A Strategic Framework for Infant Mortality Reduction: Implications for "Healthy Start"

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THE UNITED STATES RANKED 21ST AMONG DEVELoped countries in infant mortality in 1992 (Wegman 1994), despite the fact that it spends 12.2 percent of its gross domestic product on health care (Levit et al. 1991), more than any other nation. Although the provisional U.S. infant mortality rate (IMR) of 8.3 infant deaths per 1,000 live births in 1993 represents a progressive downward trend (Wegman 1994), the health care system has not been successful in closing the gap in IMRs with other developed countries (Liu et al. 1992). Moreover, infant mortality (IM) rates remain persistently high among minority populations and in large urban areas in the United States (Hogue and Hargraves 1993).

The poor international ranking of the United States, coupled with the high IMRs among populations in urban areas, led to the initiation of "Healthy Start" by the federal government in 1991. Healthy Start (HS) is a national program to reduce infant mortality (IM) in 15 selected communities with the nation's highest IMRs (Chu and Reilly 1992). It represents the most recent national effort to reduce IM, following a history

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over the past four decades of programs like Maternal and Infant Care, Improved Pregnancy Outcome, and Improved Child Health Projects (Magee and Pratt 1985; Strobino et al. 1986). Unlike these earlier programs, however, an unusually ambitious goal was set for HS: reduction of IM in the selected communities by 50 percent over five years. HS sites will receive between 12 and 23 million dollars of funds during the five-year program to meet this goal (U.S. Department of Health and Human Services 1992). Table 1 shows the targeted communities and their infant mortality rates from 1984 to 1988.

In addition to HS programs, the nation must adopt a comprehensive strategy for IM reduction in order to address successfully the problem of high IMRs in its urban areas and among its disadvantaged populations. Public policy is frequently based on simplistic solutions to complex problems, often leading to failure and the belief that these problems are intractable. For example, the HS programs have strongly emphasized enhanced access to prenatal care and provision of support services to reduce

TABLE 1
Healthy Start Communities and Infant Mortality Rates, 1984–88

Healthy Start community	Infant mortality rate
Detroit, Michigan	26.3
New Orleans, Louisiana	23.3
District of Columbia	23.2
Philadelphia, Pennsylvania	22.3
Cleveland, Ohio	21.3
Pittsburgh (Allegheny County), Pennsylvania	20.2
Baltimore, Maryland	20.1
Chicago, Illinois	19.6
New York, New York	19.4
Northern Plains Indian communities in South Dakota, North Dakota, Iowa, and Nebraska	18.7
Birmingham, Alabama	18.4
Oakland, California	17.9
Boston, Massachusetts	17.1
Lake County, Indiana	16.2
Pee Dee region of eastern South Carolina	16.1

the risk of low birthweight (LBW, defined as less than 2500 grams) and, in turn, IMRs (Mason 1991). While it is assumed that improvements in prenatal care and other interventions will contribute to lower LBW and IM rates, the potential effectiveness of these interventions in achieving the ambitious goal of a 50 percent reduction in IMRs in five years has not been systematically analyzed.

We will present a strategic framework for reducing IM and, based on this framework, we will estimate the potential effect of specific strategies on IMRs in the urban HS communities. The focus of our framework is population based, and it emphasizes the strategies that communities might undertake to reduce IM. We will outline the framework and the assumptions we made in using it to project population-based estimates. Although our analysis is technical, the results are highly relevant to the formation of policies to reduce infant mortality.

Analytic Framework for Reducing Infant Mortality

Strategies

Our framework includes four strategies for confronting infant mortality:

1. reducing the proportion of high-risk pregnancies
2. reducing the incidence of LBW and preterm births by improving the health care and behaviors of women
3. improving birthweight-specific survival by strengthening obstetric and neonatal health systems
4. reducing death from specific causes, such as sudden infant death syndrome (SIDS), during the postneonatal period

This framework of strategies recognizes, first, that IMRs are a function of two factors in a population: (1) the distribution of risk factors, and (2) risk-specific mortality rates. In order to tackle IM, one or both factors must be reduced. Second, because birthweight is the strongest risk factor for IM (McCormick 1991), further improvements in IMRs are most likely to result when LBW rates decline (McCormick 1991; Guyer, Wallach, and Rosen 1982). LBW rates, however, have remained remarkably constant over the last few decades (McCormick 1991). Finally, some causes of IM, particularly among older infants, will not be reduced by interventions that focus only on LBW or preterm births.

This strategic framework was used as the basis for estimating the impact of several known interventions on reducing IM in the 13 urban HS demonstration sites. The two rural HS communities, the Northern Plains and the Pee Dee region, were excluded from our estimates because of difficulties in capturing data for their catchment areas, which crossed state or county boundaries. The data sources and methods used to derive the estimates are described below, followed by a discussion of the rationale for each strategy, the IM reduction interventions for each strategy, and their estimated impact on IMRs in the HS cities.

Data Sources and Analytic Methods

Estimates of the impact of selected interventions within each of the four strategies were calculated using three general sources of data: vital statistics; data from studies of the effect of the selected interventions on pregnancy outcomes; and national data on exposure of pregnant women or infants to the interventions. Baseline vital statistics data were obtained from the 1987 National Linked Birth and Infant Death File (National Center for Health Statistics 1992), the most recent year for which national linked data were available for the 13 urban communities that participate in HS.

