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Special article

# A WHO Collaborative Study of Maternal Anthropometry and Pregnancy Outcomes[1]

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**Abstract**

*Objectives:* To evaluate to what degree anthropometric measurements are useful and efficient in predicting maternal and fetal outcomes in different country settings and to develop appropriate reference curves for maternal weight gain. *Methods:* A meta-analysis of 25 data sets providing information on over 111 000 births worldwide. *Results:* Attained weight indicators from pre-pregnancy (Pp) through 9 lunar months demonstrated high odds ratios (O.R.) for both low birth weight (LBW) and intra-uterine growth retardation (IUGR). The strongest effect size (O.R. = 4.0) was provided by attained weight at 7 lunar months for IUGR, when applied to women of below average pre-pregnancy weight. The study indicators showed only minor and inconsistent O.R. for preterm birth (PTB). The ability of study indicators to predict the three maternal outcomes was much weaker. Maternal height as a predictor of assisted delivery showed the highest positive O.R. (1.6), but did not meet the screening criteria. *Conclusions:* A single measurement of attained weight at 5 or 7 lunar months (16–20 or 24–28 weeks) is the most practical screening instrument for LBW and IUGR in most primary health care settings and provides warning of the need for intervention. The operational value of these findings should be demonstrated through their successful large-scale application in service settings.

*Keywords:* Anthropometry; Maternal nutrition; Pregnancy; Low birth weight

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## 1. Introduction

Maternal nutrition is a fundamental determinant of fetal growth, birth weight and infant morbidity, as well as of women's health, productivity and caring capacity [1]. Anthropometry provides a simple, reliable and low-cost method of assessing maternal nutrition status which can be universally applied at the primary care level by low-skilled workers in the community. The potential for maternal anthropometry to indicate the risk of intra-uterine growth retardation, low birth weight, pre-eclampsia and obstructed labor is based on known physiological principles [2–4], however its ability to predict other fetal and maternal outcomes is less clear and is the subject of continuing research [5–8]. It is appreciated that maternal nutrition status is associated with only a limited range of reproductive risk and that its relative contribution to the successful outcome of pregnancy will vary in relation to prevailing health conditions [4].

In 1990, the World Health Organization (WHO), Pan American Health Organization (PAHO), the United States Agency for International Development (USAID) and MotherCare International convened an international meeting to examine the relationship between maternal anthropometry and pregnancy outcome and its application to primary health care [2,9]. The meeting concluded that there was a lack of clear recommendations on preferred indicators for specific pregnancy outcomes in different health care settings and that insufficient knowledge existed about the reliability of such indicators across a range of populations. In response to these conclusions, WHO established a research project to determine:

- the degree to which anthropometric measurements are useful and efficient for predicting maternal and fetal outcomes in different service settings;
- the quantative association of specific indicators with risk for mother and fetus in different populations and,
- appropriate reference curves for weight gain to monitor pregnancy under service conditions.

Research strategy was based on a meta-analysis of existing maternal anthropometry data sets from world-wide sources. This approach was preferred to a multi-center prospective study as many suitable data sets already existed, analysis costs would be relatively low and findings would be available promptly. Twenty-five studies from 20 countries meeting pre-defined entry criteria were selected (Table 1) and the corresponding data sets submitted by collaborating investigators to provide information on more than 111 000 births. A detailed account of the complete study is published elsewhere [10].

## 2. Methodology

### 2.1. Indicators

Maternal anthropometric data available for this study consisted of: height, weight, and mid-upper arm circumference at pre-pregnancy or early pregnancy, weight for gestational age, body mass index (BMI) for gestational age and interval weight gain. Fetal outcomes for which data were widely available consisted of low birth weight (LBW), intra-uterine growth retardation (IUGR) as defined by Williams [11] and preterm birth (PTB); data on maternal outcomes were available for pre-eclampsia, post-partum hemorrhage (PPH) and assisted delivery; the last mentioned outcome aggregated all non-spontaneous births including cesarean section, forceps application and vacuum extraction.

### 2.2. Study inclusion

Studies considered for the meta-analysis were identified by key researchers from all parts of the world attending the 1990 conference. Some 55 individual investigators were identified and contacted and requested to submit a proposal for collaboration. A protocol accompanying the invitation requested detailed information on 13 areas relating to the original study, including: study design, training of personnel, and details of the

Table 1
Studies included in the meta-analysis

| Country | Abbreviation | Study |
|---|---|---|
| Argentina | ARG | Rosario study |
| Botswana | BOT | WHO hypertensive disorders of pregnancy study |
| China | CHI | WHO hypertensive disorders of pregnancy study |
| Colombia | COL | Valle del Cauea perinatal study |
| Cuba | CUB | Cuban risk approaeh study |
| Gambia | GAM | Keneba supplementation study (MRC-Dunn Nutrition Unit, Cambridge) |
| Guatemala | GUA | 'Oriente' study — INCAP |
| India (Pune) | IN(P) | WHO/SEARO multi-center study on risk for LBW |
| India (Hyderabad) | IN(H) | NIN Hyderabad anemia risk study |
| Indonesia | INO | Bogor study on risk of LBW |
| Ireland | IRE | Rotunda study, Dublin |
| Lesotho | LES | WHO hypertensive disorders of pregnancy study |
| Malawi | MAL | Malawi maternal and child nutrition study |
| Myanmar | MYN | WHO hypertensive disorders of pregnancy study |
| Nigeria | NIG | Pregnancy risk study |
| Nepal (rural) | N(R) | WHO/SEARO multi-center study on risk for low birth weight |
| Nepal (urban) | N(U) | WHO/SEARO multi-eenter study on risk for low birth weight |
| Sri Lanka | SL | WHO/SEARO multi-center study on risk for low birth weight |
| Thailand | THA | WHO hypertensive disorders of pregnancy study |
| United Kingdom | UK | Aberdeen, Scotland |
| USA (CDC—black) | US/CDC(B) | Pregnancy nutrition surveillance system (Centers for Disease Control) |
| USA (CDC—hispanic) | US/CDC(H) | Pregnancy nutrition surveillance system (Centers for Disease Control) |
| USA (CDC—white) | US/CDC(W) | Pregnancy nutrition surveillance system (Centers for Disease Control) |
| USA (NCPP—black) | USINCPP(B) | National Collaborative Perinatal Project |
| Vietnam | VIE | WHO hypertensive disorders of pregnancy study |

scope and quality of the data recorded. A WHO panel reviewed the proposals and determined a final selection. Collaborators were invited to re-analyze their data and submit a report to WHO, but additionally, they were also requested to submit a copy of the complete data set to WHO for purposes of the meta-analysis. This ensured that coding of variables was under the control of the

