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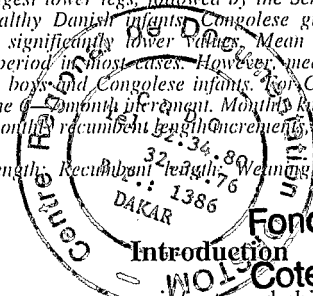
GROWTH IN KNEE HEEL LENGTH AND RECUMBENT LENGTH DURING THE WEANING PERIOD (4-7 MONTHS) IN LESS DEVELOPED COUNTRIES

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Abstract: Early infancy is a highly sensitive period for the development of stunting. Growth in knee heel length and in recumbent length was followed monthly from the age of 4 to 7 months in an urban area of Brazzaville, Congo (n = 120), a rural area of Senegal (n = 110), and an urban area of La Paz, Bolivia (n = 122). Subjects were single-born, breastfed at 4 months and had a length-for-age above -2.5 z-scores (NCHS reference). Congolese infants were longer than Bolivian infants, while Senegalese infants were in between. All were shorter than the NCHS reference at age 4 months, and faltering continued during the study period. Congolese infants had the longest lower legs, followed by the Senegalese, while Bolivians had the shortest lower legs. Compared to healthy Danish infants, Congolese girls had significantly higher values, and Bolivians of both sexes had significantly lower values. Mean monthly increments in knee heel length decreased over the 3-month period in most cases. However, mean growth was impaired during the 5-6 month interval for Senegalese boys and Congolese infants. For Congolese boys, the 5-6 month increment was significantly lower than the 6-7 month increment. Monthly knee heel length increments were not always significantly correlated with monthly recumbent length increments, while three-month increments were closely correlated.

Key words: Knee heel length; Recumbent length; Weaning period; Brazzaville/Congo; Senegal; La Paz/Bolivia.



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Introduction
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Growth faltering is common among infants and children in poor areas throughout the world. Although few children are significantly stunted before the age of one year, the process of faltering begins during infancy or even during fetal life (Waterlow 1988). Patterns of growth in length have been well studied in several countries and compared to reference data. Mean birth length is often slightly lower than the NCHS reference, and little or no catch-up growth occurs during the first months of life. Faltering begins between the ages of 3 and 6 months, depending on the geographic area (3-4 months in poor suburbs of Dakar, Senegal (Simondon 1991); 2-3 months in rural Kenya (Neumann and Harrison 1994) and Mexico (Allen 1994). In Pakistan faltering began at the age of 6 months, using local upper class urban infants as a reference, but these upper class infants faltered compared to the NCHS reference from 3-4 months (Karlberg, Ashraf, Saleemi, Yaquooob and Jalil 1993).

The study of short term linear growth is limited by the poor precision of length and height measurements. A growth increment must be larger than twice the technical error in order to be detected, since increments are calculated as the difference between two measurements. Mean monthly length increments of infants are about 2.5 cm at between 4 and 5 months and about 1.5 cm at between 6 and 7 months (Waterlow 1988), but individual increments may be much lower. Valk, Langhout-Chabloz, Smals, Kloppenberg, Cassorla and Schutte (1983) give a technical error of 0.15 cm for careful

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measurements of height taken by trained measurers. In routine surveys, the technical error may be as high as 0.49 cm for height (American Health Examination Survey, Johnston, Hamill and Lemeshow, 1972). Measurements of recumbent length are not likely to be more reliable than height measurements because active opposition of the measured infant is common. Therefore, more precise measurements of linear growth are needed for evaluation of short term growth in infants and the study of growth in knee heel length was thus initiated.

Measurements of knee heel length have been carried out with a high degree of precision in children (Valk et al. 1983) obtaining technical errors of 0.16 mm (Hermanussen, Geiger-Benoit, Burmeister and Sippell 1988), but the measuring device is very large and therefore cannot be used in field studies. Furthermore, it is suitable only for children over three years of age who are able to sit quietly and cooperate. A small, hand held knemometer was developed by one of the authors (KFM) in collaboration with the Danish Institute for Biomedical Engineering, and was shown to measure growth in knee heel length with high reliability in premature infants (Michaelsen, Skov, Badsberg and Jorgensen 1991). This measuring device is easily portable and therefore well adapted to field studies. For these reasons, it was chosen for the measurement of knee heel length of infants in the present study.

The data presented below were collected during a multicenter cohort study of the impact of supplementation on linear growth in weanlings aged 4–7 months in three less developed countries (Congo, Senegal and Bolivia).