The birthweight distribution and birthweight-specific infant mortality data for the 13 HS cities are shown in table 2. In 1987, there were nearly 270,000 births (7.1 percent of all U.S. births) and 3,900 infant deaths (10.2 percent of all U.S. infant deaths) in the HS cities, with an overall IMR of 14.48 per 1,000 live births (the U.S. rate in 1987 was 10.1). We used data for the entire population in the HS cities rather than for the specific HS catchment area (generally areas within the cities). These catchment areas generally include higher-risk neighborhoods than the cities as a whole, but we were unable to distinguish neighborhoods within the cities based on the national data.

Our analytic approach was based on population-attributable risk estimation methods. Population-attributable risk (PAR) estimates identify the proportion of infant deaths or LBW births that can be attributed to a given risk factor (Kahn and Sempos 1989). For our purposes, PAR estimates were used to calculate the prevented fraction of IM or LBW attributed to each preventive intervention (Rothman 1986). To calculate the

TABLE 2
Births, Infant Deaths, and Birthweight-Specific Infant Mortality Rates for Healthy Start Cities, 1987

Birthweight (grams)	Births		Number of infant deaths	Birthweight-specific mortality rate[a]
	Number	Percent		
<500	650	0.2	550	846.15
500–1499	5,339	2.0	1,452	271.96
1500–2499	22,892	8.5	585	25.55
2500+	240,013	89.1	1,128	4.70
Unknown	519	0.2	185	356.45
Total	269,413	100.0	3,900	14.48

[a] Infant deaths per 1,000 live births.
Source: National Center for Health Statistics (1992).

prevented fraction, it was necessary to know the following: the LBW or IM rate in the intervention and control groups, or the relative risk or odds ratio for the intervention; the LBW or IM rate in the total population; the proportion of the population exposed to the intervention; and the size of the total birth population.

Data on known interventions applicable to the four IM reduction strategies were derived from studies of the impact of these interventions on LBW and IM. Because no data were available about the impact of the interventions in the HS cities, data from national surveys were used to estimate the proportion of women or infants exposed to a given intervention. These national data sources permitted us to use the same frame of reference for all interventions. Finally, data on the LBW and IM rate in the total HS urban population, and for the size of the total birth population, were taken from the 1987 vital statistics data, as shown in table 2.

The IMR-prevented fraction for each selected intervention was estimated by projecting the effect of increases in the number of women or infants exposed to a given intervention if the HS cities were to adopt the intervention as an IM reduction strategy. For most interventions, we projected either a 50 percent decrease in exposure to risk factors, such as short birth intervals, or a doubling of rates of exposure to interventions, such as comprehensive prenatal care. These changes seemed feasible, given the funding levels for HS. In instances where it may be theoretically feasible to provide an intervention—surfactant therapy, smoking cessation programs, WIC participation—to all women or infants in need, we projected 100 percent exposure to the intervention.

The odds ratios for LBW or IM rates (from intervention studies), the current baseline (from national surveys) and projected proportions of women or infants exposed to an intervention, and the number of births and infant deaths (from vital statistics) in the HS cities were used to calculate the projected rates and the prevented fraction for each intervention. Birthweight-specific rates were applied, when appropriate. Only LBW data were available for some interventions. In these cases, we first estimated changes in the incidence of LBW resulting from increased exposure to the intervention. We then applied the birthweight-specific mortality rates in the HS cities to the changes in the birthweight distribution to determine the estimated IMR.

Three adjustments to the estimates were needed for some interventions. First, the number of deaths to infants with missing data on birthweight had to be added to our calculations when birthweight was the focus of the estimates. Although the number of infants with unknown birthweight data was small ($N = 519$), their IMR was high (356.5 deaths/1,000 live births, $N = 185$ deaths). A similar approach was taken for race-specific data because there were 11,964 births to members of races other than white or black, with an IMR of 8.00 ($N = 92$ deaths). Finally, in instances where an intervention could be calculated for neonatal mortality (first 28 days of life), but not for IM, the number of postneonatal deaths (28 days to 12 months) was added to the expected number of neonatal deaths estimated for the intervention in order to calculate the overall adjusted IMR.

It was necessary to make a number of assumptions in order to calculate the projected rates and prevented fraction for each intervention. Many of these assumptions are not right or wrong, but rather are based on the availability of data regarding exposure to, and effects of, interventions. First, we chose interventions that are potentially available to the HS programs and for which there is reasonable scientific evidence that they may reduce LBW or IM rates. We also attempted to avoid duplication of the effect of interventions by focusing on the most effective ones. The interventions we studied, however, may or may not be ones selected by the HS sites.

Second, we assumed that women in the HS cities have baseline rates of exposure to the interventions that are similar to those of women throughout the country. While we do not know the exposure rates to most selected interventions in the HS cities, the proportion of women experiencing high-risk pregnancies is likely to be higher in the HS cities than in the nation as a whole.

Third, we assumed that the impact of the interventions is similar in the HS cities to that reported in the studies we reviewed. Unfortunately, none of the available studies addressed the effectiveness of obstetric or neonatal interventions in the specific HS cities. This assumption is valid to the extent that the populations are similar and the quality of the interventions is uniform. Accordingly, we attempted, where possible, to select interventions for which there is evidence of their effectiveness in different populations, geographic areas, and health care settings. Some interventions were excluded because they did not meet this criterion.