Table 2
Definition of study variables

Low birth weight (LBW): Birth weight < 2500 g.
Intra-uterine growth retardation (IUGR): Birth weight less than the 10th pereentile weight-for-gestational age by sex of an international reference group [4,11].
Preterm birth (PTB): Gestational age at delivery less than 37 weeks.
Delivery complications (assisted delivery) Various complications of delivery have been merged and equated with assisted delivery, i.e. any delivery whicb was eoded as non-spontaneous, including cesarean section. 'Prolonged labor' was initially considered for inelusion in this category, but eventually discarded as few studies explieitly reported on this complication.
Pre-eclampsia: No generally accepted definition for hypertensive disorders of pregnancy exists. The WHO Collaborative Study on Hypertensive Disorders of Pregnancy recommended: diastolic pressure ≥ 90 mmHg, proteinuria (130 g/l urine) and/or presence of edema. To minimize difference in classification between studies, only WHO eollaborative studies were analyzed for this outcome.
Post-partum hemorrhage (PPH): Excessive bleeding during the first 24 h post-partum.
Lunar month: This bas been defined for comparability purposes in terms of a 4-week month. Thus, the 5th month of pregnancy refers to a gestational age ≥ 16 weeks and < 20 weeks, the 7th month is a gestational age ≥ 24 weeks and < 28 weeks, and the 9th month corresponds to a gestational age ≥ 32 weeks and < 36 weeks. With this definition, the typical pregnancy has a duration of 10 (lunar) months.

analyst and standardized definitions were used throughout (Table 2). All analyses were conducted on live-born singleton births with recorded gestational ages between 22 and 45 weeks. Summary results for maternal and infant outcomes and maternal anthropometry for each study are presented (Tables 3a–3c).

During the meta-analysis, due regard was payed to potential biases affecting external validity and comparability, e.g. dates of studies, mean age of mothers, endemic diseases, e.g. malaria and high prevalence of anemia, differences in the prevalence of outcomes of interest, study setting (major urban hospital, small rural clinic, developed or developing country), level of training and quality of measurement equipment, and study design. A study 'quality table' was prepared (Table 4) in order to code individual studies in terms of the main biases likely to affect conclusions.

### 2.3. Meta-analysis

As this study was directed at conclusions that would have international rather than country-specific relevance, analysis was not based on locally defined anthropometric cut-off points, as such findings would be difficult to generalize. The working solution adopted was to look for clusters of studies that could be grouped according to similar anthropometric characteristics. To this end, groups of data sets were identified by cluster analysis for each indicator and common quartile cut-off points were then employed in the estimation of study-specific effect sizes prior to the meta-analysis. The issue of cut-off point selection appropriate in this and other contexts has been investigated in detail by Habicht and co-workers [12–14].

Table 3a
Mean birth weight, gestational age at delivery and percentages for selected birth outcomes for the fetus

| Country/data set | LBW (%) | IUGR (%) | Preterm (%) | BWT (g) | (±S.D.) | Gestation (weeks) | (±S.D.) |
|---|---|---|---|---|---|---|---|
| Argentina | 6.3 | 9.7 | 7.2 | 3239 | (535) | 39.1 | (2.1) |
| Botswana | 12.5 | 8.8 | 56.0 | 3031 | (543) | 33.2 | (6.7) |
| China | 4.2 | 9.4 | 7.5 | 3164 | (424) | 39.4 | (1.9) |
| Colombia | 16.1 | 17.8 | 15.7 | 3015 | (658) | 38.6 | (3.2) |
| Cuba | 8.1 | 14.7 | 7.2 | 3174 | (544) | 39.6 | (2.4) |
| Gambia | 12.1 | 13.5 | 13.5 | 2937 | (410) | 38.8 | (1.6) |
| Guatemala | 12.5 | 25.3 | 15.8 | 2996 | (492) | 39.0 | (2.8) |
| India (Pune) | 28.2 | 54.2 | 9.7 | 2633 | (417) | 38.9 | (3.5) |
| India (Hyderabad) | 15.3 | – | – | 2782 | (414) | – | – |
| Indonesia | 10.5 | 19.8 | 18.5 | 2936 | (415) | 38.5 | (2.6) |
| Ireland | 5.6 | 6.9 | 6.2 | 3436 | (612) | 40.1 | (2.4) |
| Lesotho | 10.3 | 13.0 | 34.5 | 3078 | (543) | 36.7 | (5.4) |
| Malawi | 11.6 | 26.1 | 8.2 | 2977 | (499) | 39.3 | (1.9) |
| Myanmar | 17.8 | 30.4 | 24.6 | 2852 | (469) | 38.0 | (4.9) |
| Nigeria | 12.4 | 22.2 | 8.2 | 3052 | (584) | 39.4 | (1.7) |
| Nepal (rural) | 14.3 | 36.3 | 15.8 | 2787 | (416) | 38.9 | (3.1) |
| Nepal (urban) | 22.3 | 42.7 | 21.8 | 2760 | (498) | 36.4 | (8.9) |
| Sri Lanka | 18.4 | 34.0 | 14.0 | 2841 | (458) | 38.7 | (4.0) |
| Thailand | 9.6 | 17.0 | 21.3 | 3004 | (462) | 38.1 | (4.6) |
| United Kingdom | 6.2 | 12.3 | 4.6 | 3239 | (505) | 40.0 | (1.9) |
| US/CDC (black) | 10.6 | 11.2 | 16.6 | 3144 | (570) | 38.4 | (2.9) |
| US/CDC (hispanic) | 4.8 | 5.8 | 10.2 | 3347 | (519) | 39.0 | (2.4) |
| US/CDC (white) | 6.0 | 6.9 | 9.3 | 3355 | (566) | 39.1 | (2.6) |
| US/NCPP (black) | 13.5 | 13.6 | 21.5 | 3058 | (648) | 38.3 | (4.3) |
| Vietnam | 5.2 | 18.2 | 13.6 | 2997 | (369) | 39.1 | (3.0) |

—, no information or too few observations.

