Pubertal correlates in black and white girls

Ruth Striegel Weissman
PUBERTAL CORRELATES IN BLACK AND WHITE GIRLS

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Objectives Since pubertal maturation is an important covariate in studies that evaluate physical and social changes that occur during the teen years, we examined pubertal parameters in a group of US girls.

Study design Black and white girls recruited at age 9 were followed annually for 10 years. Preece-Baines model 1 was used to estimate tempo and growth parameters. The temporal trend between age of menarche and onset of puberty was calculated.

Results The study included 615 (77.2% prepubertal) white and 541 (49.4% prepubertal) black participants. Mean onset of puberty was 10.2 and 9.6 years in white and black girls, respectively, menarche was 12.6 and 12.0, achievement of Tanner growth stage 5 was 14.3 and 13.6, and achievement of adult height was 17.1 and 16.5 years. The Pearson’s correlation coefficient between menarche and onset of puberty was .37.

Conclusions Menarche is often used as a marker for onset of puberty and for timing of puberty. Data gathered over the past 20 years suggest only moderate correlation between menarche and onset of puberty (.37-.38), which has decreased significantly during the last 50 years. This suggests the existence of both similar and unique factors that impact the age at onset of puberty and age at menarche. (J Pediatr 2006;148:234-40)

Pubertal maturation, a dynamic period of biologic change, is an important covariate in studies that evaluate physical and social changes that occur during the teen years, and measurement of pubertal maturation often provides a better explanation for these changes during the teen years than does chronologic age. For example, measurements of hemoglobin levels1-3 and bone density during the teen years4-7 follow changes in pubertal maturation more closely than changes in chronologic age. In addition, many factors that modify risk for adult morbidity and mortality, such as central adiposity and insulin resistance, are linked to changes that occur during pubertal maturation. Parameters that are used for pubertal maturation include age at onset of puberty (timing), stage (sequence), and tempo. Many studies that examine the impact of the timing of pubertal maturation, however, interchange the age at onset of puberty with the age of menarche8. This study examines the associations among several indicators of pubertal development and whether there have been any temporal drifts among these indicators.

METHODS

Participants
The participants were from the three clinical sites of the National Heart, Lung, and Blood Institute Growth and Health Study (NGHS). Briefly, the NGHS was a longitudinal study that recruited a socio-economically diverse group of girls, ages 9 and 10 years old, at entry, from public and parochial schools in metropolitan Cincinnati, OH; the Richmond, California Unified School District; and a random sample of participants from a health maintenance organization in Washington, DC.9 The Maryland Medical Research Institute in Baltimore served as the data-coordinating center. Race was defined at study entry (1986-1987) by self-declaration of subjects and their parents (black or white) living in a racially concordant household. Hispanics and other ethnic groups were not included. The girls were born between 1977 and 1979, but only the girls born in 1977 and 1978 (age 9 at recruitment) were included in these analyses.
Procedures

The subjects were seen at annual visits for 10 years. During the annual visits, physical examinations included height, weight, sum of skin fold thicknesses (at triceps, subscapular, and suprailiac sites), pubertal maturation assessment, and, after the first year, waist and hip circumferences. The methods for anthropometric measurements have been described. Briefly, examiners were centrally trained and certified, and then recertified annually thereafter. Two measurements were taken of each variable, and a third measurement was obtained if the two differed by a pre-set amount. The mean of the two closest measurements was used. Body mass index (BMI) was calculated as kg/m². Percent of body fat was calculated from the triceps and subscapular skin folds using the formulae in Slaughter et al. Pubertal maturation assessment was performed according to Tanner growth stages for pubic hair development and by the Garn-Falkner system for areolar stages, which involves inspection as well as palpation. The Garn-Falkner areolar staging system was used to minimize confounding of breast development by adipose tissue. The correlation between the Garn-Falkner and Tanner breast staging systems are highly significant (.94). Date of menarche was asked by a female research assistant at the annual examination. Anthropometric measures at menarche were obtained from examinations within 6 months of the stated time of menarche. All physical examination procedures were conducted by female examiners.