A final assumption is that, in the absence of race- or ethnic-specific data, the effect of the interventions is similar across ethnic and racial groups. Where possible, data were obtained from the intervention studies for black and white women separately, because the HS cities contain a higher proportion of black births than the general population (50.2 percent, compared with 16.8 percent nationally in 1987) (National Center for Health Statistics 1992). Estimates were not made for other ethnic groups because intervention data are rarely reported for these groups and because vital statistics data were incomplete for Hispanic women who resided in the HS cities.

The Impact of the IM Reduction Strategies

Preventing High-Risk Pregnancies and Births

Part of the drop in IM in the United States, particularly during the 1970s, was attributed to declines in demographically high-risk pregnancies as a result of improved access to, and use of, contraceptive and family planning services (Morris, Udry, and Chase 1975; Wright 1975). Accordingly, we estimated the potential impact of family planning services on reducing IMRs in the HS cities through a reduction in three types of high-risk births: unwanted births, closely spaced births, and births to teenage women.

Data on unwanted births and pregnancy outcomes were obtained from the 1988 National Survey of Family Growth (Kendrick et al. 1990). Only data for LBW rates were available. In 1988, LBW rates were 40 percent higher for unwanted than wanted births among black and white women alike, figures similar to those reported by others (Goldenberg et al. 1991). Black women (26 percent) were more than twice as likely to report having had an unwanted birth than white women (11 percent) (Kendrick et al. 1990). Projection of a 50 percent drop in the percentage of unwanted births, using the survey data, yielded an estimated decline in the number of LBW births by 1,027. Applying the race- and birthweight-specific mortality rates to the change in number of LBW births, infant deaths were estimated to decrease by 90 deaths, for a 2.3 percent decline in the IMR from 14.48 to 14.14 infant deaths per 1,000 live births in the HS cities (table 3).

Next, we estimated the impact of a decline in short birth intervals, using data from the 1980 National Natality Survey reported by Miller (1991), the most recent national data available. Data on rates of neonatal mortality were used here; neither overall IM data nor race-specific data were available. The odds of a neonatal death associated with a very short birth interval, less than 12 months, was quite high—4.94—although the odds ratio was close to 1 for intervals of 12 to 17 months. The proportion of women with short intervals among second or higher births was quite low: less than 4 percent for intervals less than 12 months and 16

TABLE 3
Estimated Effect[a] of Family Planning Interventions on Infant Mortality Reduction

Intervention	Estimated IMR	Estimated deaths averted	Percent decline in IMR
Baseline	14.48	0	0.0
Reduce unwanted births	14.14	90	2.3
Reduce short birth intervals	14.14	91	2.3
Reduce teen births	14.34	37	0.9

[a] The estimated IMRs were calculated separately for each intervention; they do not represent the combined effect of all family planning strategies.
Abbreviation: IMR, infant mortality rate.

percent for intervals between 12 and 17 months. These proportions were multiplied by the proportion of second, or more, births in the HS cities (58.5 percent) to obtain overall population-based estimates of the frequency of short intervals. Projection of a 50 percent reduction in the shortest intervals—those under 12 and 12–17 months—yielded an estimated drop in the IMR of 2.3 percent (table 3).

Our final estimate involved the potential impact of a 50 percent decline in teenage births on IMRs. Data on teenage births and IMRs were available for the HS cities (National Center for Health Statistics 1992). The odds of an infant death for births to mothers aged 17 or less was 1.60 for whites and 1.10 for black women in these cities in 1987. The respective odds ratios for 18- to 19-year-olds were 1.35 and 0.92. A drop of 50 percent in the percentage of births to teenage mothers in the HS cities had only a small estimated effect on the IMR: it declined by 0.9 percent, to a rate of 14.34.

In general, the estimates presented in table 3 suggest that the impact of reductions in high-risk pregnancies on IM in the HS cities would not be large. One reason for their small impact stems from the fact that enormous declines must occur in the number of high-risk births in order for even a minimal change in the IMR to occur. The estimates for unwanted births must be viewed with caution because of the difficulties in measuring this construct.

Preventing Low Birthweight and Preterm Births

One reason the United States ranks well below other industrialized nations in IM is the high proportion of infants born preterm or LBW (Liu et al. 1992; Guyer, Wallach, and Rosen 1982). We examined three interventions that, with increased access to and use by pregnant women, may result in a reduction in LBW rates and, in turn, IM: comprehensive prenatal care; smoking cessation programs; and increased use of WIC services. It is generally assumed that these three interventions affect IM primarily through an effect on LBW, although a direct effect on IM, independent of birthweight, has been shown for a least two of the interventions: prenatal care (Strobino et al. 1985) and WIC (Rush et al. 1988a,b).

Comprehensive Prenatal Care. Prenatal care is frequently cited as an important intervention to reduce IM (Committee to Study the Prevention of Low Birthweight 1985). In addition to recommendations for further widespread use of early and continuous prenatal care, policy makers have recently endorsed changes in the content of prenatal care (Expert Panel on the Content of Prenatal Care 1989), as well as programs for the prevention of preterm births (Committee to Study the Prevention of Low Birthweight 1985).

Evaluation of the scientific literature led us to two conclusions regarding the potential impact on IM of changes in the use of prenatal care. First, valid estimates of the effect of the timing or number of prenatal visits on IM cannot be made from available data. Most studies of routine prenatal care include data sources like vital records, which contain limited information about variables like health behaviors and complications of pregnancy that may confound the relation between use of care and pregnancy outcomes. Self-selection for care cannot be dismissed as the primary explanation for the findings of these studies. Moreover, the results of more rigorously designed studies show little or no effect of changes in the use of routine prenatal care on LBW rates. (Strobino et al. 1986; Peoples, Grimson, and Daughtry 1984).