Table 3b
Mean maternal age and percentages for selected pregnancy outcomes

| Country/data set | Maternal age (± S.D.) | Assisted delivery (%) | Pre-eclampsia (%) | Post-partum hemorrhage (%) |
|---|---|---|---|---|
| Argentina | 24.5 ± 6 | — | — | — |
| Botswana | 25.4 ± 6 | 8.5 | 7.3 | — |
| China | 27.3 ± 2 | 14.2 | 2.3 | 1.5 |
| Colombia | 24.0 ± 6 | 27.0 | 15.4 | 0.5 |
| Cuba | 23.8 ± 5 | 26.9 | — | — |
| Gambia | 27.3 ± 7 | — | — | — |
| Guatemala | 26.9 ± 7 | — | — | — |
| India (Pune) | 21.7 ± 4 | 3.6 | < 1.0 | — |
| India (Hyderabad) | 25.1 ± 5 | — | — | — |
| Indonesia | 25.1 ± 5 | 8.5 | — | — |
| Ireland | 27.5 ± 5 | — | — | — |
| Lesotho | 26.1 ± 6 | 9.3 | 5.5 | 4.4 |
| Malawi | 25.1 ± 7 | — | — | — |
| Myanmar | 26.5 ± 6 | 14.2 | 2.3 | 0.5 |
| Nigeria | 23.4 ± 5 | 14.4 | — | — |
| Nepal (rural) | 22.7 ± 5 | 2.2 | < 1.0 | — |
| Nepal (urban) | 24.0 ± 5 | 27.6 | 5.3 | — |
| Sri Lanka | 27.5 ± 5 | 5.7 | < 1.0 | — |
| Thailand | 25.0 ± 5 | 16.8 | 6.1 | 1.0 |
| United Kingdom | 22.3 ± 4 | — | — | — |
| US/CDC (black) | 22.7 ± 5 | — | — | — |
| US/CDC (hispanic) | 24.2 ± 5 | — | — | — |
| US/CDC (white) | 23.4 ± 5 | — | — | — |
| US/NCPP (black) | 23.6 ± 6 | — | — | — |
| Vietnam | 27.2 ± 4 | 4.4 | 3.5 | 2.1 |

—, no information or too few observations.

The Confidence Profile Method, developed by Eddy et al. [15], was employed in the meta-analysis. This is a Bayesian method that permits the calculation of a posterior probability curve describing the combination of the study effects (or odds ratios in this instance). Potential heterogeneity in the results across the data sets was determined by Hedges and Olkin's $Q$-test [16]. Subsequently, a weighted regression analysis was used to investigate variation in effect size in relation to the study characteristics as noted by Kramer [17].

The study was divided into two stages: first, specification of effect size for each indicator in respect of the three fetal and three maternal outcomes by meta-analysis and second, evaluation of indicators with adequate effect size, to be used for screening under different service conditions. Effect size was expressed as an odds ratio based on the frequency of the outcome occurring in the lowest quartile of the indicator distribution compared with that occurring in the highest quartile; this identified the degree of risk relative to the prevailing optimum rather than to an absolute standard. As further refinement, the effect size of each indicator was calculated when applied to known high-risk sub-groups to determine any change of magnitude that could be achieved by such anthropometric pre-selection. The sub-groups were: (i) mothers of below average height and (ii) mothers with below average pre-pregnancy weight. Indicators with the greatest effect size were then assessed to determine their usefulness as screening instruments against criteria based on recommendations by Habicht et al. [18]: specificity $> 0.7$ and sensitivity $> 0.35$ in 40%

Table 3c
Means of selected anthropometric measurements for maternal height, pre-pregnancy weight (Wtpp), pregnancy weight at 5, 7 and 9 months, full-term weight gain and arm circumference (MUAC)