The aims of the present work are to describe linear growth in recumbent length and in knee heel length in weanlings, and to compare growth in knee heel length with growth in recumbent length in the three study areas.

Material and Methods

The study was conducted according to a common protocol in two African countries (Brazzaville, Congo and a rural area of Senegal) and in La Paz, Bolivia, in 1993. In order to be included in the study, the infants had to meet the following conditions: be single-born, breastfed at the age of 4 months and have a length for age of not below -2.5 z-scores of the NCHS reference at 4 months (three infants in the Congo and in Senegal and two infants in La Paz were too short to be included). Parents would have no plans for emigration out of the study area. Mothers had to give their informed, oral consent to the study. Mean height for mothers was 159.9 cm in the Congo, 148.7 cm in Bolivia and 160.4 cm in Senegal. Mean birth weight was 3.09 kg and mean birth length 48.7 cm in the Congo ($n = 102$, maternity hospital data).

In all settings, measurements were taken on four occasions, at age 4 months (± 7 days), and 4, 8 and 13 weeks later (at ages 4.0, 4.9, 5.8 and 7.0 months). Ages will herewith be referred to as ages 4, 5, 6 and 7 months. Measurements were taken in the children's homes in the Congo and Senegal, and at the local health clinic in Bolivia. Recumbent length was the mean of three consecutive measurements using a Holtain infantometer (resolution: 0.1 cm). Knee heel length was the mean of five consecutive measurements using the hand held knemometer (resolution: 0.01 mm). A small printer/computer attached to the measuring device calculated mean value and standard deviation immediately in the field. If standard deviation was above 0.8 mm, a new series of five measurements was taken. This second set of measurements was seldom necessary. A detailed description of the measurement technique can be found in

Michaelsen et al. 1991. There was one single measurer per setting (AG in the Congo, a technician in Senégel and JB in Bolivia). Only infants with a complete data set were included in the analysis.

Reliability of knee heel length measurements was tested in the Senegalese study setting by measuring 30 infants twice by the same observer (two series of five measurements at about 20–30 min intervals). There was no significant difference between the first and second measurements, although the second mean tended to be higher than the first mean (mean difference was -0.26 mm, $p = 0.062$ using paired t -test). The technical error was 0.54 mm using $r = \sqrt{\Sigma d^2/2N}$, where d is the difference between the first and second measurement and N the number of comparisons. The coefficient of variation was 0.32% using $CV = r/x$, where x is the overall mean of measurements. The reliability of recumbent length measurements was not evaluated, but within each series of three measurements, the technical error was 0.18 cm in Senegal. Inter-setting reliability could not be assessed for technical and financial reasons.

Results

Total numbers of study subjects by country and by sex are given in *Table 1*. There were between 52 and 67 infants of each sex in each of the countries.

Table 1. Number of infants with complete data set

Sex	Senegal	Congo	Bolivia
Boys	58	64	67
Girls	52	56	55
Both	110	120	122

Mean recumbent length by age is given in *Figure 1* for all three countries, together with the NCHS reference. Congolese infants were the longest, followed by the Senegalese, while Bolivian infants were the shortest. The only significant difference was between the Congolese and Bolivian boys ($p < 0.001$ from 6 months). All groups were significantly shorter than the reference population at all ages. At the age of 4 months, Congolese boys were 1.6 cm shorter ($p < 0.001$) and Congolese girls were 1.1 cm shorter ($p < 0.01$). Further faltering occurred during the study period, and at the age of 7 months, Congolese boys were 2.4 cm shorter and the girls 2.1 cm shorter than the reference.

Mean knee heel length by age is shown together with reference values from the Copenhagen cohort study (*Figure 2*). The relationship between the three study countries was the same as for recumbent length, but there were more significant differences. Congolese infants had significantly longer lower legs than the Senegalese ($p < 0.001$ for both boys and girls at 6 months) and Bolivian infants had significantly shorter lower legs than the Senegalese ($p < 0.001$ and $p < 0.01$ for boys and girls, respectively, at 6 months).