Second, preterm birth prevention programs appear to have little impact on reducing preterm births among low-income women. These programs use risk-assessment instruments to target high-risk women for more intensive interventions like cervical exams and use of tocolytic agents in the event of preterm labor. Although the results of studies with historical or nonequivalent controls suggest that these programs may reduce preterm births (Buescher et al. 1988; Covington et al. 1988; Herron, Katz, and Creasy 1982; Konte, Creasy, and Laros 1988), they have not been supported by clinical trials among low-income women (Konte, Creasy, and Laros 1988; Collaborative Group on Preterm Birth Prevention 1993; Goldenberg et al. 1990). Because the clinical trials indicated that these programs had no impact, estimates of their effect on IMRs were not calculated.

We assessed the potential effect of increased use of comprehensive prenatal care on IM in the HS cities. The Expert Panel on the Content of Prenatal Care (1989) concluded that comprehensive prenatal care, particularly if implemented early in pregnancy, can improve pregnancy outcomes for low-income women, the target population of HS. Comprehensive care includes ancillary services, such as psychosocial counseling, nutritional counseling, and health education, in addition to medical and obstetric services.

The results of several nonequivalent control-group, quasi-experimental studies (Sokol et al. 1980; Korenbrot 1984; Peoples, Grimson, and Daughtry 1984; Buescher et al. 1988; Handler and Rosenberg 1992; Buescher and Ward 1992) have consistently shown reductions ranging from 16 to 50 percent in the odds of LBW associated with comprehensive care. Data from clinical trials are not available for comprehensive care. Although data from these quasi-experimental studies were used here, they are constrained by the possibility that differences between women with and without comprehensive care may be due to their having dissimilar characteristics.

Data from the study by Buescher and Ward (1992) were used to calculate the impact of comprehensive prenatal care on reducing very low birthweight (VLBW) and LBW rates and, in turn, IM in the HS cities. In this study, Medicaid-eligible white and black women who received comprehensive prenatal care from health departments in North Carolina were compared with Medicaid-eligible women who received care from private providers; no other investigators reported data by race. Comprehensive care was associated with a 25 percent reduction in LBW rates for white women and a 15 percent reduction for black women, after adjustment for confounding variables. The respective reductions in VLBW (births less than 1500 grams) rates were 22 and 31 percent. These odds ratio estimates are in the mid-range of estimates from other studies.

An estimate of the baseline proportion of pregnant women who receive comprehensive prenatal care services was derived from the prenatal provider portion of the 1988 National Maternal and Infant Health Survey (National Center for Health Statistics 1991). Comprehensive care was defined, using these data, to include medical prenatal services and one or more of the following: nutrition education or counseling; psychosocial counseling; or health education. Using the weighted data for the maternal survey sample, the proportion of women estimated to have received comprehensive prenatal care in 1988 was 11.5: 11.1 percent for white women and 13.3 percent for black women.

Our estimate of the effect of comprehensive prenatal care was based on a doubling of the proportion of women who received comprehensive prenatal care. Using the race-specific data from Buescher and Ward for LBW and VLBW, we estimated that the IMR would be reduced by 2.5 percent if use of comprehensive care were to double (table 4). This estimate may be modest, given the liberal definition of comprehensive prenatal care that we used for the survey data.

TABLE 4
Estimated Effect[a] of Low-Birthweight Interventions on Infant Mortality Reduction

Intervention	Estimated IMR	Estimated deaths averted	Percent decline in IMR
Baseline	14.48	0	0.0
Double usage of comprehensive care	14.12	96	2.5
Smoking cessation for all smokers	14.34	37	0.9
Full WIC participation	14.18	79	2.0

[a] The estimated IMRs were calculated separately for each intervention; they do not represent the combined effect of all LBW interventions.
Abbreviations: IMR, infant mortality rate; WIC, Supplemental Nutrition Program for Women, Infants and Children.

Smoking Cessation Programs. Smoking cessation during pregnancy has been promoted as a means of reducing both LBW and IM rates. Although routine health education, a component of comprehensive prenatal care, often covers the hazards of smoking during pregnancy, smoking cessation programs are more intensive than these routine health education efforts, often involving multicomponent, self-help health education or frequent follow-up.

Most studies of smoking or smoking cessation are observational, and were not considered in our estimates. Since 1972, 12 randomized clinical trials (RCTs) of smoking cessation have been conducted (Floyd et al. 1993; Li et al. 1992); only two studies from the United States (Donovan 1977; Sexton and Hebel 1984) and two from the United Kingdom (Donovan 1977; MacArthur, Newton, and Knox 1987) have published data on birthweight. The RCT data were used because they were less likely to be limited by intervention and control-group selection bias.

Our estimates of the impact of smoking cessation programs are based on data from the RCT in Birmingham, Alabama, by Windsor and colleagues (Li et al. 1992; Windsor et al. 1993). This trial, administered entirely in a prenatal clinic setting, provides odds ratios for LBW for smokers, quitters, reducers, and nonsmokers. It included approximately 800 women recruited from four public health clinics in Jefferson County, Alabama, between 1986 and 1991. The intervention consisted of multicomponent, self-help health education; salivary cotinines were used to validate smoking status. The quit rates were 14.3 percent for the experimental group and 8.4 percent for the control group. Among women who did not quit, 17.4 percent reduced smoking and 72.9 percent experienced no change. The quit rates are comparable to rates found by MacArthur and colleagues (MacArthur, Newton, and Knox 1987), but are substantially lower than the rates reported by Sexton and Hebel (Sexton and Hebel 1984); in this latter trial, extensive contact was made with women outside the clinic setting.