| Country/data set | Height ± S.D. (cm) | Wtpp ± S.D. (kg) | Wt5 ± S.D. (kg) | Wt7 ± S.D. (kg) | Wt9 ± S.D. (kg) | Wt gain ± S.D. (kg) | MUAC ± S.D. (cm) |
|---|---|---|---|---|---|---|---|
| Argentina | 157 ± 5 | 57.6 ± 10 | — | — | — | 10.8 ± 5 | — |
| Botswana | — | — | 59.5 ± 9 | 61.4 ± 9 | 63.4 ± 10 | — | — |
| Myanmar | 151 ± 5 | 46.9 ± 8 | 49.1 ± 6 | 50.1 ± 6 | 51.6 ± 7 | — | 23.3 ± 2 |
| China | 160 ± 4 | 50.5 ± 5 | 52.1 ± 6 | 56.0 ± 6 | 59.3 ± 6 | 11.7 ± 4 | 23.6 ± 1 |
| Colombia | 155 ± 7 | 57.6 ± 10 | 56.0 ± 10 | 59.3 ± 9 | 62.7 ± 9 | 10.1 ± 5 | — |
| Cuba | 157 ± 6 | 55.5 ± 10 | — | — | — | 4.6 ± 1 | — |
| Gambia | 157 ± 6 | 50.1 ± 6 | 52.0 ± 6 | — | 56.9 ± 7 | 6.5 ± 3 | 25.1 ± 2 |
| Guatemala | 148 ± 5 | 47.6 ± 6 | 51.4 ± 5 | 50.9 ± 6 | 55.1 ± 6 | 7.1 ± 3 | 22.6 ± 1 |
| India (P) | 150 ± 5 | 42.1 ± 4 | 44.0 ± 5 | 45.8 ± 4 | 47.5 ± 5 | — | 22.3 ± 1 |
| India (H) | 150 ± 5 | 45.9 ± 7 | — | — | — | — | 22.4 ± 2 |
| Indonesia | 149 ± 4 | 46.0 ± 6 | 47.4 ± 6 | 50.3 ± 6 | 52.7 ± 6 | — | 23.9 ± 2 |
| Ireland | 158 ± 5 | 58.8 ± 8 | 60.0 ± 8 | 63.4 ± 8 | 66.8 ± 8 | 11.0 ± 3 | — |
| Lesotho | 156 ± 7 | 62.7 ± 11 | 64.6 ± 9 | 65.3 ± 10 | 67.3 ± 10 | — | — |
| Malawi | 155 ± 6 | 51.1 ± 6 | 53.5 ± 6 | 55.6 ± 6 | 56.6 ± 6 | 4.7 ± 3 | 25.4 ± 2 |
| Nigeria | 156 ± 6 | — | — | — | — | — | — |
| Nepal (R) | 150 ± 5 | 43.0 ± 5 | 44.9 ± 5 | 47.0 ± 5 | 48.8 ± 5 | — | 22.3 ± 2 |
| Nepal (U) | 150 ± 5 | 44.6 ± 6 | 43.1 ± 9 | 45.5 ± 5 | 50.3 ± 6 | — | 21.9 ± 2 |
| Sri Lanka | 150 ± 5 | 43.5 ± 7 | 44.3 ± 6 | 47.0 ± 6 | 49.3 ± 7 | — | 23.4 ± 2 |
| Thailand | 153 ± 5 | 49.9 ± 7 | 51.5 ± 6 | 53.9 ± 6 | 56.4 ± 7 | 8.0 ± 4 | 24.8 ± 2 |
| UK | 159 ± 6 | 58.1 ± 8 | 59.8 ± 8 | 63.1 ± 8 | 66.4 ± 9 | 11.6 ± 3 | — |
| US/CDC(B) | 162 ± 6 | 65.6 ± 16 | — | — | — | 13.5 ± 6 | — |
| US/CDC(H) | 158 ± 6 | 62.3 ± 14 | — | — | — | 12.8 ± 6 | — |
| US/CDC(W) | 163 ± 6 | 64.0 ± 15 | — | — | — | 14.4 ± 6 | — |
| US/NCPP(B) | 161 ± 6 | 60.1 ± 12 | — | — | — | 10.5 ± 4 | — |
| Vietnam | 152 ± 4 | 46.6 ± 5 | 48.3 ± 9 | 49.2 ± 4 | 50.2 ± 4 | 5.6 ± 3 | 22.8 ± 1 |

—, no information or too few observations.

or more of the 25 component studies.

### 2.4. Weight gain curves

Serial weight gain data were available for 13 of the 25 studies, however preliminary analysis confirmed that there were substantial differences in mean weight gain between countries. In order to allow for such differences, cluster analysis for this characteristic was again used to assemble country studies in four groups with gain curves of increasing magnitude. Average monthly weight gain curves associated with births < 2500 g, 2500–3000 g and > 3000 g were computed for each of the four country clusters.

## 3. Results and discussion

### 3.1. Indicator analysis

Tables 5 and 6 summarize the largest indicator O.R.s in respect of the three infant and three maternal outcomes. Indicators are grouped by those requiring a single measurement (height, arm circumference, attained weight and BMI) and those requiring multiple measurements (weight gain). Odds ratios are given for each indicator, as applied to the total sample as well as to the low height and weight sub-groups.

### 3.2. Fetal outcomes

Attained weight indicators from pre-pregnancy (Pp) through 9 lunar months (32–36 weeks) demonstrate high odds ratios for both LBW and IUGR; these ratios are increased when calculated for the defined anthropometric sub-groups. The similarity of indicator performance for these two outcomes reflects the nature of the study sample and implies that most LBW reported is due to IUGR rather than preterm birth [19]. The strongest effect size (4.0) in this group is provided

Table 4
Characteristics of the individual studies having a bearing on their quality

| Country | Location | Design of original study | Sample | Training | Number of cases[a] | Case exclusion | Method of estimation of pregnancy duration | Pre-pregnancy measurements[b] |
|---|---|---|---|---|---|---|---|---|
| Argentina (1984–1986) ARG | City of Rosario | Reptrospective: clinical records using standardized forms for data extraction | All mothers delivering in 3 hospitals (2 public, 1 private) | Trained personnel routinely used to obtain data | 5634 | Singleton births only | Last menstrual period (LMP) | By recall |
| Botswana (1980–1981) BOT | Cities of Garhorone and Molepolole | Propsective: pregnant women identified and followed to delivery | All pregnant women in defined geographical area | Personnel trained specifically for study | 2491 | None | LMP | Based on measurement early in pregnancy |
| China (1981–1982) CHI | 6 sub-districts of Nanshi in city of Shanghai | Prospective: pregnant women identified and followed to delivery | All pregnant women in defined geographical area | Personnel trained specifically for study | 4753 | None | LMP | Based on measurement early in pregnancy |
| Colombia (1989) COL | City of Cali | Retrospective: clinical records using standardized forms for data extraction | All mothers delivering in 3 hospitals | Personnel trained for data extraction from records | 4598 | None | LMP | By recall |
| Cuba (1981) CUB | Mixed urban and rural centers | Retrospective: clinical records using standardized forms for data extraction | All mothers delivering in 10 hospitals during 6 month study | Personnel trained for data extraction from records | 4779 | None | LMP | Based on measurement early in pregnancy |
| Gambia (1976–1984) GAM | Keneba village | Prospective: longitudinal study. Period post May 1980 community supplementation trial | All pregnant women in defined geographical area | Trained Personnel | 379 | None | Dubowitz (within 5 days of delivery) | Actual |
| Guatemala (1969–1977) GUA | 4 highland rural villages | Prospective: longitudinal randomized community supplementation trial | All pregnant and lactating women were followed throughout pregnancy and for a period post-partum | Trained personnel following detailed protocol | 286 | Women who received a calorie supplementation during pregnancy | LMP | By recall early in pregnancy Actual pre-pregnancy weight and MUAC available for women becoming pregnant dur- |

