Dynamic Skinfold Thickness Measurements: a Noninvasive Estimate of Neonatal Extracellular Water Content

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Summary

Application of a Harpenden caliper to a neonate's skinfold results in an exponential decline of the skinfold thickness, stabilizing within 50-60 sec. In order to elucidate the meaning of this decline, simultaneous measurements of skinfold thickness (SFT, by Harpenden caliper connected to a chart recorder), corrected bromide space (CBS, in ml/kg), plasma volume (ml/kg, by T-1824 dilution) and interstitial water (IW, in ml/kg = CBS-plasma volume) were obtained in 18 term and 18 preterm neonates. Skinfold thickness was measured at the midtricipital (MT) and subscapular (SS) sites. The magnitude of SFT decline was estimated as the difference between 0-60 sec readings expressed in % of 0 second reading (% Δ SFT). The rate of SFT decline was estimated as the slope of the semilogarithmic plot from 4-20 sec after caliper application (Δ SFT).

The 36 neonates whose birthweights ranged from 620-3700 g and whose gestational ages ranged from 27-41 wk were studied within 12 h of birth. Mean CBS, IW, % Δ MT, % Δ SS, Δ MT and Δ SS were higher in preterm than in term neonates ($P < 0.001$). Mean plasma volume was higher in preterm neonates ($P = 0.009$), but the difference disappeared after exclusion of six polycythemic term neonates from the calculations. The magnitude of SFT decline correlated well with both CBS (% Δ MT versus CBS: $r = 0.71$ and % Δ SS versus CBS: $r = 0.71$) and IW (% Δ MT versus IW: $r = 0.71$ and % Δ SS versus IW: $r = 0.70$). The rate of decline correlated moderately but highly significantly with both CBS (Δ MT versus CBS: $r = 0.50$ and Δ SS versus CBS: $r = 0.42$) and IW (Δ MT versus IW: $r = 0.51$ and Δ SS versus IW: $r = 0.43$). Exclusion of five neonates less than 30 wk in gestation improved the correlations with both % Δ SFT and Δ SFT.

These data suggest that the decline in SFT measurements after caliper application results from the expression of subcutaneous IW from the skinfold and that both the amount of water expressed and the rate of its expression increase linearly with the amount of extracellular and IW in the body.

Speculation

Both the magnitude and the rate of skinfold thickness compressibility or expressibility appear to be intimately related to extracellular and interstitial water contents of the neonatal body. Dynamic skinfold thickness measurements may therefore be noninvasive estimates that are representative of body hydration and that may be used in research on neonatal body composition as well as clinically to evaluate hydration status of sick neonates.

Skinfold thickness measurements are commonly used in anthropometric studies. Our earlier data indicated that in neonates a rapid decrease in measured skinfold thickness occurred after application of a Harpenden caliper, but that readings stabilized

by 60 sec (3). We speculated that the difference between the 15- and 60-sec readings, expressed in % of the 15-sec reading, provided a noninvasive estimate of subcutaneous interstitial water. In order to define the relationship between decrease in skinfold thickness and body water contents, a Harpenden caliper was modified to provide a continuous tracing of skinfold thickness on a chart recorder. Simultaneous skinfold thickness, extracellular and interstitial water estimates were obtained.

MATERIALS AND METHODS

Thirty-six neonates were studied within 12 h of birth with their parents' consent. They were selected at random from those neonates who required umbilical vessel catheterization either for arterial blood gas monitoring or for determination of umbilical venous hematocrit to confirm or rule out neonatal polycythemia (10). Birthweights were measured to the nearest 10 g. Gestational ages were calculated from the mother's menstrual history, often but not always checked by sonographic determination of biparietal diameter, and confirmed by physical examination of the neonate (6). A gestation of less than 37 wk defined prematurity. Normal intrauterine growth was defined by a birthweight between the 10th and 90th percentiles for gestational age, sex, and race. Intrauterine growth retardation was defined by a birthweight below the 10th percentile. Separate birthweight-gestational age tables were used for white Latin-American (Gibbs, unpublished data), white Anglo-American (8) and black (8) neonates.