Data from the 1988 National Maternal and Infant Health Survey provided estimates of baseline rates of quitting (7.8 percent), reducing (5.2 percent), continued smoking (16.9 percent), and never smoking (70.1 percent) for the HS cities in the absence of universal smoking cessation interventions. Rates for quitting, reducing, and continued smoking from the Windsor trial were then applied to births in the HS cities, assuming that all smokers (29.9 percent) were exposed to a smoking cessation intervention. Odds ratios for LBW for continuous smokers, reducers, and quitters, compared with never-smokers from Windsor's (Collaborative Group on Preterm Birth Prevention 1993) study, were 1.92, 1.73, and 1.18, respectively. The number of LBW births was estimated to be reduced by 440, using these data for all estimated pregnant women who smoked in the HS cities. The IMR, applying the birthweight-specific rates to the reduced number of LBW births, was estimated to drop by 0.9 percent (table 4), to 14.34.

Increased Utilization of WIC. The Supplemental Nutrition Program for Women, Infants and Children (WIC), which is federally funded and locally administered, has been promoted as a vehicle to enhance favorable pregnancy outcomes for women (Paige and Davis 1986; Paige 1993). Estimates of the effect of WIC on IM were derived from the National Historical Evaluation Study of Pregnancy Outcomes (Rush et al. 1988a,b), one of the four studies constituting the WIC national evaluation during its first decade of operation (1972–81). This study was chosen because it is the largest WIC evaluation to date. Moreover, it is not constrained by the limitations of most other WIC evaluations in which selection bias of participants is a major problem. Data were analyzed from 1,149 counties in 17 states and the District of Columbia. The reduction in IM associated with WIC was estimated to be 1.49 infant deaths per 1,000 live births, using a measure of WIC participation defined by the number of women served divided by the number eligible to participate in the program (Rush et al. 1988a,b).

The effect of WIC was estimated, assuming that the benefit to the total population arises from women who are actually enrolled in the program. To estimate the baseline number of WIC participants, we first determined the percentage of the birth population at or below 185 percent of poverty in the HS cities, the maximum level for WIC eligibility. Data from the 1990 Census (U.S. Census Bureau 1990) indicated that 54.7 percent of women in the HS cities lived in families (with children under 5) whose incomes were below 185 percent of the poverty level. We next interpolated the national figures on WIC enrollment rates for 1984, 1986 (U.S. Department of Agriculture 1990), 1989, and 1990 (D. Thomas 1993: personal communication) to obtain an estimated enrollment rate for 1987, the same year as the vital statistics data (WIC enrollment rates rose from 40 percent in 1984 to 85 percent in 1989 and 1990). Applying the interpolated rate of 64 percent to the HS cities, and assuming full participation of all income-eligible women in WIC, infant deaths in an estimated 53,063 newly enrolled women would decline by 79, for a decrease in the overall IMR of 2.0 percent, to 14.18 (table 4).

Reducing Birthweight-Specific Mortality

Of the four IM reduction strategies, the best documented success in reducing IM in a population has been achieved through decreases in birthweight-specific mortality. The large decline in IM in the United States between the 1960s and the 1980s was due primarily to reduced birthweight-specific mortality rates (McCormick 1991; Lee et al. 1980). This decline is presumed to have been achieved through the more widespread access of LBW infants to neonatal intensive care, although direct empirical evidence is lacking (Sinclair et al. 1981).

Access to Risk-Appropriate Care. Part of the reduction in birthweight-specific mortality has been credited to the creation of systems of regionalized perinatal care in which maternity and newborn services are organized into a hierarchy of levels of technologically sophisticated care (Lee et al. 1980). These systems were created to ensure that, by assessing the risks of mothers and newborns, risk-appropriate care, particularly intensive care, is made available to all mothers and infants. As regionalization progressed, large declines were noted in neonatal mortality of LBW infants in several geographic areas (Nugent 1982; Miller, Densberger, and Krogman 1983; Goldenberg et al. 1985; McCormick, Shapiro, and Starfield 1985).

To estimate the potential effect of ensuring the availability of intensive perinatal and neonatal care, we chose the HS city with the lowest race-specific neonatal and early postneonatal mortality (deaths between 28 days and six months) rates among LBW (500–2500 grams) infants as a gold standard, assuming that much of the credit for these lower rates goes to provision of high-risk care to mothers and newborns in the chosen city.

Boston had the lowest race-specific neonatal and early postneonatal mortality rates among LBW infants, after excluding cities with fewer than 10 black or white infant deaths among their LBW population because of concern about the instability of small numbers. Using the Boston rates for black and white births, we estimated an IMR of 12.64, for a 12.7 percent reduction and a total of 495 deaths averted (table 5).

Surfactant Therapy. A recent advance in improving survival among LBW infants is surfactant therapy, which is used to reduce the risk of respiratory distress syndrome (RDS) among preterm infants. A number of clinical trials indicate improved survival of infants who receive synthetic and natural surfactant, either prophylactically or as a rescue treatment when RDS has already developed (Soll and McQueen 1992). The United States approved the use of synthetic and animal surfactant in 1990 and 1991, respectively (Jobe 1993).