Table 4 (*Continued*)
Characteristics of the individual studies having a bearing on their quality

| Country | Location | Design of original study | Sample | Training | Number of cases[a] | Case exclusion | Method of estimation of pregnancy duration | Pre-pregnancy measurements[b] |
|---|---|---|---|---|---|---|---|---|
| India (Pune) (1990) IN(P) | Urban and rural | Prospective: pregnant women identified and followed to delivery | All deliveries at hospital during study period | Personnel trained specifically for study | 4307 | None | LMP | Based on measurement early in pregnancy |
| India (Hyderabad) (1983–1985) IN(H) | Urban slums on outskirts of Hyderabad | Two phase prospective study — baseline study of all women of reproductive age; phase 2 ineluded all pregnant women | All deliveries at hospital during study period | Trained interveiwers for baseline | 546 | None | LMP | Actual |
| Indonesia (1983) INO | Municipality of Bogor (West Java) and surrounding villages | Prospective study of women throughout pregnancy and 1 month post-partum | All 1st trimester pregnant women recruited | Trained interveiwers | 1647 | None | LMP | By recall (early in pregnancy) |
| Ireland (1979–1980) IRE | City of Dublin | Retrospective: elinical records using standardized forms for data extraction | All deliveries at hospital during study period | Personnel trained for data extracton from records | 6424 | None | LMP | Based on measurement early in pregnancy |
| Lesotho (1982) LES | 2 rural communities | Prospective: pregnant women identified and followed to delivery | All pregnant women in defined geographical area | Personnel trained specifically for study | 1071 | None | LMP | Based on measurement early in pregnancy |
| Malawi (1986–1989) MAL | 3 rural communities | Prospective: women identified in baseline study and recaptured during pregnancy | All mothers enrolled early in pregnancy | Trained personnel following detailed protocol | 938 | None | Modified Dubowitz | Actual—as measured during baseline study |
| Mynamar (1981–1982) MYN | Communities in urban and rural areas | Prospective: pregnant women identified and followed to delivery | All pregnant women in defined geographical area | Personnel trained specifically for study | 3542 | None | LMP | Based on measurement early in pregnancy |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nigeria (1976–1978) NIG | Urban | Retrospective: clinical records using standardized forms for data extraction | All deliveries at hospital during study period | Personnel trained for data extraction from records | 15 159 | None | LMP | Based on measurement early in pregnancy |
| Nepal (rural) (1990) N(R) | Rural | Prospective: pregnant women identified and followed to delivery | All deliveries at hospital during study period | Personnel trained specifically for study | 2529 | None | LMP | Based on measurement early in pregnancy |
| Nepal (urban) (1990) N(U) | Urban | Prospective: pregnant women identified and followed to delivery | All deliveries at hospital during study period | Personnel trained specifically for study | 3629 | None | LMP | Based on measurement early in pregnancy |
| Sri Lanka (1990) SL | Rural | Prospective: pregnant women identified and followed to delivery | All deliveries at hospital during study period | Personnel trained specifically for study | 1851 | None | LMP | Based on measurement early in pregnancy |
| Thailand (1979–1980) THA | Rural and urban centers | Prospective: pregnant women identified and followed to delivery | All pregnant women defined in geographical area | Personnel trained specifically for study | 4124 | None | LMP | Based on measurement early in pregnancy |
| United Kingdom (1971–1976) UK | City of Aberdeen, Scotland | Retrospective: clinical records using standardized forms for data extraction | All deliveries at hospital during study period | Trained clerks | 4803 | None | LMP | Based on measurement early in pregnancy |
| USA (CDC—white) (1989) US/CDC(W) | 17 states and District of Colombia | Retrospective: surveillance sytem using standardized forms for data extraction from clinical records | Low-income women participating in assistance programs | Technical assistance to participating clinics in data collection/ management | 16 481 | None | LMP | By recall |
| USA (CDC—black) (1989) US/CDC(B) | Ditto | Ditto | Ditto | Ditto | 4614 | None | LMP | By recall |

Table 4 (*Continued*)
Characteristics of the individual studies having a bearing on their quality

| Country | Location | Design of original study | Sample | Training | Number of cases[a] | Case exclusion | Method of estimation of pregnancy duration | Pre-pregnancy measurements[b] |
|---|---|---|---|---|---|---|---|---|
| USA (CDC —hispanic) (1989) US/CDC(H) | Ditto | Ditto | Ditto | Ditto | 2205 | None | LMP | By recall |
| USA (NCPP —black) 1970s US/NCPP(B) | 12 different state and university hospitals | Retrospective: surveil-lance sytem using standardized forms for data extraction from clinical records | Low-income women attending participating clinics | Technical assistance to participating clinics in data collection/ management | 12 792 | Live-born singleton births only | LMP | By recall |
| Vietnam (1982–1984) VIE | City of Hanoi and 1 rural district | Prospective: pregnant women identified and followed to delivery | All pregnant women in defined geo-graphical area | Personnel trained specifically for study | 4428 | None | LMP | Based on measurement early in pregnancy |

[a] This refers to the total number of observations. Missing values on individual variables can significantly reduce numbers for analysis.
[b] Pre-pregnancy weight, where available, might refer to either (a) an actual measurement prior to pregnancy, (b) a measurement taken at an antenatal visit during the first trimester, or (c) by recall.

