transport team.

Transferring a critically ill patient requires organization and teamwork. The transport procedure utilized at the Stanford Medical Center is outlined in figure 1. Telephone consultation by the primary (referring) physician with a senior nursery physician (transport coordinator) initiates the transport process. The transport coordinator contacts the medical team and selects the mode of transport. The remainder of the transport process is handled as noted. Teamwork between the various links in the system is essential.

A communications system linking the two involved hospital nurseries, their personnel, the transport team, and the members of the ambulance groups is required. The communications system facilitates the transport and allows rapid interchange of acutely acquired information regarding the patient and/or the various links of the transport. Telemetry of vital signs is not of primary importance. The medical transport team must be capable of handling emergency conditions that arise. There is very little a specialist at the center can do to help the medical team if the patient becomes acutely hypoxic because

†Bigelow DB: Personal communication.

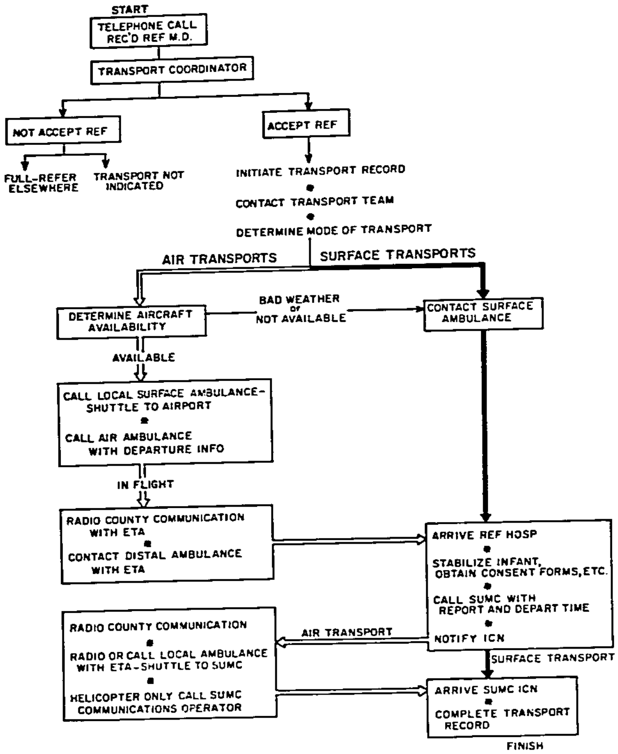

FIG. 1. Process for transports by surface or air.

of a pneumothorax requiring insertion of a chest tube.

Because of the large number of referrals, a newborn intensive care unit frequently may be filled to capacity. To avoid refusing a needed transfer, a programmed communications network with several neighboring regional care centers is advisable. With such a network, prompt referral and bed assignment can be made from one intensive care service to another. The characteristics of such a network will vary depending on the demography of the region. For example, in Arizona, nurseries in Phoenix and Tucson are linked in one network; in Northern California, 13 regional and intermediate care nurseries are so linked; whereas in New York City 73 hospitals and 16 premature centers are included in an organized program. The United States Air Force also has a referral system that links most of its primary care nurseries with a regional care center in San Antonio, Texas.[22]

Many factors enter into the choice of the ambulance or other carrier system to be used. Whatever system is chosen, interhospital transit time should be kept to a minimum. The required transit times will vary, depending on many factors and conditions. In a metropolitan area, a transit time of 45 minutes may be accomplished easily, whereas a transport between a regional center and primary facility 385 miles away will take two hours by fixed-wing aircraft.

Where the referral area for the center includes both metropolitan and rural communities, a combination of carriers may be used. In Colorado, surface ambulances are used in the metropolitan area of Denver, and helicopters service the mountainous rural communities. Selection of the carrier depends on many factors, and the choice varies widely among transport services. Special ambulances have been designed and utilized for interhospital transfer of critically ill infants.[23] These ambulances are equipped for mobile intensive care. Reports from centers that have utilized these ambulances, however, indicate there are a number of major problems associated with their use.‡ They are slow, difficult to work in, and motion sickness is not uncommon. In addition, the specialized ambulance may not be available because it is being used to transport another patient. Unless a similar back-up vehicle is available, a regular surface ambulance will have to be utilized. An alternative approach, utilized by many transport services, is to use a regular ambulance service, augmented by portable mobile intensive care equipment which is carried by the transport team. When a combination of surface and air transport is to be used, this approach has obvious advantages.