Our estimates of the effect of surfactant are based on the assumption that it will be administered to all preterm infants in tertiary care hospitals who weigh between 750 and 1250 grams. Soll and McQueen (1992)

TABLE 5
Estimated Effect[a] of Birthweight-Specific and Postneonatal Mortality Intervention on Infant Mortality Reduction

Intervention	Estimated IMR	Estimated deaths averted	Percent decline in IMR
Access to risk-appropriate care	12.64	495	12.7
Surfactant therapy	13.94	142	3.6
Change in sleep position	13.93	146	3.7

[a] The estimated IMRs were calculated separately for each intervention; they do not represent the combined effect of all strategies.
Abbreviation: IMR, infant mortality rate.

used meta-analysis techniques to combine the results of clinical studies of surfactant. Because of slightly greater reductions in mortality associated with artificial compared to natural surfactant (6.4 percent vs. 4.8 percent), our estimates are based on the study results for artificial surfactant. Soll and McQueen (1992) noted that the prophylactic administration of synthetic surfactant decreased mortality by 26.4 percent among infants in the treatment group (birthweight: 500–1350 grams; gestational age: 25–33 weeks) when compared with infants in the control group. Because the majority of infants in the trials weighed at least 700 grams at birth, we applied the typical relative risk of 0.74 from the meta-analysis of prophylactic synthetic surfactant trials to births weighing from 750 to 1250 grams in the HS cities. A drop in the IMR of 3.6 percent to a rate of 13.94 (table 5) was estimated if all infants in this weight range received surfactant therapy.

Reducing Mortality during the Postneonatal Period

The strategies discussed above focus on reducing risk factors arising during the antepartum or early neonatal period. In the United States, approximately one-third of infant deaths occur during the postneonatal period. The major cause of postneonatal death is sudden infant death syndrome (SIDS), accounting for one-third of postneonatal deaths in 1991 (*Morbidity and Mortality Weekly Reports* 1992). The recent recommendation by the American Academy of Pediatrics (AAP) to reduce SIDS by encouraging caregivers to place healthy infants on their side or back (lateral or supine) while sleeping (American Academy of Pediatrics 1992) is the focus of our estimates. Other causes of postneonatal deaths were not addressed because of the heterogeneous nature of these deaths and the multiple interventions that would be required to prevent them.

Suddent Infant Death Syndrome. Several studies have been undertaken to ascertain the impact of modifiable risk factors on the incidence of SIDS. These factors include infant sleep position, maternal smoking, breast feeding, and thermoregulation during sleep (Mitchell et al. 1992; Ponsonby et al. 1992; Schoendorf and Kiely 1992). We focus on infant sleep position, even though the AAP recommendation continues to be a source of debate, because it may provide an opportunity to reduce the death toll from SIDS in the United States.

Odds ratio estimates for prone sleep position and SIDS were obtained from the work of Beal and Finch (1991). They calculated a common odds ratio for the prone position (2.72, 95 percent confidence interval of 2.27–3.26) from the six case control studies that defined sleep position as the "usual position"; no adjustments, although performed in some studies, were made for matching or other factors. Beal and Finch reported this estimate as conservative because adjusting for other factors would have increased the common odds ratio. Indeed, Mitchell and colleagues (1992) note a greater odds ratio in their study in New Zealand. We did not use this estimate because of the high baseline rate of SIDS in New Zealand compared with that found in the United States.

Our estimate of the percentage of infants (79 percent) who slept in a prone position in the United States prior to the AAP recommendation was based on data from a study by the National Institute of Child Health and Human Development on risk factors for SIDS (Hoffman et al. 1988). No estimates were available for the expected response to the AAP recommendation, so calculations were based on a 50 percent reduction in the percentage of infants who currently sleep prone. The IMR from SIDS in the HS cities in 1987 was 1.87 per 1,000. A 50 percent reduction in the proportion of infants sleeping prone was estimated to result in a 3.7 percent decrease in the IMR for the HS cities (table 5).

All Strategies Combined

As a final assessment of the HS goal of a 50 percent reduction in IM, we calculated the combined effect of all four strategies on IM, assuming independence of the interventions. Two estimates were calculated: the first, by adding the reduction in infant deaths for all interventions. The cumulative reduction in the IMR by adding each is shown in table 6.

For the second, the effect of each intervention was estimated in a sequential fashion. The reductions in LBW resulting from interventions to reduce high-risk pregnancies were used as the starting point here, followed by the prenatal interventions to reduce LBW. The changes in the birthweight distribution from these interventions then became the basis for estimating the effect of reductions in birthweight-specific mortality.

Figure 1 shows the cumulative results for the two estimates. The estimated combined impact of all interventions, assuming independent ef-

TABLE 6
Summary of Anticipated Reductions in Infant Mortality from Selected Interventions

Intervention	Estimated IMR	Estimated deaths averted	Cumulative percent decline in IMR
Baseline	14.48	0	0.0
Unwanted births	14.14	90	2.3
Birth interval	14.07	109	5.1
Teenage births	14.34	37	6.1
Comprehensive prenatal care	14.12	96	8.5
Smoking	14.34	37	9.5
WIC	14.18	79	11.5
Risk-appropriate care	12.64	495	24.2
Surfactant therapy	13.94	142	27.8
SIDS	13.93	146	31.6
Total (maximum effect)	9.91	1,231	31.6

Abbreviations: IMR, infant mortality rate; WIC, Supplemental Nutrition Program for Women, Infants and Children; SIDS, Suddent Infant Death Syndrome.

fects, is less than the 50 percent target; a 31.6 percent reduction in the rate was estimated, to 9.91 infant deaths per 1,000 live births, if all the interventions were independent. The sequential estimate is even less: only a 26.7 percent reduction in IMRs is projected for all interventions combined.