Table 5
O.R. values (95% C.I.) by indicator or fetal outcomes

| Indicator | LBW | IUGR | PTB |
|---|---|---|---|
| Maternal height | 1.7 (1.6–1.8) | 1.9 (1.8–2.0) | 1.2 (1.1–1.2) |
| Mid-upper arm circumference | 1.9 (1.7–2.1) | 1.6 (1.4–1.8) | 1.2 (1.0–1.3) |
| Pre-pregnancy weight | 2.3 (2.1–2.5) | 2.5 (2.3–2.7) | 1.4 (1.3–1.5) |
| Attained weight by month 5 | 2.4 (2.0–2.8) | 2.7 (2.3–3.2) | 0.9 (0.8–1.1) |
| Attained weight by month 7 | 2.4 (2.1–2.7) | 3.0 (2.7–3.3) | 0.9 (0.8–1.0) |
| Attained weight by month 9 | 2.5 (2.2–2.9) | 3.1 (2.7–3.4) | |
| Pre-pregnancy BMI | 1.8 (1.7–2.0) | 1.8 (1.7–2.0) | 1.3 (1.1–1.4) |
| BMI month 5 | 1.6 (1.3–2.0) | 2.1 (1.7–2.4) | 0.7 (0.6–0.9) |
| BMI month 7 | 1.9 (1.6–2.2) | 2.3 (2.0–2.6) | 0.9 (0.7–1.0) |
| BMI month 9 | 1.8 (1.6–2.1) | 2.2 (2.0–2.5) | |
| Weight gain: pre-pregnancy to month 5 | 1.5 (1.0–2.0) | 1.8 (1.0–2.9) | 0.4 (0.3–0.6) |
| Weight gain: pre-pregnancy to month 7 | 1.5 (1.1–1.9) | 1.8 (1.5–2.2) | 0.7 (0.6–0.9) |
| Weight gain: pre-pregnancy to month 9 | 1.6 (1.3–2.1) | 2.0 (1.7–2.4) | |
| Weight gain: month 5 to month 7 | 1.6 (1.3–2.0) | 1.7 (1.4–2.0) | 1.4 (1.1–1.7) |
| Weight gain: month 5 to month 9 | 1.7 (1.3–2.1) | 1.7 (1.4–2.1) | |
| Weight gain: month 7 to month 9 | 1.2 (1.0–1.4) | 1.4 (1.2–1.6) | |
| Sub-group of mothers with below average maternal height | | | |
| Pre-pregnancy weight | 2.6 (2.3–2.9) | 2.9 (2.7–3.2) | 1.4 (1.3–1.6) |
| Attained weight by month 5 | 2.6 (2.0–3.2) | 3.2 (2.6–3.9) | 1.0 (0.8–1.3) |
| Attained weight by month 7 | 2.6 (2.3–3.1) | 3.5 (3.0–4.0) | 0.9 (0.8–1.1) |
| Attained weight by month 9 | 2.9 (2.5–3.4) | 3.4 (3.0–3.9) | |
| Weight gain: pre-pregnancy to month 5 | 1.9 (1.2–2.9) | 2.7 (1.9–3.9) | 0.4 (0.3–0.6) |
| Weight gain: pre-pregnancy to month 7 | 2.0 (1.4–2.9) | 2.8 (2.1–3.7) | 0.7 (0.6–0.9) |
| Weight gain: pre-pregnancy to month 9 | 2.2 (1.6–3.1) | 3.1 (2.4–4.0) | |
| Weight gain: month 5 to month 7 | 2.6 (1.9–3.6) | 2.6 (1.9–3.4) | 1.8 (1.4–2.4) |
| Weight gain: month 5 to month 9 | 2.7 (1.9–4.0) | 2.6 (1.9–3.5) | |
| Weight gain: month 7 to month 9 | 1.8 (1.4–2.3) | 2.2 (1.8–2.6) | |
| Sub-group of mothers with below average pre-pregnancy weight | | | |
| Attained weight by month 5 | 2.4 (1.8–3.3) | 3.8 (2.9–5.0) | 0.9 (0.7–1.2) |
| Attained weight by month 7 | 2.7 (2.1–3.5) | 4.0 (3.2–4.8) | 1.0 (0.8–1.3) |
| Attained weight by month 9 | 2.8 (2.2–3.5) | 3.7 (3.1–4.5) | |
| Weight gain: pre-pregnancy to month 5 | 2.6 (1.5–4.3) | 5.4 (3.6–8.2) | |
| Weight gain: pre-pregnancy to month 7 | 3.4 (2.2–5.1) | 5.2 (3.8–7.2) | |
| Weight gain: pre-pregnancy to month 9 | 3.2 (2.1–4.9) | 5.5 (4.1–7.4) | |
| Weight gain: month 5 to month 7 | 2.0 (1.3–3.5) | 2.7 (1.7–4.2) | 1.6 (1.0–2.6) |
| Weight gain: month 5 to month 9 | 1.6 (0.8–2.8) | 2.4 (1.5–3.7) | |
| Weight gain: month 7 to month 9 | 1.7 (1.1–2.5) | 2.6 (2.0–3.4) | |

by attained weight at 7 lunar months (24–28 weeks) for IUGR, when applied to women of below average pre-pregnancy weight. The study indicators show only minor and inconsistent O.R.s for PTB and their application to defined sub-groups does not produce any major improvement in performance. All four attained weight indicators met the screening criteria for LBW, while attained weight at Pp, 5 and 9 months met the criteria for IUGR. Pre-pregnancy weight and BMI just met the screening criteria for PTB.

Expressed in service terms this implies that weights taken at pre- or early pregnancy and 5 or 7 lunar months are useful indicators of LBW and