To calculate the temporal trend in the correlation between age of menarche and onset of study, large multiple studies were selected from the literature. The papers that were reviewed included Reynolds (1948), Nicolson (1953), Marshall (1969), Bielicki (1975), Taranger (1976), Largo (1983), de Ridder (1992), and the current study. A regression analysis was calculated which used the year of birth of the study cohort as the independent variable, and the correlation between age of onset of puberty and age of menarche as the dependent variable. The Pearson’s correlation coefficient was calculated between the independent and dependent variables.

Analyses

Age of entry into puberty was defined as the age at areolar stage 2 or at pubic hair stage 2, whichever occurred earlier. Age of menarche was calculated from date of birth to date of first menstrual period. Age of completion of puberty was calculated at age in which areolar stage 4 or pubic hair stage 5 was identified, whichever came later.

A height curve was fitted by cubic spline for each subject, which was used to estimate the peak height velocity (PHV) and corresponding age. Height velocities were estimated initially by calculating \( \frac{(HT_{t+1} - HT_{t})}{(T_{t+1} - T_{t})} \), where the time interval between two consecutive visits \((T_{t+1} - T_{t})\) fell within a window between 9 and 15 months. Final adult height was estimated initially by obtaining the heights at three consecutive visits \((t, t-1, \text{ and } t+1)\), where the difference in height between the first and third visits was less than 1.5 cm. Final adult height was estimated as the average of those three heights. For each subject, the Preece-Baines height growth curve model 1 (PB1) was fitted to the height data using calculated final adult height, height at PHV, and age of PHV. Estimates for the PB1 model were calculated using the least squares error method.

Growth and puberty parameters were estimated separately by race. Comparisons between races were performed by Student’s \( t \) test for PHV, age of PHV, final adult height, age of final adult height, and age at menarche. The mean and corresponding standard deviations are reported. Because the dates associated with pubertal events could not be observed precisely, but can be estimated by noting the ages before and after the occurrence of that event, interval-censored data were used. That is, the subject may have experienced onset of puberty before enrollment into the study, and, thus, her onset of pubertal maturation (and that stage of pubertal maturation) is left censored. To optimally use the information regarding onset and completion of puberty from the NGHS data and to acknowledge the censored nature of the data, survival regression analysis was used to estimate the median as well as 5th and 95th percentiles for age of entering puberty, age of completing puberty, as well as time intervals between age of PHV, age of final adult height, and age at menarche. Survival regression analysis is a statistical technique designed to study the occurrence and timing of events, particularly for censored data. Survival regression analyses were performed with and without adjustment for other growth parameters.

The study was approved by the Institutional Review Boards of the University of Cincinnati and Children’s Hospital Medical Center, Cincinnati, OH; University of California at Berkeley; and Westat/Group Health Association in Rockville, MD. All participants and their parents/legal guardians gave informed consent.

RESULTS

Analyses included all participants who were 9 years old at recruitment, which included 541 black (49% prepubertal) and 615 white (77% prepubertal) girls. Overall cohort retention was 89% at year 10 of the study. Because of incomplete growth data from missed visits, only 817 subjects remained in the Preece-Baines height growth curve model 1 analyses.

The ages for selected puberty parameters are given in Table I. Black participants had a significantly younger age for onset of puberty, age at PHV, menarche, attainment of areolar 4/pubic hair 5 (“end of puberty”), and age at attainment of adult height when compared to white participants (all \( P < .0001 \)). Race-specific Pearson’s correlation coefficients for selected puberty parameters are given in Table II.