Many considerations enter into the choice between use of a helicopter or fixed-wing aircraft as an ambulance. The presence of a heliport or heliport site at the referral hospital, weather conditions, the distance between the community hospital and the nearest airport, the type of air carrier available, and the size of the carrier cabin must all be considered. Despite increasing enthusiasm for helicopter-ambulances as emergency vehicles, most community hospitals do not have readily available helicopter facilities. Of the 30 community hospitals served by the Stanford Newborn Transport Service, only 11 have heliports. On the other hand, 21 have airports within five miles (10 minutes). Most hospital heliports are capable of handling only small or medium-sized helicopters. Unfortunately, these helicopters have either limited cabin size or weight loads inadequate for medical transport. For example, the Bell Jet Ranger, a helicopter popular for police and ambulance work, has a passanger capacity of three. The medical team complement is thus limited to a maximum of two and can carry only minimal transport equipment. A two-person medical team is usually adequate, but additional personnel are frequently desirable for training purposes, to aid in multiple deliveries, or to aid in providing assisted ventilation. Furthermore, with its regular cabin configuration, an infant can be transported only by placing the transport incubator across the laps of two of the passengers. When the cabin configuration is modified for adult ambulance work (litter added), only one medical attendant can be carried. The helicopter is advantageous in interhospital transport where there is not an airport nearby.

Comparison of safety statistics for helicopters and fixed-wing aircraft indicates a better margin of safety for fixed-wing aircraft. A National Transportation Safety Board report on air accidents is available for 1971.[24] For each 100,000 hours flown, there were 20.4 accidents in single-engine fixed-wing aircraft, 8.69 accidents in multi-engine fixed-wing aircraft, and 27.5 accidents in rotorcraft (helicopters). The accident rate for the air-taxi group, the type of aircraft preferable for air ambulance work, is 7.2/100,000 miles flown. Fixed-wing aircraft accident data thus compared favorably with helicopter accident data.

Selection of the aircraft must be made with careful thought. As with other types of ambulances, the safety of the medical team is of prime importance. Other considerations include regional weather patterns, cabin size, weight and passenger capacity, the ease with which the patient can be transferred in and out of the aircraft, the capability of providing intensive care within the cabin, the availability of cabin pressurization, and the length of the landing strips of the airports to be utilized. Single-engine fixed-wing aircraft mostly have small cabins with little working space. Frequently the cabin door is over the wing, an awkward entry route while provid-

‡Brady J, Ferrara AC: Personal communication.

TABLE 1. Design Criteria for Transport Incubator

1) Ability to provide a neutral thermal environment
2) Easy access to the infant for intensive care, including assisted ventilation
3) Monitoring of heart rate, inspired oxygen, core and/or skin temperature, and blood pressure
4) A fail-safe humidified oxygen/air delivery system with a three-hour capability
5) Adequate lighting of the unit under all conditions
6) Portable light-weight rechargeable power units for the heating, lighting, and monitoring systems with adequate power for three hours
7) Means of safely stabilizing the unit in the incubator to prevent injury during suden changes in speed or altitude

ing intensive care. The optimal solution is for the regional care center to associate with a full-time professional airplane organization capable of providing the appropriate aircraft with professional pilots available at all times. The pilots must be fully licensed and capable of handling any type of flight plan. The airplane organization can be either civilian or military.

