Optimal Sites and Depths for Skin Puncture of Infants and Children as Assessed from Anatomical Measurements

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Postmortem measurements were made of distances from skin surface to underlying bone/cartilage on 43 children (up to 8 y old; weights from 0.7 to 26.4 kg) to determine optimal sites and lengths of lancet tips for skin puncture of the heel, great toe, and middle finger. For measuring depths, a needlelike probe was devised that minimized disfigurement. As long as the infant's heel was available for puncture prior to callus formation (to about six months), it offered the greatest depth and the bone/cartilage of the lateral/medial sites was considerably deeper than posterior sites. At age six months, the mean distance of skin surface to bone/cartilage in the middle finger was 2.5 mm, the lower 95% prediction interval being 1.5 mm. Lengths of lancet tips for finger puncture should therefore be made <1.5 mm. To get the desired volumes of blood, a compromise must be reached between depth and width of the lancet tip.

The most commonly used means for obtaining blood for laboratory procedures in a pediatric hospital is skin puncture (1). Although this is generally regarded as a very safe procedure, penetration to or into bone or cartilage is undesirable because of possible injury and the increased chance of infection (2). We recently treated a three-week-old newborn with an osteomyelitis of the calcaneus ascribed to a nafcillin-resistant Staphylococcus aureus infection presumably introduced at a heel-puncture site. Blumenfeld et al. (3) measured the depth from surface of skin to subcutaneous fat and from surface of skin to hard tissues (bone, cartilage) at necropsy, using incisions into the heel. Of the 40 newborns they studied, 10 weighed ≤1 kg. These authors observed depths to bone/cartilage of 2.4–5.2 mm at the lateral/medial plantar sites and 1.3–3.5 mm at the posterior site. Their ratio of the mean depths of posterior to lateral/medial sites in the heel was 0.51 in this group of small infants, indicating that the lateral/medial sites offer almost twice the distance for skin puncture with a correspondingly greater chance of avoiding bone/cartilage. This ratio increased modestly with weight to a maximum of 0.60.

Using a different technique involving a simple probe, and measuring skin surface to bone/cartilage, we confirm this aspect of the findings of Blumenfeld et al. and extend these studies to the great toe and middle finger. Our data indicate that shorter lancet tips are needed, particularly for children weighing ≤25 kg, as based on depths to bone/cartilage measured in the middle fingers.

Materials and Methods

This study involved 43 children, examined postmortem. They ranged from 0 days to 8 years old, and weighed from 0.7 to 26.4 kg. Twenty newborns were <10 days old, another 11 were 1.2 to six months old; the remaining 12 were 1.0–8.0 years old.

To measure depths from skin surface to underlying bone/cartilage, we used the probe shown in Figure 1, made of 018-gauge stainless-steel dental wire (diameter 0.46 mm; Unitek Corp., Monrovia, CA 91016). A movable, reasonably tight-fitting plastic baffle, obtained from the plunger of an anesthetic carpule (Astra, Westborough, MA), was inserted on the wire. The tip of the probe was sharpened before use.

In practice, the probe was thrust perpendicularly through the skin at the sites indicated in Figure 2 until the underlying bone/cartilage was detected by resistance. The baffle was then lowered to the skin surface with just enough pressure to flatten the surface of the skin. The probe was then removed. The distance from the tip of the probe to the bottom of the baffle was considered to be the depth to the bone/cartilage. The probe leaves little disfiguration and meets the standards of our institution's human subject research committee for waiver of consent.

To measure depth, we used a vernier caliper (Helios Caliper; Glgow & Co., Chicago, IL), the accuracy and precision of which were checked in three ways by using two standard gauge blocks made according to National Institute of Standards and Technology specifications by DoAll Continental Machines Inc., Savage, MN. The CV (%) obtained with a 1.984-mm-long block varied between 0.20 and 2.32; with a 5.00-mm-long block, it was between 0.00 and 2.00.

Fig. 1. Probe for studying depth from skin surface to underlying bone/cartilage
The rubber baffle is pliant and moveable on the stainless-steel wire.
DEPTH of PUNCTURE
(Anatomical Study)

Fig. 2. Sites used for measuring depths from skin surface to underlying bone/cartilage
The probe was applied at each of the three positions indicated by the dots on the heel, great toe, and middle finger

Results

There were nine sites measured for depth on most patients. To determine whether there was a difference between sites, we used a one-way analysis of variance with repeated measures. A highly significant difference was found \( F(256) = 3, P < 0.0001 \). We then used the Neuman–Keuls test to examine the difference between sites more specifically.

In general, heel sites were significantly deeper than toe sites, which were in turn significantly deeper than finger sites. Results for three points on either the toe or the finger did not differ significantly from one another, nor did the medial/lateral points on the heel, but the mean depth of the lateral/medial heel (5.86 mm, SD 2.65) was significantly greater than the mean posterior site (5.08 mm, SD 2.76), in confirmation of the work of Blumenfeld et al. (3). The depth at each site, in order from the greatest to the least, was as follows: lateral heel, medial heel, posterior heel, lateral toe, medial toe, distal toe, lateral finger, medial finger, and distal finger. This order was the same for all the ages we studied.

Locations not significantly different from each other were averaged to provide a more stable estimation of the depth to bone/cartilage. Results for all locations on the three fingers were averaged to provide a single estimate of depth, and the same for the great toe. For the heel, medial and lateral sites were averaged, but not combined with the posterior measurements. Consolidation of data for these sites resulted in four sets of measurements.