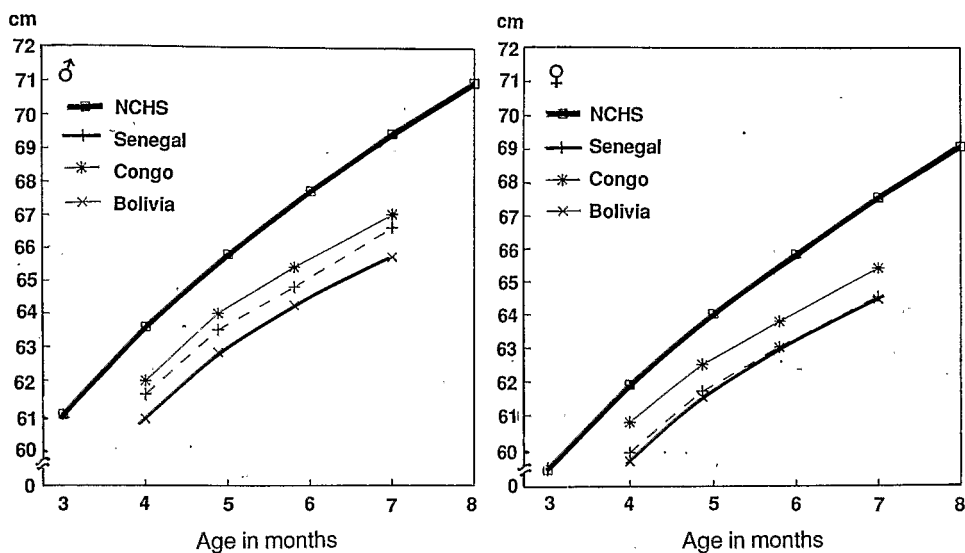


Fig. 1: Mean recumbent length by age and country in boys (left) and girls (right)

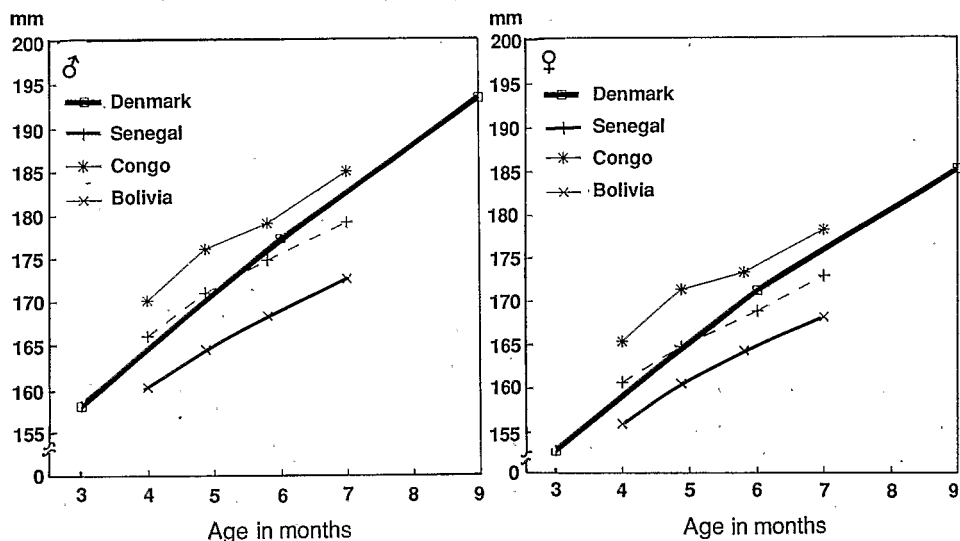


Fig. 2: Mean knee heel length by age and country in boys (left) and girls (right)

Comparisons with the Western reference at the age of 6 months gave completely different results from those seen for recumbent length, since Congolese values were slightly higher than the reference in both sexes ($p < 0.05$ for the girls). Senegalese infants had values which were very similar to those of the reference, and only Bolivian infants had lower values ($p < 0.001$ in both sexes).

Increments in recumbent length between 4 and 7 months were very similar between the three countries (Table 2). In the Congo and Senegal, boys had significantly higher increments than girls ($p < 0.05$), while Bolivian boys and girls had similar values. Increments in knee heel length between 4 and 7 months showed the same pattern as the attained knee heel length: Congolese infants had the highest values and Bolivian infants had the lowest values (Table 3). The only significant difference between countries was between Congolese boys and Bolivian boys ($p < 0.01$).