Noise factors must also be considered when choosing an appropriate type of ambulance carrier, both because of problems in communication and in terms of possible hearing loss to the patient and medical personnel. Seventy-four infants, equally divided between infants transported by air carriers to Stanford and infants delivered at the center itself, were examined for hearing loss at the time of hospital discharge and during follow-up visits. Twenty-six of 27 infants transported had no detectable hearing loss. One infant delivered at the center had a detectable hearing loss. These results are compatible with the concept that a single exposure to noisy aircraft is not hazardous. Repeated exposures may be harmful, depending on precautions taken and the type of aircraft. Medical personnel who participate regularly in air transport should keep informed as to the hazards of hearing loss.[25]

Radical changes have occurred in the treatment of critically ill newborn infants in the past ten years. Among the important concepts introduced is that of on-line, or minute-to-minute, monitoring of cardiovascular and pulmonary indices. In addition, assisted ventilation is now a standard component of the treatment of respiratory distress syndrome.

Intensive care and therapy are best practiced in an open environment in which the temperature of the air is monitored and controlled to produce a neutral thermal environment. The open concept is particularly important when the infant requires assisted ventilation, as this necessitates continuous entry into the infant's environment.

In the area of patient transport, application of this open concept for intensive care has lagged behind, primarily because application of radiant heat in an open environment is difficult to attain with a transport incubator. The transport units commonly used are an adaptation of the Isolette or closed-box type of incubator. These incubators are heated by forced air or a combination of forced air and radiant heat. A neutral thermal environment is provided for the infant when the unit is closed to the outside, but if the unit is opened to provide intensive care for any extended period (more than 5–10 minutes), the neutral thermal environment is lost. In addition, the method of administering intensive care through small windows or hand-sealed portholes is cumbersome and restricting. Although the commercial units are lightweight and portable, oxygen and monitoring equipment are not built-in components. When these devices are added to the incubator, the resulting package is heavy and difficult to carry. These incubators thus do not meet the criteria we believe essential (table 1).

The Departments of Anesthesia and Pediatrics of the Medical School and the Division of Mechanical Engineering of the Stanford School of Engineering (Professor R. J. Moffat) have recently developed a transport incubator that more closely meets all essential criteria. The objective of the design was to produce a self-contained transport module for critically ill infants requiring intensive care transport. Accessibility and portability with maintenance of a neutral thermal environment were of prime importance. The present unit (fig. 2) is the result of experience gained in more than 500 transport cycles. The infant is warmed by radiant heat from a transparent plastic hood and, with a clear hood, is visible from every side of the

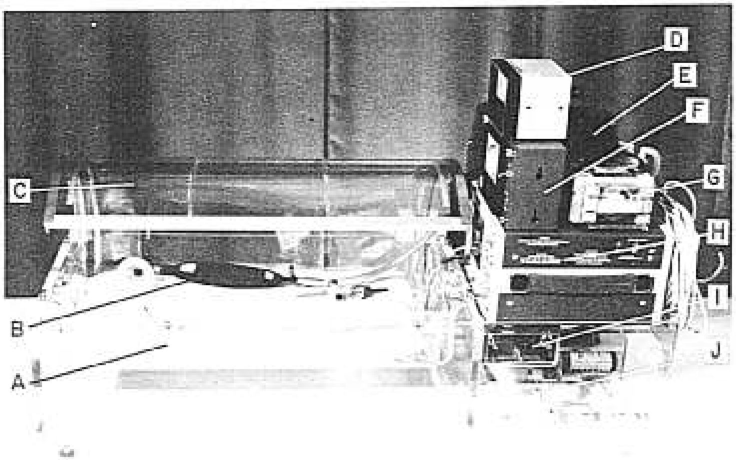

FIG. 2. Stanford Mark III Transport Incubator. *A*, infant tray; *B*, modified Jackson-Rees ventilation setup for assisted ventilation; *C*, semicylindrical rotatable heating hood; *D*, oxygen monitor (fuel-cell type); *E*, liquid oxygen unit (500-liter capacity); *F*, temperature monitor (battery-powered); *G*, infusion pump (battery-powered); *H*, two-channel (EKG, pulse, blood pressure selection) battery-powered electronic monitor; *I*, temperature control panel for heating hood; *J*, emergency drug and intubation module (battery pack and compressed air tank not shown).

unit. The hood is arranged in such a way that the attending physician has continuous access to the infant through one end of the compartment and, with one motion, can completely expose the infant when emergency care from more than one attendant is required. The hood retracts to a storage position beneath the infant tray in such a way that no additional space is required above or behind the unit. This is of importance when the system is being used in cramped quarters such as a helicopter. An intermediate latching mechanism permits the hood to be positioned at either of two intermediate positions (¼ or ½ open).