Skinfold thickness was measured at the midtricipital (MT) and subscapular (SS) sites with a Harpenden caliper (13) as previously described (3). Instead of obtaining measurements exactly 15 and 60 sec after application of the caliper, skinfold thickness was recorded on a chart during at least 60 sec from the time of caliper application. A Harpenden caliper and a Cole Palmer model 8376-10 linear chart recorder (14) were modified to produce continuous recordings of skinfold thickness (Fig. 1 and 2). A linear motion potentiometer was mounted to the right jaw of the caliper while the sliding contact was connected to the left jaw. This contact was adjusted mechanically to the zero point of the linear motion potentiometer. As the jaws were opened, the slider moved across the linear motion potentiometer, causing an increasing voltage to be applied to the recorder input. The voltage was derived from a resistance network connected across a +5 volt source provided by the chart recorder supply and varied proportionally with distance between the jaws of the caliper. The resistor network consisted of a 30 kilo-ohm potentiometer for span adjustment, a 10 kilo-ohm linear motion potentiometer, and a 2 kilo-ohm potentiometer to counteract nonlinearity of the linear motion potentiometer due to arching of the caliper jaws. A "normally-closed" microswitch, connected in series with the voltage supply, was mounted on the trigger of the caliper. Its function was to break the power connection when pressure was applied to open the jaws of the caliper.

Fig. 1. Modified Harpenden caliper and chart recorder.

This prevented overloading the recorder input when the caliper was opened and allowed a more sensitive setting to be chosen on the recorder. The decline in skinfold thickness with time (Fig. 3) was estimated in magnitude and rate. The magnitude of the decline was estimated as the difference between the 0- and 60-sec readings expressed as % of the 0-sec reading (% Δ MT and % Δ SS). The rate of decline was estimated by the slope of the decline curve on semilogarithmic plot, from 4–20 sec after caliper application (S Δ MT and S Δ SS).

Corrected bromide space (extracellular water) and plasma volume (10-min albumin space with T-1824 as the albumin tag) were estimated simultaneously after intra-arterial or intravenous injection via an intravascular catheter of a sterile solution containing 3.9 g/dl of bromide (sodium salt) (15) and 22.6 mg/dl of T-1824 (Evans' Blue) (16) in 0.9 g/dl sodium chloride. The exact amount of marker injected was calculated from the measured concentration of the injectate, the weight of injectate administered and the

Fig. 3. Typical dynamic skinfold tracings obtained at the midtricipital (MT) and subscapular (SS) sites in a 32 wk, 1640 g neonate.

Fig. 2. Schematic drawing of electrical circuitry permitting recording of caliper measurements.

specific gravity of the injectate. An average of 74.2 mg/kg (range, 55.5–86.5 mg/kg) bromide and 0.5 mg/kg (range, 0.4–0.6 mg/kg) of T-1824 were injected. Bromide concentrations were determined in triplicate on the injectate solution and on plasma samples obtained before and 1 h after injection of the marker by a micro-adaptation of Wolf and Eadie's technique (12). The corrected bromide space was calculated using the following formula:

Corrected bromide space

$$= \frac{\text{Amount of bromide injected}}{\text{1-h plasma bromide concentration}} \times \frac{0.90}{0.95 \times 0.934}$$

where 0.90 corrects for an estimated 10% intracellular bromide (5), 0.95 corrects for the Donnan equilibrium and 0.934 corrects for the proportion of water in plasma (4). Concentrations of T-1824 were determined in triplicate on the injectate solution and on plasma samples obtained before and exactly 10 min after injection of the marker by a double wavelength technique (2). Interstitial water was assumed to be the difference between corrected bromide space and plasma volume. Volumes were expressed in ml per kg of body weight.

Statistical analysis was performed by means of Student's *t* test and regression analysis.

RESULTS

Of the 35 neonates who were studied, 23 were boys and 13 were girls (Table 1). All but five were of Latin-American ethnic background, four were white Anglo-American and one was black. Birthweights ranged from 620–3700 g; 19 neonates were less than 2500 g, six were less than 1500 g and five were less than 1000 g. Gestational ages ranged from 27–41 wk; there were 18 term and 18 preterm neonates. Of the preterm babies, five were less than 30 wk. All but one neonate were normally-grown and one term baby was growth retarded *in utero*. Postnatal age at the time of study ranged from 1.5–11.5 h; 18 neonates were 6 h or less, only five were 10 h old or more.

Results of the variables studied are summarized in Table 2. Mean ($\pm$ S.D.) corrected bromide space (CBS) estimates were significantly higher in preterm than in term neonates (640 ± 70.7 ml/kg *versus* 504 ± 80.1 ml/kg, $P < 0.001$). Although mean plasma volumes were higher in preterm than in term neonates (52 ± 5.8 ml/kg *versus* 47 ± 6.0 ml/kg, $P = 0.009$), this difference disappeared when values from six polycythemic term neonates, whose plasma volumes are known to tend to be lower than in their normocythemic peers (2), were excluded from calculations (52 ± 5.8 ml/kg *versus* 49 ± 5.8 ml/kg). Mean interstitial water (IW) estimates were also higher in preterm neonates (590 ± 59.6 ml/kg *versus* 457 ± 79.8 ml/kg, $P < 0.001$). Decreases in skinfold thickness measurement, estimated both in magnitude and in rate, were on the average greater for preterm neonates. Mean % Δ MT were $35 \pm 8.9\%$ for preterm and $23 \pm 4.5\%$ for term neonates ($P < 0.001$) and mean % Δ SS were $39 \pm 7.4\%$ and $23 \pm 6.2\%$, respectively ($P < 0.001$). Mean Δ MT $\times 10^4$ was 45 ± 15.3 for preterm babies and 27 ± 9.8 for term neonates ($P < 0.001$),