Discussion

The Year 2000 Objectives for the Nation propose a reduction in the IMR to 7 per 1,000, and in the LBW rate to 5 percent (U.S. Department of Health and Human Services 1991). Even if the HS programs achieve their goal of a 50 percent reduction in IMRs over their five-year demonstration period, the IM rates in the HS communities will still not meet the Year 2000 objectives. Moreover, the reductions in IM that can be achieved by any single intervention are modest at best.

Our calculations indicate that, based on our current knowledge of effective interventions, none of the HS sites can expect to reach their goal,

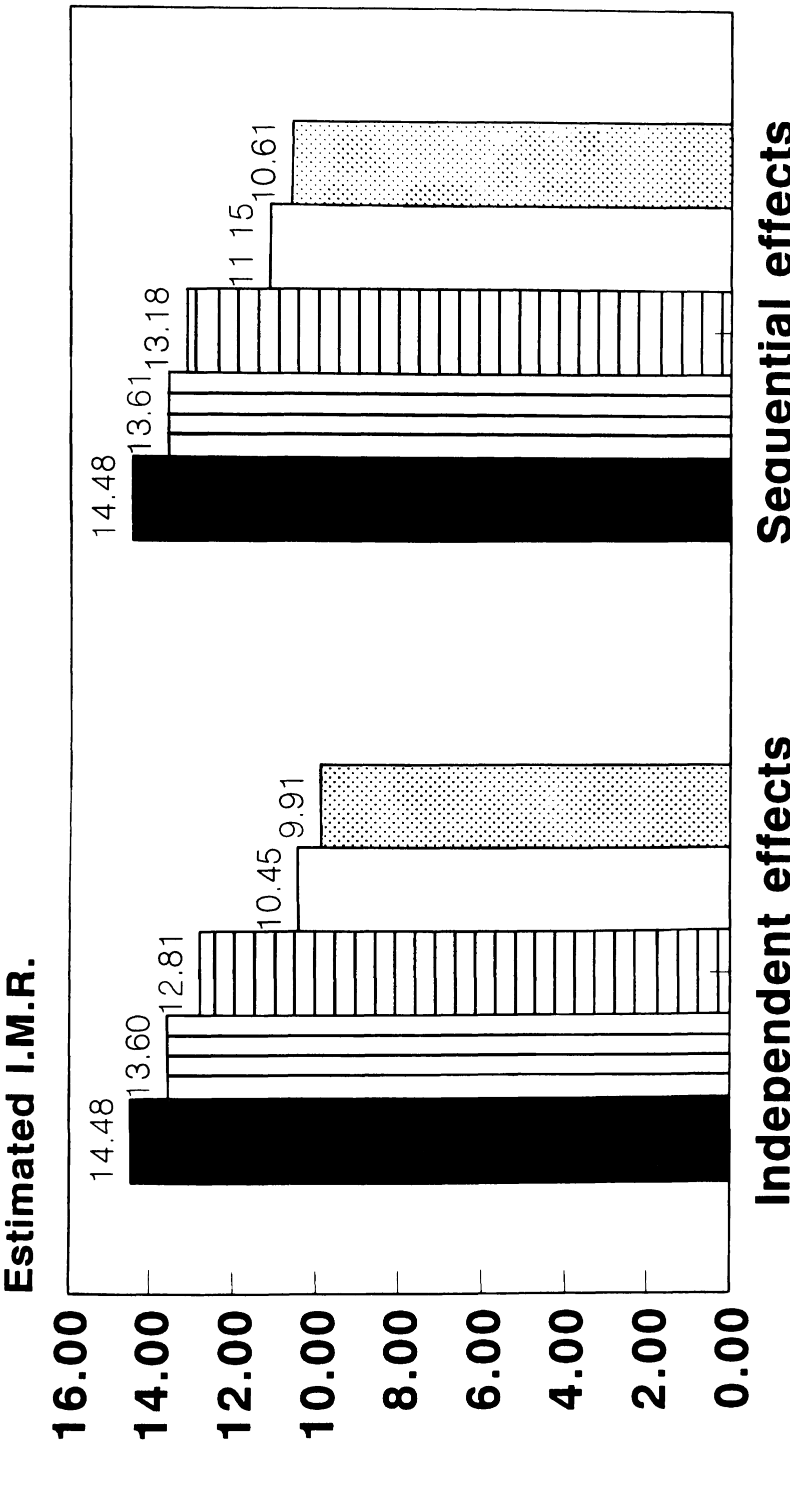

FIG. 1. Combined effect of infant mortality reduction strategies: estimated independent and sequential effects. ■, infant mortality rate for 1987; ▥, prenatal intervention; ⊡, sudden infant death syndrome; ⊟, family planning; □, birthweight-specific mortality.

even if they adopted all of the strategies that we evaluated. Under the unlikely assumption that the interventions are independent, the combined effect of all interventions would still yield at most about a 30 percent reduction in IM (table 5). Moreover, only one intervention would result in an IM reduction of over 5 percent: increasing the availability of risk-appropriate obstetric and neonatal care. Its estimated effects, however, may be overly optimistic. This intervention has not specifically been supported with HS funds, but rather is a possible structural change that may accompany changes in HS-funded services.