Comparative testing of two commercially available incubators, as well as this new radiant-heat unit, in a cold-environment chamber indicates that the radiant-heat transporter is superior in ability to provide a neutral thermal environment at low external temperatures under conditions necessary to provide intensive care.[26,27] A neutral thermal environment can be provided with the hood in the semi-open position with complete visibility of and adequate access to the infant at an external temperature of 14 C.

The transport incubator, with ancillary equipment, weighs 59 pounds, considerably less than other portable incubators. In addition, it has its own portable power supply. The power supply is a separate unit and weighs 75 pounds, still too heavy to be ideal, but a considerable improvement. This transport unit can be used in ambulances, helicopters, and airplanes. A problem still to be solved is a method for safely mechanically stabilizing the infant within the incubator.

Other essential equipment includes a fail-safe humidified oxygen delivery system for the delivery of assisted ventilation with continuous positive airway pressure. Oxygen may be delivered either as a gas or as liquid oxygen combined with compressed

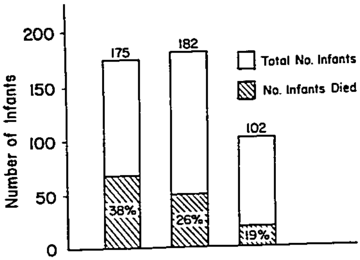

FIG. 3. Annual mortality of transported infants. Data for the years 1972, 1973, and the first six months of 1974 are included.

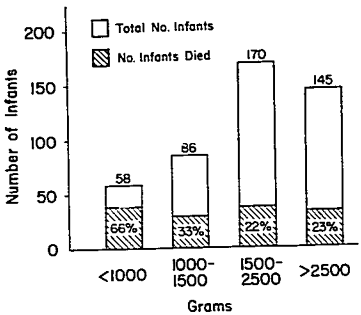

FIG. 4. Mortality by birth weight of transported infants. The differences between the various birth weights are consistent with those expected for non-transferred patients.

air. The concentration of oxygen delivered must be monitored. Emergency treatment of pneumothorax may be necessary during transport, and should be anticipated. A portable suction device for tracheal aspiration should be included. Electronic monitoring of the heart rate is necessary, as ambulance carriers are noisy and the heart rate of a patient may be inaudible with the aural stethoscope. Portable lightweight electronic monitors for on-line blood pressure measurement are now available and will be helpful in many instances. Continuous monitoring of the infant's body temperature is necessary.

A significant advance in transport electronic monitoring would be inclusion of monitors for all these variables in one module. In addition, this module should have real time and interval time clocks as an aid to charting significant patient events. Another needed addition is provision for continuous tape-recording of vital signs, oxygen concentration, and voice by use of a small cassette tape recorder which would be attached or integrated into the monitor module. This recording device would be similar to the "black box" carried on commercial aircraft.

Evaluation of the impact of a medical transport system that satisfies the suggested requirements is difficult. Patient selection by the referring physician is hard to control and introduces an unknown quantity into the analysis. This variable is becoming less significant as regionalization of newborn care proceeds. Third-party insurance carriers and licensing agencies such as the California Crippled Children Services and the California State Department of Health are making it increasingly easy for a physician to transport the critically ill infant from a primary care facility to an intermediate or regional care center.

In order to evaluate the effect of a model transport system on neonatal mortality, a prospective study was begun by the Stanford Newborn Transport Service in 1972. Results of this study are reported for a 2½-year period from January 1, 1972, to July 1, 1974.