Table 6
O.R. values (95% C.I.) by indicator for maternal outcomes

| Indicator | Assisted delivery | Pre-eclampsia | Post-partum hemorrhage |
|---|---|---|---|
| Maternal height | 1.6 (1.5–1.7) | 0.8 (0.7–1.0) | 0.7 (0.5–1.0) |
| Mid-upper arm circumference | 0.8 (0.8–0.9) | 0.6 (0.5–0.8) | 0.6 (0.5–0.8) |
| Pre-pregnancy weight | 1.0 (0.9–1.0) | 0.7 (0.6–0.8) | 0.6 (0.4–1.1) |
| Attained weight by month 5 | 0.9 (0.8–1.1) | | 0.9 (0.4–1.7) |
| Attained weight by month 7 | 0.9 (0.8–1.0) | 0.8 (0.7–1.0) | 0.9 (0.6–1.5) |
| Attained weight by month 9 | 0.8 (0.7–0.9) | 0.7 (0.6–0.8) | 0.6 (0.4–0.8) |
| Pre-pregnancy BMI | 0.7 (0.6–0.8) | 0.7 (0.6–0.9) | 0.8 (0.5–1.4) |
| BMI month 5 | 0.7 (0.6–0.8) | 1.2 (0.9–1.7) | 1.2 (0.4–3.3) |
| BMI month 7 | 0.6 (0.5–0.7) | 0.9 (0.7–1.0) | 1.1 (0.6–2.0) |
| BMI month 9 | 0.7 (0.6–0.8) | 0.6 (0.5–0.8) | 1.0 (0.7–1.6) |
| Weight gain: pre-preguancy to month 5 | 1.0 (0.8–1.2) | 1.1 (0.8–1.5) | 0.5 (0.1–1.6) |
| Weight gain: pre-pregnancy to month 7 | 0.7 (0.6–0.9) | 0.8 (0.6–0.9) | 0.7 (0.4–1.4) |
| Weight gain: pre-pregnancy to month 9 | 0.7 (0.6–0.8) | 0.6 (0.5–0.7) | 0.6 (0.3–1.1) |
| Weight gain: month 5 to month 7 | 0.7 (0.6–0.9) | 0.7 (0.6–1.0) | 0.9 (0.4–2.0) |
| Weight gain: month 5 to month 9 | 0.8 (0.6–1.0) | 0.3 (0.3–0.4) | 0.9 (0.3–3.0) |
| Weight gain: month 7 to month 9 | 0.9 (0.7–1.0) | 0.6 (0.5–0.8) | 0.7 (0.3–1.2) |

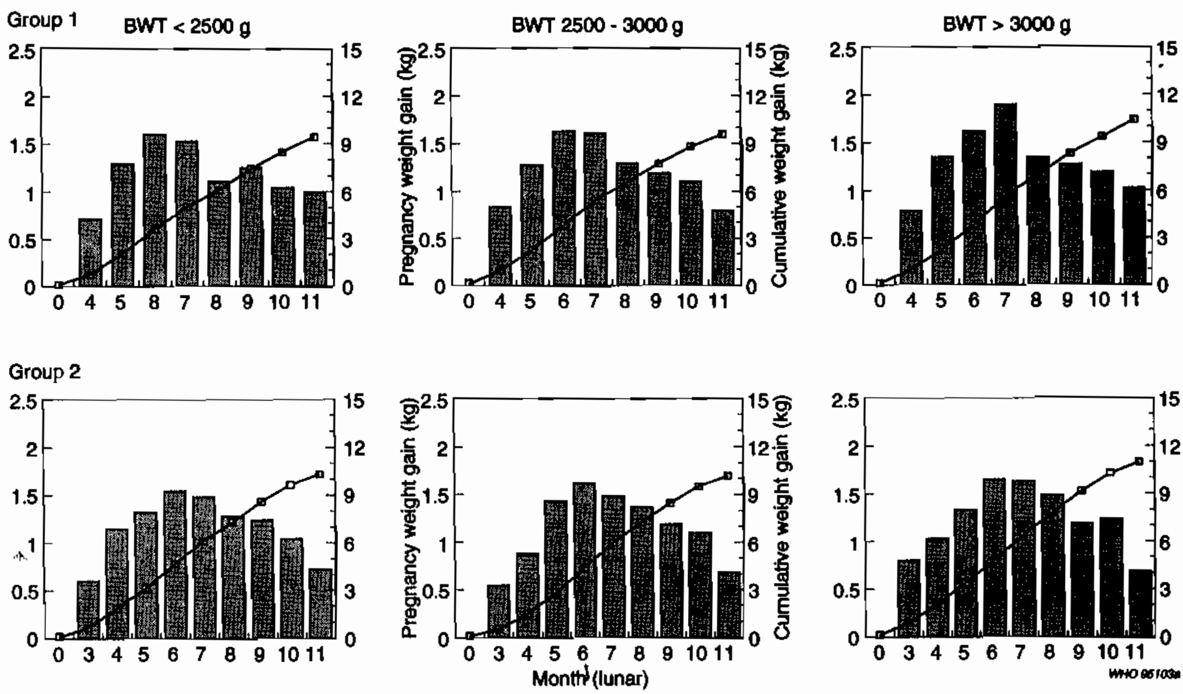


Fig. 1. Mean monthly (lunar) maternal pregnancy weight gain and eumulative weight gain by birth weight outcome (in order from left: BWT < 2500 g, 2500 ≤ BWT ≤ 3000 and BWT > 3000 g) for groups I and 2. Calculations based on live-born, singleton, term births. Note: Country listing by group for weight gain curves. Group l: India (Pune), Sri Lanka, Nepal (Urban), Nepal (Rural). Group 2: Indonesia, Myanmar, Thailand, Vietnam.