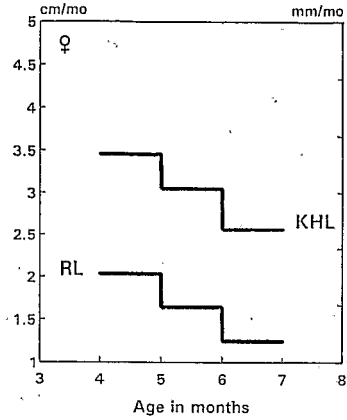
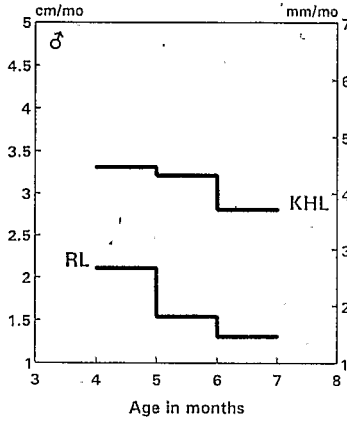


Fig. 3: Mean monthly increments in knee heel length (KHL, mm/mo) and in recumbent length (RL, cm/mo) in Bolivian boys (left) and girls (right)

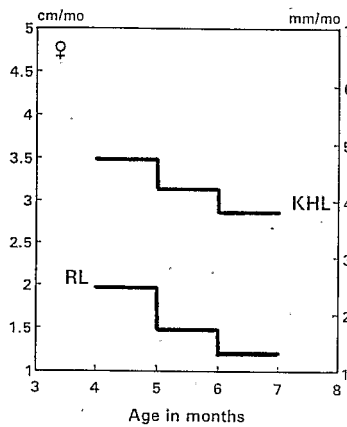
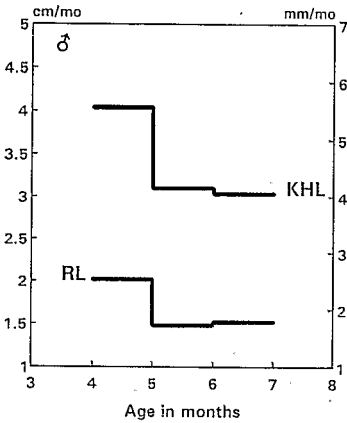


Fig. 4: Mean monthly increments in knee-heel length (KHL, mm/mo) and in recumbent length (RL, cm/mo) in Senegalese boys (left) and girls (right)

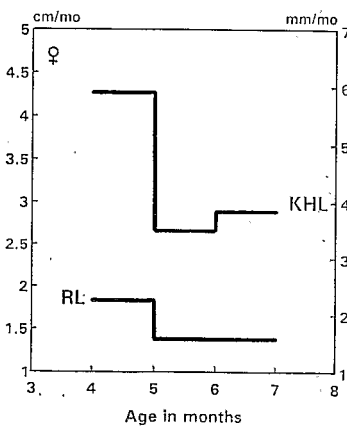
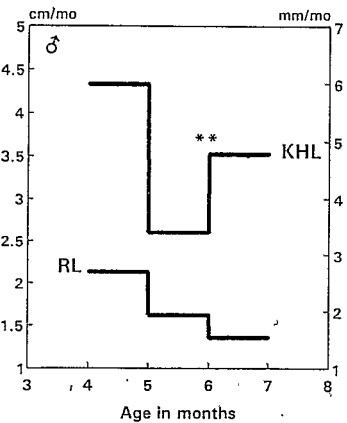


Fig. 5: Mean monthly increments in knee heel length (KHL, mm/mo) and in recumbent length (RL, cm/mo) in Congolese boys (left) and girls (right)

Table 2. Increments in recumbent length at 4–7 mo (cm/3 mo), by sex and country

Country	Boys		Girls	
	mean	SD	mean	SD
Senegal	4.98	1.02	4.56	1.15*
Congo	5.05	1.11	4.60	1.10*
Bolivia	4.83	1.09	4.79	0.82

*Boys vs. girls: $p < 0.05$

Table 3. Increment in knee heel length at 4–7 mo (mm/3 mo), by sex and country

Country	Boys		Girls	
	mean	SD	mean	SD
Senegal	13.23	4.11	12.58	3.83
Congo	14.36	4.17	13.14	4.59
Bolivia	12.31	2.94	12.13	2.86

**Bolivian boys vs. Congolese boys: $p < 0.01$

Mean monthly increments by age in the three study populations are shown in *Figures 3 to 5*. The general pattern was one of decreasing velocities during the 3 months. However, there were some exceptions. Senegalese boys (*Figure 4*) and Congolese girls (*Figure 5*) had almost the same values during the 5–6 month period as during the 6–7 month period. Monthly increments of Congolese boys (*Figure 5*) showed an unexpected pattern, with the 6–7 month knee heel increment being significantly higher than the 5–6 month increment ($p < 0.01$). This local minimum in knee heel length increments was not noted in the recumbent length increments, which decreased with age. For Congolese boys, a discrepancy was thus found between mean increments in recumbent length and in knee heel length.