The Stanford Newborn Intensive Care Nurseries have served as a regional care facility for 13 years. Modernization of the newborn transport service was begun in 1970 following a comparison of the mortality rates of two groups of infants treated in our newborn intensive care unit. The infants admitted from our own delivery room were compared with infants admitted from other hospitals: the mortality rate was less than 5 per cent in the group delivered at Stanford, compared with more than 30 per cent mortality in the group delivered at other hospitals and subsequently transferred to Stanford. Granted that the populations were different, however, the high mortality found in the transferred group prompted an attempt to revamp the transport system for our regional care program. Until 1970, infants were transferred by a pediatric house officer with the patient placed in a "closed-box" incubator heated only when an electric power source was available. If the incubator was opened for any length of time to provide intensive care, the infant became hypothermic.

Despite the large geographical area served, a radius of 150–250 miles, all infant transports were by surface ambulance. The feeling among referring pediatricians was one of questionable hope for any critically ill babies to be transferred. A question frequently asked was, "Is the baby in good enough shape to survive the transport?"

Spurred by the American military and the European civilian experiences with transport of the critically ill patient, the Stanford neonatology service decided to make an effort to develop a true concept of regional care for the critically ill infant. The thrust of the project was to provide optimal medical and surgical care for all critically ill infants in the regional care area through a continuing education program and by the development of a high-quality transport system.

The Stanford nurseries are a regional care facility for 56 hospitals with approximately 45,000 deliveries a year in a geographical area extending 250 miles south, 100 miles east, and 15 miles north. There are eight neonatal intensive care centers in the San Francisco Bay Area. Although Stanford does not receive all transferred infants from this area, it does serve as a major referral facility.

A 1973 survey of the 56 hospitals indicated that 15 hospitals cared for fewer than five sick neonates a year and 36 hospitals cared for fewer than 25 a year. A study of the specialized newborn equipment available in these hospitals indicated that 16 of the 56 hospitals did not have radiant heat warmers, and 14 of the hospitals did not have either heart-rate or respiratory monitors.

In 1971, new guidelines for the newborn transport service were developed. These guidelines closely follow those previously discussed. The medical transport team is staffed by anesthesia and neonatology faculty and house staff, newborn intensive care nurses, and respiratory therapists. The transport coordinator designates the appropriate medical personnel for a specific transport, depending on the anticipated medical problems. The transport is financed by traditional patient billing/third-party insurance methods.

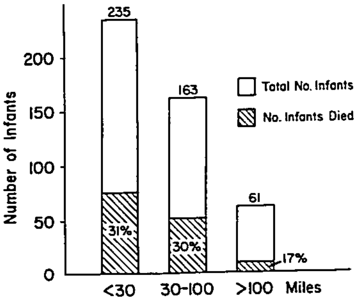

FIG. 5. Mortality by interhospital distance of transported infants. The difference between the mortality rates of patients transported less than 100 miles and more than 100 miles is significant, $P < 0.05$.

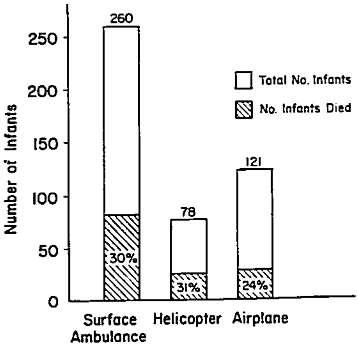

FIG. 6. Analysis of mortality by mode of transport. The differences in mortality rates of the three groups are not significant.

In the first year of the program (1971), transport zones of less than 30 miles, 30–100 miles, and more than 100 miles were established to aid in selection of the transport carrier. Transfers from hospitals less than 30 miles away were carried out by surface ambulance, transfers from hospitals 30–100 miles away by helicopter or fixed-wing aircraft, and transfers from hospitals more than

TABLE 2. Cost of Transport (Dollars)*—1975

	Interhospital Distance (Miles)			
	25	50	100	250
Surface ambulance	195	245	295	445
Helicopter	355	465	655	—
Fixed-wing aircraft	—	400	585	790

* All transport costs are cost-accounted, including medical transport team and primary and secondary carriers.