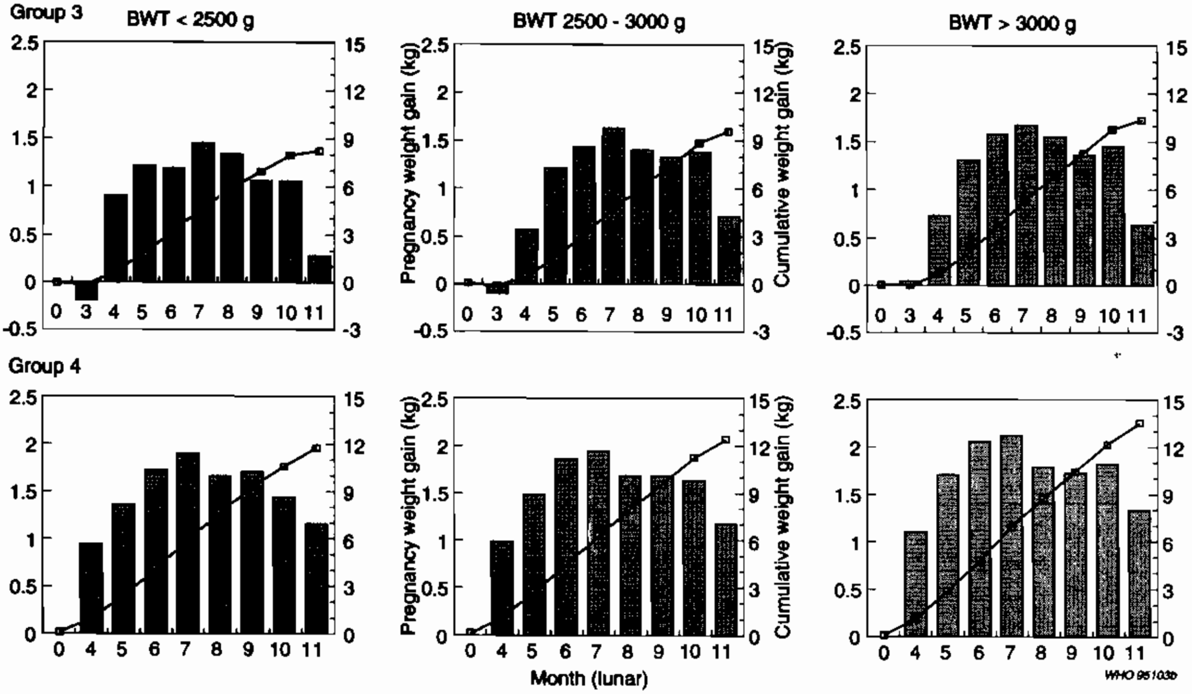


Fig. 2. Mean monthly (lunar) maternal pregnancy weight gain and cumulative weight gain by birth weight outcome (in order from left: BWT < 2500 g, 2500 ≤ BWT ≤ 3000, and BWT > 3000 g) for groups 3 and 4. Calculations based on live-born, singleton, term births. Note: Country listing by group for weight gain curves. Group 3: China, Colombia, Malawi. Group 4: Ireland, UK.

IUGR risk and provide warning of the need for intervention. However, the ability of the study indicators to predict PTB is very limited. Neither maternal height nor arm circumference emerge as effective indicators for any of the fetal outcomes in this analysis. It should be recalled, however, that in this study the cut-off point applied to each indicator was the 25th percentile. If a lower cut-off point was used, such as the 10th percentile, the corresponding indicators would show a much stronger effect size, albeit with some loss of sensitivity for screening.

### 3.3. *Maternal outcomes*

The ability of study indicators to predict the three maternal outcomes was much weaker. Maternal height as a predictor of assisted delivery showed the highest positive O.R. (1.6) but met the screening criteria in only 5 of 13 studies (38%). The effect size of this indicator can be greatly improved if the cut-off point is lowered, as is commonly the case in antenatal services. Again, while this would improve specificity, the corresponding loss of sensitivity could be critical in the prevention of obstructed labor. For the other two outcomes, most indicators showed O.R.s of 1 or less indicating a neutral or reduced risk of unfavorable outcome associated with the lowest quartile. Low maternal weight and weight gain are associated with IUGR and thus are likely to reduce the risk of assisted delivery. As PPH is associated with difficult and prolonged labor, this could also account for the reduced risk of PPH. Conversely, pre-eclampsia is associated with rapid weight gain in later pregnancy and thus the upper quartile may in fact include individuals at increased risk. Clearly these 'negative risk' indicators cannot be used to exclude the risk of such serious adverse outcomes, although they may support the perceived advantages to the mother of 'eating down' in pregnancy [8].

### 3.4. Service applications

The final consideration applied to indicators selected on the basis of effect size and screening capacity was their aptness for use under varying conditions of service delivery, particularly in the context of primary health care. The study considered three common constraints on the effective delivery of primary care:

(1) the frequency of contact with the mother: single or multiple visits,
(2) the availability of equipment: whether scales are provided and,
(3) the scope of services: coverage, registration and worker skills.

The selected fetal indicators were examined in the context of these constraints to identify preferred choices under different service conditions. Where no scales are available, height and arm circumference are the only feasible indicators for LBW and IUGR, though they did not meet the selection criteria defined for this study. Where scales are available and early registration is the norm, weights at 5, 7 and 9 lunar months are valid indicators of LBW and IUGR; where women's health care is comprehensive, pre-pregnancy weight and BMI are also valid for LBW, IUGR and for PTB. None of the weight gain indicators met the criteria for effect size so no advantage is conferred by multiple measurements. Height and arm circumference indicators do not benefit from multiple measurements as the former is static, except in the case of adolescent pregnancy, and the latter is not sufficiently responsive over short time periods in most developing countries.

### 3.5. Weight gain curves

Weight gain curves permit the primary health care worker to monitor the progress of pregnancy and to assess the risk of certain adverse outcomes. Figs. 1 and 2 show mean monthly weight gains with superimposed cumulative gain curves for the four country groups selected by cluster analysis.

The mean weight gain curves for the 4 country groups had similar trajectories in the first two trimesters, however the trajectory of the highest gain group (group 4) did not decline in the third trimester to the same extent as the other three. More detailed examination revealed that the critical difference associated with favorable birth weight outcome in poor countries (groups 1 and 2) was the shift in peak gain into the 7th lunar month (24–28 weeks); this is consistent with the results of the first part of the analysis which identified attained weight at 7 months as the best indicator of IUGR. The extension of peak gain into the 7th month occurred with all birth weight outcomes, including low birth weight, in the two most afffluent groups (groups 3 and 4) probably reflecting a change in distribution between the IUGR and PTB components of LBW.

## 4. Conclusions

A single measurement of attained weight at 5 or 7 lunar months (16–20 or 24–28 weeks) is the most practical screening instrument for LBW and IUGR in most primary health care settings. Identification of IUGR at this stage of pregnancy, however, may not allow sufficient time for fetal growth to be improved by effective food supplementation [20]. The efficiency of this indicator can be improved under program conditions by applying locally derived cut-off points determined by analysis of service records or by prospective study. The operational value of these findings can only be verified by the improvement of impact indicators in large scale programs. Such verification will depend not only on the widespread and systematic use of the selected indicators, but also on the effectiveness of interventions to correct the associated problems of maternal and fetal health [21].

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