Age and weight were correlated with each other and with skin depth, but in this study weight correlated better with depth. Because weight tends to increase very rapidly in the early postnatal months, we used a log transform of the weights. The depth measurements were also transformed to their logarithms, to adjust for a skewed distribution. These log-log transformations allowed simple linear regression lines to be computed. (In the Figures, the original scale of measurement is used.) Two separate regression analyses were performed, one for children six months old or younger, another for those one year or older.

Infants six months and younger. Figure 3 illustrates depth across the various sites as a function of weight. All four sites had significant positive slopes, reflecting an increase in depth with weight during the first six months of life. The log-log intercept, slope, mean square error, and \( r^2 \) values were, respectively, 0.207, 0.315, 0.0125, and 0.60 for finger; 0.284, 0.399, 0.0125, and 0.68 for toe; 0.442, 0.292, 0.0235, and 0.44 for posterior heel; and 0.525, 0.320, 0.0142, and 0.57 for medial/lateral heel.

Figure 3 also illustrates the lower prediction interval, which provides an estimate of the lower boundary for 95% of the population. For example, estimates of the lower surface-to-bone depth 95% prediction interval for a 4-kg infant were 1.63 mm for finger, 2.19 mm for toe, 2.33 mm for posterior heel, and 3.32 mm for medial/lateral heel.

Finger-surface-to-bone/cartilage depth. Figure 4 illustrates depth as a function of weight for all values available for the finger. Data are presented in this section for only the finger because it represents the only practical puncture site of the four sites tested for ages greater than one year. Data available for 11 children older than one year were combined with those younger to develop a regression model of finger depth on weight. Figure 4 shows that finger-depth data are much less skewed than the other sites. For this reason the regression model in this section was based on "raw" finger means and log weight. Furthermore, residual analysis of the model showed that the data were normally distributed, with a skew not significantly different from the normal distribution.

All ages up to 8 years, N = 41

Fig. 4. Depth as a function of weight for all values available for the midfinger
Each point is an average of three measurements per finger. The line of regression (dotted) and the lower 95% prediction interval (bold) are shown
distributed only if weight was log-transformed. The dotted line through the points in Figure 4 demonstrates visually that this is a reasonable model. The intercept, slope, mean square error, and $r^2$ values for finger depth vs log body weight were 1.694, 1.452, 0.277, and 0.72, respectively.

Figure 4 also presents the lower boundary for the 95% prediction interval. With this model the lower 95% prediction interval for a 4-kg infant falls above 1.71 mm, quite similar to the result (1.63 mm) predicted only with data from infants six months and younger. The lower 95% prediction interval for a 10-kg child was 2.28 mm. Although 10 kg was approximately the 50 percentile weight for a one-year-old infant, four of our 11 infants older than one year weighed <10 kg.

**Discussion**

Several circumstances may preclude use of the heel and toe for skin puncture: presence of casts covering potential puncture sites of both feet, severe malformations of the feet, impaired circulation as with "cath leg," and so many previous "sticks" that no clear area remains for use on either foot (previously used sites must be strictly avoided to minimize infection). Alternative sites have not been studied. The earlobe of the newborn is too small for consideration.

After about six to 12 months of age, callus formation, causing marked impenetrability of the heel and toe, obviates the use of these sites for skin puncture. At age six months, our patients have a median weight of about 4 kg and, as mentioned above, a lower 95% confidence interval of 1.5 mm in the distal phalanx of the middle finger. At 25-kg weight (about 5 y), the lower limit of skin surface to underlying bone/cartilage in the middle finger is 2.4 mm. Lancet tips to be used on fingers should therefore be <2.4 mm for this age group. But the added unmeasured effect of compression during the puncturing process makes it imperative that the tip be even shorter. Studies are needed to determine the depth reduction caused by compression, and how much it is counterbalanced by the gripping technique used in the process.

For depths reported by Blumenfeld et al. (3), no compression before penetration of a lancet tip was taken into account. Obviously this is incorrect. Blood may be obtained when depths of the lancet or puncturing device are as little as 1 mm—e.g., Simplate® (Organon Teknika Corp., Durham, NC), and Tenderfoot™ Surgicut® (International Technidyne Corp., Edison, NJ). These devices, however, consume much more of the plantar surface, with incisions being respectively 5 and 2.5 mm wide, particularly of the heel, than others such as the Neolet™ (Sherwood Medical, St. Louis, MO) (4) and the Blue Microtainer Brand Safety Flow Lancet (Becton Dickinson and Co., Rutherford, NJ) that allow punctures 1.8 and 1.9 mm deep, but these are 0.9 and 1.0 mm wide, respectively. Thus, compression during skin puncture is an important consideration because it can be assumed to reduce the distance from skin surface to underlying bone/cartilage with regard to depth of puncture; however, the width or diameter (if cylindrical) of the puncturing device needs to be considered as well. A compromise must be reached between the width of the incision, and thus the punctured surface consumed, and the expected volume of blood to be obtained. The thickness of the lancet must also be considered.

The probe designed for this study may have penetrated the soft cartilage of the finger of the infants of lowest weights. In such cases, the depths measured to the bone/cartilage surface may have been slightly more than the actual values, although the technique of gently probing should have minimized this source of error.

**References**