The median interval from the onset of puberty to age of menarche in black participants was 2.7 years and 95th percentile was 4.5 years. For white participants, these values were 2.5 and 4.4 years, respectively. Table II gives the correlations of this interval (age at onset of puberty to age of menarche) to selected puberty parameters. Of note, the interval was correlated negatively to age at onset of puberty but was correlated...
Table I. Values for selected puberty parameters, by race (in years), with 95% confidence intervals

<table>
<thead>
<tr>
<th>Onset</th>
<th>Agepub</th>
<th>Duratpub</th>
<th>AgePHV</th>
<th>PHV</th>
<th>Menarche</th>
<th>Agemat</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>10.23 (10.15, 10.31)</td>
<td>14.26 (14.17, 14.35)</td>
<td>4.03 (3.93, 4.13)</td>
<td>11.91 (11.77, 12.05)</td>
<td>7.18 (7.04, 7.32)</td>
<td>12.60 (12.53, 12.67)</td>
</tr>
<tr>
<td>Black</td>
<td>9.59 (9.50, 9.68)</td>
<td>13.55 (13.46, 13.64)</td>
<td>4.16 (4.05, 4.27)</td>
<td>11.46 (11.31, 11.61)</td>
<td>7.23 (7.07, 7.39)</td>
<td>12.00 (11.93, 12.07)</td>
</tr>
</tbody>
</table>

Onset, onset of puberty; median values, N = 452 white, 278 black; 278 white, 278 black; t^2 = 49.4, df = 1; P < .0001 (by race).
Agepub, age completion of puberty/secondary sexual characteristics; median values, N = 580 white, 523 black; \( \chi^2 = 110.9, df = 1; P < .0001 \) (by race).
Duratpub, duration of puberty; median values, N = 580 white, 523 black; NS (by race).
AgePHV, age at peak height velocity; mean values, calculated from PB-1, N = 313 white, 225 black; t = 4.36, df = 500; P < .0001 (by race).
PHV, peak height velocity, cm; mean values, N = 313 white, 225 black; NS (by race).
Menarche, age of menarche; mean values, N = 576 white, 518 black; t = 5.38, df = 2084; P < .0001 (by race).
Agemat, age completion of growth; mean values, calculated from PB-1, N = 313 white, 224 black; t = 6.46, df = 483; P < .0001 (by race).

Table II. Correlations (Pearson’s correlation coefficients) between selected puberty parameters in girls recruited at age 9, by race

<table>
<thead>
<tr>
<th>Onset puberty</th>
<th>Age PHV</th>
<th>Menarche</th>
<th>Age end pub</th>
<th>Age adult ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset puberty</td>
<td>.363***</td>
<td>.381***</td>
<td>.326***</td>
<td>.328***</td>
</tr>
<tr>
<td>Age PHV</td>
<td>.365***</td>
<td>.532***</td>
<td>.284***</td>
<td>.012</td>
</tr>
<tr>
<td>Menarche</td>
<td>.224***</td>
<td>.290***</td>
<td>.235***</td>
<td>.256***</td>
</tr>
<tr>
<td>Age end pub</td>
<td>.327***</td>
<td>.529***</td>
<td>.144***</td>
<td>.283***</td>
</tr>
<tr>
<td>Age adult ht</td>
<td>-.279***</td>
<td>.753***</td>
<td>.190***</td>
<td>.185*</td>
</tr>
<tr>
<td>Interval onset to menarche (W)</td>
<td>-.192***</td>
<td>.411***</td>
<td>.836***</td>
<td>.190***</td>
</tr>
<tr>
<td>Interval onset to menarche (B)</td>
<td>-.192***</td>
<td>.411***</td>
<td>.836***</td>
<td>.190***</td>
</tr>
</tbody>
</table>

*P < .01; **P < .001; ***P < .0001.
Values in bold are from black participants.

positively to the other pubertal parameters. In a regression analysis, the duration of the interval was related to race (β coefficient = −.428 years, white race shorter; P < .0001), age of menarche (β coefficient = +.676 years/year increase in menarche; P < .0001), and the z-score of percent body fat at onset of puberty (β coefficient = +.192 years/unit z-score of body fat; P < .0001). In a regression that added the proportion of body fat at menarche to the model, the interval was related to race (β coefficient = −.381 years, white race longer, P < .0001), age of menarche (β coefficient = +.619 years/year increase of menarche, P < .0001), z-score of percent body fat at onset of puberty (β coefficient = −.159 years/unit of z-score of body fat, P = .0056), and z-score of percent body fat at menarche (β coefficient = +.402 years/unit z-score of body fat, P < .0001).