Table 1. Characteristics of the study population (mean $\pm$ S.D. and range)

Characteristic	Term neonates (<i>n</i> = 18)	Preterm neonates (<i>n</i> = 18)
Birthweight (gr)	3130 ± 499 (2180–3700)	1640 ± 636 (620–2640)
Gestational age (wk)	39 ± 1.4 (37–41)	32 ± 3.0 (27–36)
Postnatal age (h)	7.2 ± 1.95 (4.0–10.6)	5.5 ± 2.87 (1.5–11.5)

Table 2. Body water and dynamic skinfold thickness estimates (means $\pm$ S.D. and range)

Variable	Term neonates	Preterm neonates	<i>P</i> ¹
Corrected bromide space (ml/kg)	504 ± 80.1 (396–655)	640 ± 70.7 (541–762)	< 0.001
Plasma volume (ml/kg)	47 ± 6.0 (37–58)	52 ± 5.8 (44–64)	$= 0.009$
Interstitial water (ml/kg)	457 ± 79.8 (354–610)	590 ± 59.6 (497–707)	< 0.001
% Δ MT (%)	23 ± 4.5 (15–40)	35 ± 8.9 (17–53)	< 0.001
Δ MT $\times 10^4$	27 ± 9.8 (13–49)	45 ± 15.3 (19–68)	< 0.001
% Δ SS (%)	23 ± 6.2 (14–64)	39 ± 7.4 (27–52)	< 0.001
Δ SS $\times 10^4$	25 ± 14.9 (11–70)	46 ± 13.9 (18–71)	< 0.001

¹ Term vs Preterm Neonates.

whereas mean Δ SS $\times 10^4$ was, respectively, 46 ± 13.9 and 29 ± 14.9 ($P < 0.001$).

As shown in Figure 4, declines in skinfold thickness measurements correlated linearly with CBS estimates. Excluding skinfold thickness and CBS values from neonates who were less than 30 w of gestation increased the correlation coefficients and decreased the $S_{y \cdot x}$. Although all correlation coefficients were statistically highly significant, the correlation was better for the magnitude of decline, % Δ MT ($r = 0.71$) and % Δ SS ($r = 0.71$) than for the rate of decline, Δ MT ($r = 0.50$) and Δ SS ($r = 0.42$).

Declines in skinfold thickness measurements also increased linearly with IW estimates (Fig. 5). Again, the correlations were improved by excluding neonates of less than 30 wk gestation. The magnitude of decline, % Δ MT ($r = 0.71$) and % Δ SS ($r = 0.70$), correlated better with IW than the rate of decline, Δ MT ($r = 0.51$) and Δ SS ($r = 0.43$).

The various estimates of decline in skinfold thickness measurements correlated well with each other:

$$\Delta$$
MT $\times 10^4 = 1.23$ % Δ MT + 0.8

$$r = 0.72$$
 ($P < 0.001$) $S_{y \cdot x} = 11.2$

$$\Delta$$
SS $\times 10^4 = 1.15$ % Δ SS + 1.8

$$r = 0.74$$
 ($P < 0.001$) $S_{y \cdot x} = 11.2$

$$\% \Delta$$
SS = 0.82 % Δ MT + 7.4

$$r = 0.71$$
 ($P < 0.001$) $S_{y \cdot x} = 7.6$

$$\Delta$$
SS $\times 10^4 = (0.74 \Delta$ MT $\times 10^4) + 10.8$

$$r = 0.69$$
 ($P < 0.001$) $S_{y \cdot x} = 12.0$

DISCUSSION

Skinfolds contain a double layer of skin and subcutaneous tissues. Their thickness has been commonly equated to that of subcutaneous fat (3). This implies that the double skin thickness is negligible in relation to the total skinfold thickness—an assumption that is certainly not warranted in preterm neonates (Shanklin, personal communication, 1974). Several investigators have noted some decline in skinfold thickness (SFT) readings after application of a Harpenden caliper in children and adults. Fletcher (7) recorded cinematographically a 3–9% decline over a 2–5-sec period. Booth *et al.* (1) mentioned waiting for all needle movements to cease before taking a reading. Orpin and Scott (9) observed an initial rapid phase of needle movement and read the SFT when the movement had stopped. No explanation of the decline was attempted by these investigators. In an earlier study, we demonstrated a rapid exponential decline of SFT measurements under