There is clearly overlap among the strategies. For example, the successful use of surfactant is closely related to availability of intensive maternal and neonatal care. Similarly, part of the influence of comprehensive prenatal care on LBW may be due to lowered maternal smoking, even without the use of specific smoking cessation programs (Sexton and Hebel 1984). The effect of WIC on IM may, in part, be related to a woman's use of prenatal care. Thus, it is likely that the combined impact of all the interventions will fall far short of the 50 percent goal for the HS sites.

Although our framework for IM reduction is comprehensive, the estimates we presented here do not fully capture the current or emerging problems contributing to high IM that need to be addressed in the HS cities. For example, we did not capture the contribution of multiple births to IM. In 1983, twins accounted for only 2 percent of births, but 10 percent of infant deaths (Kleinman, Fowler, and Kessel 1991). Moreover, between the early 1970s and late 1980s, higher-order multiple births (triplets or higher) increased by 80 percent among whites, and by 9 percent among black women, after accounting for secular changes in births to older women (Kiely, Kleinman, and Kiely 1992).

The emerging prominence of AIDS as a cause of death among infants was also not addressed. The impact of human immunodeficiency virus (HIV) infection and acquired immune deficiency syndrome (AIDS) on the rate of postneonatal mortality is determined by many factors, including the seroprevalence of HIV infection among childbearing women, the rate of mother-to-child transmission, and the life expectancy of newborns who acquire the disease. Assuming a high seroprevalence of 4 per 1,000 women in the HS cities (similar to the high rates in several inner-city populations) (Gwinn et al. 1991), a high perinatal transmission rate of 30 percent (Oxtoby 1990), and a death rate of between 8.5 and 17 percent for infected infants during the first year of life (Blanche et al.

1989; European Collaborative Study 1991; Italian Multicenter Study 1988), approximately 27 to 55 infant deaths in the HS cities, respectively, could be attributed to the transmission of maternal HIV infection. With rising rates of seroprevalence among pregnant women, increases in IMRs due to AIDS, although not large, will counterbalance small improvements from HS programmatic changes.

A variety of medically based interventions were not addressed in our estimates that could have small, but tangible, effects on IM if they were more widely used. For example, more widespread use of genetic screening could reduce the number of deaths due to genetically related congenital anomalies by reducing high-risk pregnancies that are carried to term. These interventions were not discussed here because they generally require considerable investment of resources—for example, screening of all women—to affect a relatively small proportion of the population.

Finally, programs or services directed to reducing substance use during pregnancy were also not considered in our estimates. Neither population-based data on drug use nor data from evaluations of drug treatment programs for pregnant women were available to us. Although a number of substance abuse treatment programs for pregnant women have recently been funded, data from the evaluation of these programs have not yet become available (E. Hutchins 1994: personal communication). Most earlier programs were not evaluated. Moreover, the number of infants actually affected by drug use may be sufficiently small to have only a marginal effect on IMRs in a population.

In the making of public policy, we are likely to adopt single, and often simplistic, approaches that may not enable us to achieve our goals. This is the case at present with the focus on improving access to prenatal care as the major vehicle to reducing infant mortality. As our analysis suggests, reducing IM in a community is not a simple task. Failure to do so, unfortunately, reinforces the public sense that these social problems are intractable. The ebb and flow of public funding to perinatal health programs in part reflects this fluctuating confidence in public health efforts. A more comprehensive set of strategic alternatives, such as we have proposed, may lead to more realistic objectives and a more thoughtful assessment of potential successes and failures.

In the HS communities, political will and the scientific knowledge base must be mobilized to assure that they do not fail in their efforts to reduce IM. The 15 HS sites are faced with the momentous task of significantly reducing IM over five years. Our estimates provide them, as well as other communities, with empirically based projections for IM reduction that can be used to mobilize politicians and policy makers into developing new efforts and sustaining current ones. These communities are currently using different combinations of intervention strategies designed to address the needs of their diverse populations. We studied some of these interventions; others we did not. Community-based interventions in the HS communities include public information campaigns; outreach and case management to improve access to prenatal care; innovative clinical and support services, enhancement of family planning, and access to both; specialized support services like transportation, substance abuse treatment, mental health, male partner involvement, and youth initiatives; service integration through one-stop shopping and enhancement of provider networks; and quality assurance (Howell et al. 1994). The diversity of intervention strategies reflects the multiple causes of infant mortality, many of which have their roots in social inequities (Wise 1990).

The calculations presented here are not intended to depersonalize reduction of IM to the level of an accounting exercise. Infant mortality is a human tragedy as well as a medical crisis and a public health emergency of national significance. Public officials and policy makers must, nevertheless, carefully think through the numerical implications of their objectives. Societal goals and programmatic objectives must operate through the proximal biological determinants of IM if they are to be successful. Our intent in writing this article was to identify such pathways in order to facilitate a strategic planning process toward the goal of reducing IM.

Our estimates of the impact of known interventions suggest that IM rates can be reduced by a nontrivial amount in the HS cities, even if this reduction falls short of the 50 percent goal. Our current knowledge should make it possible to use the HS responses in an effective manner. We must not lose this opportunity to continue to promote such programs to reduce infant mortality.

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