A regression analysis of determinants of age of menarche, which included race, age at onset of puberty, body fat at onset of puberty, and body fat at menarche, explained 30% of the variance (R^2 = .30). The β estimates for each were as follows: race (β coefficient = +.252 years, white race longer, P = .0018), age at onset of puberty (β coefficient = −.373 years/year increase in onset of puberty, P < .0001), z-score percent body fat at onset of puberty (β coefficient = −.756 years/unit z-score of body fat, P < .0001), and z-score percent body fat at menarche (β coefficient = +.821 years/unit z-score of body fat, P < .0001). Figure 1 demonstrates the significant inverse relationship between the correlation of the onset of puberty and age of menarche, by year of birth of the cohort. The relationship is significant (P < .01), with a slope of −.87 (confidence interval = −.98, −.35).

**DISCUSSION**

This study sought to examine the associations between several indicators of pubertal development in a group of women born from 1977 to 1978, as well as the temporal drift in the correlation between onset of puberty and age of menarche. The cross-sectional PROS study from the United States noted earlier ages of pubertal maturation than previously reported. Girls in The Netherlands appeared to have a younger age at onset of puberty between 1965 and 1980, but the onset of pubertal appears to have stabilized since that time. Several European studies have noted earlier maturation of immigrant children compared to European children, particularly those who moved to Europe as young children. 

Age of menarche in Western nations had seemingly dropped steadily through the 1960s. Using probit analysis of cross-sectional data from the PROS study, Herman-Giddens concluded there appeared to be no significant decrease in age of menarche. Comparing data from NHES to NHANES (the former from 1963 through 1970, and the latter from 1988 through 1994), age of menarche dropped .21 to .34 years, of unclear clinical significance. Alternatively, data from the Bogalusa Heart Study note that the median age of menarche has decreased nearly 10 months in black and 2 months in white girls between 1973 and 1994. Similarly, in the Fels Longitudinal Study, there was a small but signifi-
significant decrease in age of menarche, particularly in more recent birth cohorts. The following three methods are commonly used to estimate age of menarche: (1) status-quo, which establishes whether menarche has been attained and is analyzed by probit or logit analysis; (2) retrospective, which is impacted by recall bias and length of time since the occurrence; and (3) prospective, which may be impacted by attrition bias as potentially by length of time since occurrence.

The earlier age of maturation often has been attributed to improved socioeconomic status and general health. The age of onset of puberty, however, may serve as a sensitive and early marker of the interaction between genes and the environment (eg, the secular changes noted in the decrease in age of menarche are greater in blacks than in whites). Although girls with early menarche tended to have significantly higher BMIs than girls with average or later menarche, these differences may not be seen until after menarche. Leptin appears to serve a permissive factor for the onset of puberty. Leptin levels are greater in blacks, even with adjustment for fat mass and pubertal maturation, leading to conjecture that greater body fat in prepubertal black girls may increase the likelihood for earlier puberty. A longitudinal analysis noted that much of the apparent effect of timing of menarcheal age on adult obesity results from the effect of childhood obesity. The increases in relative weight, however, may be a consequence rather than a determinant of age of menarche, or secular changes in BMI and mean age at menarche could be independent phenomena.

The median values for the interval between the ages of onset of puberty with that of menarche were 2.7 years in black girls and 2.5 in white girls. These values are somewhat greater than the mean values listed in the literature, although similar to those extracted from the PROS data set. The mean value reported from a contemporary study in a Spanish community was 1.96 years; earlier reports note values from 2.08 to 2.7 years. Of note, the mean values from the present study were 2.11 in 261 black girls and 2.25 in 417 white girls who had complete information. This study used median values because the mean value of the interval was not distributed normally. The current study noted a positive correlation of the interval with the age of menarche and a negative correlation with age of pubertal onset, similar to previous studies. Girls who enter puberty later have a more rapid progression to menarche and, as noted previously, may suggest a “catch-up” phenomenon of those with later maturation. The authors of this study also noted higher levels of follicle-stimulating hormone, estradiol, and free estradiol, reflecting a potentially more advanced negative feedback system in girls who enter puberty later. The reader may note that the z-score of body fat at onset of puberty increases the interval in a regression analysis with race and age of menarche, but that it decreases the interval when race, age of menarche, and z-score of body fat at menarche are included in the analysis. The correlation between this interval (onset of puberty to age of menarche) and z-score of body fat at onset of puberty was −.068 (P = .025), suggesting that the associations between pubertal parameters may change, depending on how the data are compared.