TABLE 3. Mortality Rates by Initial Post-transfer Arterial *p*H

	Number of Infants	Died	Mortality Rate* (Per Cent)
*p*H < 7.2	77	48	62
*p*H > 7.2	297	70	24

* The difference between the mortality rates in the two groups is significant, $P < 0.001$.

TABLE 4. Mortality Rates by Core Temperature Immediately after Transfer

	Number of Infants	Died	Mortality Rate* (Per Cent)
<35.5 C	54	35	65
>35.5 C	405	101	25

* The difference between the mortality rates in the two groups is significant, $P < 0.001$.

100 miles away by fixed-wing aircraft only. In 1973, helicopter transport was discontinued (except on rare occasions), because of the complicating factors previously discussed. Transports of less than 50 miles are now carried out by surface ambulance, and the remainder by fixed-wing aircraft.

The approximate costs of transport in 1975 in this program by regular surface ambulance and chartered helicopter or fixed-wing aircraft are noted in table 2. Surface ambulances or fixed-wing aircraft are available at all times, as well as helicopters if needed.

Four hundred fifty-nine infants less than a month old were transferred during the period from January 1, 1972, to July 1, 1974. Annual mortality rates decreased with each successive time period (fig. 3). Not surprisingly, mortality was highest in the babies with the lowest birth weights (fig. 4).

Comparison of mortality by interhospital distance indicated no statistical difference between transports less than 30 miles and transports of 30–100 miles (fig. 5). Mortality of patients transferred from hospitals more than 100 miles away was significantly decreased ($P < 0.05$). The difference in mortality may be related to unknown factors such as patient selection, although preliminary analysis of this patient population by age at transfer, admitting diagnosis, and birth weight does not substantiate the assumption that the referring physician is preselecting the infants to be transferred. At the least, interhospital transports of more than 100 miles do not appear to present a greater hazard compared with those of less than 100 miles.

Analysis of mortality by mode of transport indicates no statistical difference among those transferred by surface ambulance, helicopter, or fixed-wing aircraft (fig. 6).

Of interest are the differences in survival of infants with severe acidosis (Table 3) or hypothermia (Table 4). These physiologic measurements were significant predictors of outcome ($P < 0.001$). A review of the 102 transported infants in the first six months of 1974 showed that in four of six cases, infants with core temperatures of less than 35.5 C were actually warmed during transport.

On the basis of these data in this system the mode of transport and the transport distance of this system do not appear to affect neonatal mortality. Patient stabilization and reduction of the severity of the physiologic derangements at or before the time of transfer by the primary and regional care center personnel are of considerable importance.

On the basis of this experience, we conclude that regional care programs for critically ill newborn infants offer hope for improved patient care. An integral part of these programs is a well-functioning medical transport system capable of delivering high-quality intensive care during the transfer period. Skill in management prior to and during transfer so as to reduce the severity of disturbances permitted during transfer is of primary concern. Resultant increased survival of these infants hopefully may lead to a further decrease in mortality in the neonatal population.

The anesthesiologist, because of training in the diagnosis and treatment of acutely ill patients, can, by adding his or her expertise to these programs, provide needed leadership. These transport systems, designed for use of a specific patient population, can ultimately serve as a model for development of interhospital transport programs of critically ill patients of any age.

The material presented in this paper represents the work of many individuals. The author is particularly indebted to his co-workers, Philip Sunshine and John D. Johnson (Director and Associate Director of the Stanford nurseries), Robert J. Moffat (co-designer of the transport incubator), Leonard Indyk (consultant in biophysics who tested the transport incubator and suggested a significant modification in the design), Lloyd Gano (designer of the incubator power supply), and Robin A. Birch (fabricator of the transport incubator). The author also thanks C. Philip Larson, Jr., and William M. Dolan for their critical review of the manuscript and Irving Schulman for his support and encouragement.

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