Fig. 4. Relation between decline in skinfold thickness and corrected bromide space (CBS) estimate. Decline in skinfold thickness measured at the midtricipital (MT, left) and subscapular (SS, right) sites are expressed as % of initial reading ($\% \Delta$, top) and as slope of curve on semilogarithmic plot ($S \Delta$, bottom). The regression line $\pm 2S_{y,x}$ is superimposed on the scatterplot of individual values. Triangles represent neonates of 27-29 wk gestation who were excluded from calculations.

caliper pressure in neonates (3). The magnitude of this decline was expressed as the difference between SFT readings obtained 15 and 60 sec after caliper application in % of the 15-sec reading ($\% \Delta SFT$). The observation that $\% \Delta SFT$ followed a definite pattern related to the degree of gestational maturity and intrauterine growth suggested that the skinfold contained some compressible or expressible component. We postulated this component to be subcutaneous interstitial water. Attempts to correlate $\% \Delta SFT$ with simultaneously obtained estimates of extracellular water in premature neonates on the one hand, in normally-grown and macrosomic infants of diabetic and nondiabetic mothers on the other hand, failed (unpublished data). Summers *et al.* (11), however, reported a weak correlation ($r = 0.41$) between $\% \Delta SFT$ and corrected bromide space, but they defined $\% \Delta SFT$ as the difference between SFT readings obtained 5 and 60 sec after caliper application expressed in % of the 5-sec reading. This report was published in abstract form and never confirmed by a manuscript

detailing the data. The inference, though, was that the magnitude of SFT decline during the first 15 sec after caliper application was of key importance.

In order to avoid errors associated with obtaining precisely timed measurements, we modified a Harpenden caliper to produce a continuous recording from the moment of application. Simultaneous estimates of SFT and extracellular water suggest an intimate relationship between the rate and magnitude of SFT decline and both corrected bromide space (or total extracellular water) and interstitial water (or extravascular extracellular water). It does appear, therefore, that the exponential decline of SFT measurements under caliper pressure indeed results from the expression of interstitial water from the skinfold. Because the amount of water expressed increases linearly with the proportion of extracellular water in the body, dynamic skinfold measurement might be useful to assess body hydration noninvasively.

The correlation between both magnitude and rate of SFT

Fig. 5. Relation between decline in skinfold thickness and interstitial water (IW) estimate. Decline in skinfold thickness measured at the midtricipital (MT, left) and subscapular (SS, right) sites are expressed as % of initial reading (%Δ, top) and as slope of curve on semilogarithmic plot (SΔ, bottom). The regression line $\pm 2S_{y,x}$ is superimposed on the scatterplot of individual values. Triangles represent neonates of 27-29 wk gestation who were excluded from calculations.

decline with either CBS or IW improved when neonates less than 30 wk of gestation were excluded. This was probably related to the difficulty of securing a large enough skinfold in tiny babies for the caliper to grip and to the possibility that the skinfold contained little or no subcutaneous matter. Calipers with smaller end plates need to be designed for use in less mature neonates.

In conclusion, our data suggest that dynamic skinfold thickness measurements might be indicative of body hydration in neonates and might in some clinical situations replace the more invasive dye-dilution techniques. The magnitude of decline in skinfold thickness (%ΔSFT) correlates better with corrected bromide space and interstitial water ($r = 0.70-0.71$) than the rate of decline (SΔSFT, $r = 0.42-0.51$) and would therefore appear to be more useful clinically. With 95% confidence limits of ± 150 ml/kg for the prediction of corrected bromide space and interstitial water from %ΔSFT and 95% confidence limits of ± 200 ml/kg for the prediction from SΔSFT, the technique is qualitative rather than quantitative. Serial measurements could be expected to be of greater clinical value than single determinations. Further speculation on the clinical significance of the technique must await serial data and data obtained in edematous or dehydrated neonates.

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17. The authors are grateful to Harry D. Stokes, Frank A. Quijano and Michael F. McDuffy of the University's Instrumentation Shop for modifying the Harpenden calipers to meet their needs.
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19. This research was supported in part by Biomedical Research Grant number RR05654 of the National Institutes of Health, Bethesda, Md.
20. Received for publication December 8, 1981.
21. Accepted for publication June 1, 1982.