Using data gathered during the past 20 years, only moderate correlation between menarche and onset of puberty (.37–.38) was found, whereas earlier studies (gathered from women born between 1920 and the 1960s) have reported much higher correlations (.64–.86). Of note, the correlations between the various pubertal parameters reported in this manuscript are somewhat lower than those reported in the literature, as noted in Table III, although they are comparable with values noted by Largo. Other authors have noted the moderate correlation between menarche and onset of puberty, suggesting that these two markers of pubertal maturation in girls are not parallel events.

As noted above, the interval between these two variables is impacted by race (suggesting variable genetic sensitivities) as well as body composition at onset of puberty and at menarche. The decreased correlation in women born over this 50-year span could reflect interactions between body composition, environmental influences (such as endocrine disruptors), and genetic polymorphisms. There are differences in measurement reliability between these studies, which may have impacted the correlation coefficients. It is unlikely, however, that these measurement differences would have led to a systematic bias that resulted in the significant relationship between onset of puberty and age of menarche.

Although not based on national probabilistic sampling, this study includes black and white girls with broad socioeconomic representation. Many girls had entered pubertal maturation before being recruited into the study (22.8% of white and 50.6% of black participants). The statistical methods used in this study, incorporating interval-censored data with survival regression analysis, are well suited to minimize these limitations.
from large, cross-sectional representative studies such as NHANES\textsuperscript{26,27,47,48} and PROS.\textsuperscript{22} The race-specific values for onset of puberty and age of menarche compare favorably with data generated from those studies, especially NHANES (Table IV). Although there was excellent retention of the cohort, several girls were not included in the Preece-Baines model for growth (Table I). Those who were included in the model (compared to those not included in the model) were more likely to be white (50.9\% compared to 48.9\%, \( P \leq 0.002 \)) and, in a race-stratified analysis, had a later onset of puberty (.18 years, \( P \leq 0.007 \)).

There appeared to be minimal differences in adult height between those included and excluded from the model (.6-1.1 cm). Despite these limitations, many authors have reported that the Preece-Baines model is superior to other models for evaluating growth parameters,\textsuperscript{20} including data derived from national growth sets \textsuperscript{49} and both normal as well as impaired growth states.\textsuperscript{50}

Menarche is often used as a marker for onset of puberty and for timing of puberty. When using analyses from more recent data, there is only moderate correlation between menarche and onset of puberty (.37-.38), whereas studies of women born several decades earlier have reported much higher correlations (.64-.86). This suggests that there are unique factors in contemporary studies that impact the age at onset of puberty and age at menarche. It is of clinical and research importance that age of menarche may not be interchangeable with age of onset of puberty.\textsuperscript{11}

The authors gratefully acknowledge the long-term commitment of all NGHS participants and their families who contributed to this study, and the NGHS study personnel for their dedication to the project, and Susan Cunningham for assistance with manuscript preparation.