Table 4. Correlation coefficients between increments in knee heel length and in recumbent length

Interval	Senegal	Congo	Bolivia
4–5 mo	0.13	0.18*	0.05
5–6 mo	0.27**	0.05	0.28**
6–7 mo	0.49***	0.02	0.14
4–7 mo	0.65***	0.31***	0.29**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To test whether growth in recumbent length and that in knee heel length were synchronous, correlation coefficients between individual increments in recumbent length versus knee heel length were computed for each monthly interval (4–5, 5–6, 6–7) and for the total study period (4–7 mo). Some of the coefficients for 1 month periods were high, while others were close to zero (*Table 4*). For the 3-month period, all coefficients were significant.

Discussion

The NCHS reference was used for recumbent length because it gives values at monthly intervals. The Copenhagen cohort study was used as a reference for knee heel length, since measurements were taken using the same measuring device and technique, and since no other references exist. Infants from the Copenhagen cohort study had longer recumbent length than the NCHS reference in both sexes (0.6 cm for boys and 0.5 cm for girls at age 6 months; KFM, unpublished data).

Congolese infants were longer than Senegalese in both sexes, although differences were not significant. This difference is probably due to socio-economic differences between samples, since Congolese infants lived in an urban environment with much higher educational levels of their parents, probably higher income and better access to health care services. Feeding patterns differed, with earlier introduction of supplements to breast milk in the Congo (unpublished data). The Bolivian infants were the shortest, despite the urban environment. Bolivian infants were Amerindians of the Aymara ethnic group, and they lived at an altitude of 3 700 to 4 000 meters. Infants living at high altitudes have lower gains in length than lowlanders during the first months of life (Eveleth and Tanner 1990). The mean height of Bolivian mothers was only 148.7 cm, and small mothers are likely to give birth to small infants. Unfortunately, the birth length of Bolivian infants was not known.

An unexpected finding of the study was that of the long lower legs of African infants living in deprived environments as compared to healthy Danish infants. However, it is well known that African adults have body proportions different from those of European adults, with relatively longer legs. These differences are thought to be genetic in origin (Eveleth and Tanner 1990), and they might exist from birth or even *in utero*. However, as intercountry reliability of knee heel measurements was not evaluated, comparisons of knee heel length between countries should be made with caution, and further studies are needed to confirm these findings.

In Senegal and the Congo, linear growth seemed to be impaired during the 5—6 month interval as compared to the 6—7 month interval, both for recumbent length and for knee heel length. The explanation which seems most likely at the present time is an increased prevalence of morbidity, especially diarrhea, during the 5—6 month interval. Since morbidity data were collected, this hypothesis can and will be tested. The explanation of the discrepancy between growth in knee heel length and in recumbent length described for Congolese boys might be due to a greater sensitivity of knee heel length growth to environmental factors. This hypothesis will also be tested using morbidity data and other growth data such as body weight, which is very sensitive to environmental stress.

Growth in knee heel length was studied mainly to evaluate growth with higher precision, thereby making analysis of short term growth more efficient than what would have been possible measuring only recumbent length. Evaluation of measured increments was done by comparison to increments in recumbent length, but discrepancies occur and it is difficult to determine whether these are due to insufficient precision of measurement of either of the two variables, or whether growth in knee heel length and recumbent length is partly independent over short intervals, such as one month. The higher correlations for the 3-month interval compared to monthly intervals can be explained both by relatively less importance of measurement imprecision over longer intervals and by "smoothing out" of true short-term growth differences over longer periods.

Other authors have compared increments in knee heel length to increments in recumbent length and found low correlations. Dean, Schentag and Winter (1990) found that, in 25 children aged 3—16 years, the ratio of 4-weekly increments in knee heel length related to height increments varied from 0.1 to 40. Correlation coefficients were not given. The authors concluded that apparent mini-growth spurts in the leg do not appear to occur simultaneously with growth in the spine.

Indeed, increasing evidence of the irregular nature of growth (Hermanussen et al. 1987; Lampl, Veldhuis and Johnson 1992) is important for the comprehension of the results shown above, but the hypothesis of saltation cannot explain the low correlation between short-term increments in knee heel length and recumbent length. It implies, on the contrary, that the whole body is growing synchronously in order to achieve an increment in recumbent length of about 1 cm within a few days (Lampl et al. 1992). More studies of both normal and impaired growth are needed in order to understand the relationship between growth of the limbs, spine and total length.

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