### REFERENCES


### Table III. Pubertal correlates from key historical studies

<table>
<thead>
<tr>
<th>Correlates</th>
<th>Nicholson and Hanley\textsuperscript{14}</th>
<th>Largo and Proder\textsuperscript{18}</th>
<th>Taranger and Prader\textsuperscript{17}</th>
<th>Bielicki\textsuperscript{16}</th>
<th>Marshall and Tanner\textsuperscript{15}</th>
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</thead>
<tbody>
<tr>
<td>Onset: men</td>
<td>.74</td>
<td>.47/.44</td>
<td>.74/.58</td>
<td>.72</td>
<td>.76</td>
</tr>
<tr>
<td>Men:PHV</td>
<td>.71</td>
<td>.82</td>
<td>.84</td>
<td>.92</td>
<td>.71</td>
</tr>
<tr>
<td>B2:PHV</td>
<td>.80</td>
<td>.60</td>
<td>.80</td>
<td>.78</td>
<td>.68</td>
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<td>PH2:PHV</td>
<td>.75</td>
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<td>.73</td>
<td>.68</td>
<td>.68</td>
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<tr>
<td>B2:B5</td>
<td>.80</td>
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<td>.77</td>
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<td>PH2:PH5</td>
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<td>.34</td>
<td>.77</td>
<td>.77</td>
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</tr>
<tr>
<td>B2:PH2</td>
<td>.75</td>
<td>.34</td>
<td>.77</td>
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</table>

### Table IV. Comparison of ages of onset of puberty and age of menarche: NGHS, PROS, and NHANES (adapted from Herman-Giddens et al\textsuperscript{33})

<table>
<thead>
<tr>
<th>Study</th>
<th>Breast development</th>
<th>Pubic hair development</th>
<th>Menarche</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White</td>
<td>Black</td>
<td>White</td>
</tr>
<tr>
<td>Current study</td>
<td>10.44</td>
<td>9.78</td>
<td>10.40</td>
</tr>
<tr>
<td>PROS</td>
<td>9.96</td>
<td>8.87</td>
<td>10.51</td>
</tr>
<tr>
<td>NHANES Wu et al.\textsuperscript{47}</td>
<td>10.3</td>
<td>9.5</td>
<td>10.6</td>
</tr>
<tr>
<td>NHANES Sun et al.\textsuperscript{48}</td>
<td>10.38</td>
<td>9.48</td>
<td>10.57</td>
</tr>
<tr>
<td>NHANES Chumlea et al.\textsuperscript{27}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NHANES Anderson et al.\textsuperscript{26}</td>
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</tr>
</tbody>
</table>
Fifty Years Ago in The Journal of Pediatrics

CONGENITAL ATRESIA OF THE ILEUM

The authors describe the course of a neonate with ileal atresia complicated by meconium peritonitis. The infant’s symptoms included abdominal distension and bilious emesis with initial abdominal radiographs revealing minimal bowel dilatation but with evidence of pneumoperitonenum. Radiographs were repeated secondary due to worsening clinical status and revealed progressive pneumoperitoneum. During an exploratory laparotomy, using 1% Novocain for anesthesia, a perforation was discovered and a total of 48 cm of small intestine was resected. After a primary closure, the infant succumbed over the next 24 hours. The authors emphasized the importance of investigating bilious emesis in infants and that passage of meconium on the first day of life does not exclude the diagnosis of intestinal atresia, especially the more distal atresias as in this case. Their conclusions still hold true in 2005.

Since this infant’s birth in 1954, however, neonatal medical and surgical care has made tremendous strides in respect to pediatric anesthesia and nutritional support. As a result, the care provided for a similar infant today differs greatly from the practices of fifty years ago. Today, pediatric surgeons would immediately perform an exploratory laparotomy based upon the initial radiographic findings of pneumoperitoneum. The myth that infants do not experience pain has since been dispelled and specialized pediatric anesthesiologists and neonatalogists provide both peri- and post-operative analgesia and anesthesia for infants. Although initially used only in adults, epidurals or continuous infusions of narcotics for pain relief is common practice in infants and children.

Even if the infant had survived the immediate post-operative period, long-term survival at that time would have been questionable following a 48 cm small intestinal resection. Not until the advent of Total Parenteral Nutrition (TPN) in the late 1960s did prolonged survival become a reality for children with “short gut syndrome.” Currently, TPN serves as the primary bridge until intestinal adaptation or, in some cases, small bowel transplantation. The development of specialized semi-elemental and amino-acid based formulas has also increased the chance that infants with short gut syndrome will attain intestinal autonomy. Fifty years later, current advancements with analgesia, anesthesia, and nutritional support lead to successful resuscitation and prolonged survival for infants with intestinal resections for a variety of etiologies including ileal atresia.

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YMPD2043
10.1016/j.jpeds.2006.01.028