New Reference Curves for Head Circumference at Birth, by Gestational Age

WHAT’S KNOWN ON THIS SUBJECT: Head circumference (HC) at birth reflects brain development in utero. However, HC charts used in Canada are either dated, mixed-gender, nonrepresentative of lower gestational ages, or reflective of other populations in the world.

WHAT THIS STUDY ADDS: We developed recent and gender-specific reference curves for HC at birth for singletons of 23 to 41 completed weeks’ gestational age, which included a large number of very prematurely born infants, reflecting the current geotemporal Canadian population and advances in obstetric care.

abstract

BACKGROUND: The measurement of head circumference (HC) at birth reflects intrauterine brain development. HC charts currently used in Canada are either dated, mixed-gender, nonrepresentative of lower gestational ages (GAs), or reflective of other populations.

METHODS: To create both birth weight and HC curves, we combined weight and HC data from the Canadian Neonatal Network (CNN) database (admissions in NICUs across Canada) with McGill’s Obstetrical Neonatal Database (MOND; all births at a tertiary hospital in Montreal, Canada). We included CNN data for GAs of 23 to 34 weeks (2003–2007) and MOND data for GAs of 35 to 41 weeks (1995–2008). Nonsingleton, congenital anomalies, and measurements greater than ±4 SD from the mean were excluded. Distributions of birth weight and HC at each GA were statistically (penalized spline regression) smoothed. Birth weight curves were compared with recent Canadian reference curves and HC curves with historical and/or frequently used curves.

RESULTS: We included 39,896 births (3121 births at <30 weeks’ GA) to generate the curves. Current weight curves were similar to Canadian reference charts for both genders. Weight and HC measurements in boys were higher than in girls. When classified according to recent international references, the proportion of CNN-MOND infants at ≥32 weeks’ GA with HCs <10th percentile was significantly underestimated. When classified according to historical reference curves, a significant number of CNN-MOND infants of all GAs with HCs <10th and >90th percentiles were misclassified.

CONCLUSIONS: We developed recent gender-specific reference curves for HC at birth for singletons at 23 to 41 completed weeks’ GA, which included a large number of very premature infants, reflecting the current geotemporal Canadian population.

AUTHORS: Alexandre Barbier, MD, PhD,a Ariane Boivin, PhD,a Woojin Yoon, MSc,a Danielle Valleraud,a Robert W. Platt, PhD,b,d François Audibert, MD,e Keith J. Barrington, MD,e Prakesh S. Shah, MD,f,g Anne Monique Nuyt, MD,a,h and the Canadian Neonatal Network

Departments of aPediatrics (Neonatology), and dObstetrics and Gynecology, Sainte-Justine University Hospital and Research Centre, University of Montreal, Quebec, Canada; bDepartment of Pediatrics (Neonatology), Faculty of Medicine, McGill University, Montreal, Quebec, Canada; cMaternal-Infant Care (MiCare) Research Centre, Toronto, Ontario, Canada; and hDepartment of Pediatrics, University of Toronto, Toronto, Ontario, Canada

KEY WORDS: growth charts, fetal growth, microcephaly, macrocephaly, preterm birth, birth weight, head circumference, reference curves, brain growth

ABBREVIATIONS

AHC—appropriate head circumference
CNN—Canadian Neonatal Network database
GA—gestational age (completed weeks)
HC—head circumference
LHC—larger head circumference
MOND—McGill Obstetric and Neonatal Database
SHC—small head circumference

Dr Barbier and Boivin contributed equally to this work.

www.pediatrics.org/cgi/doi/10.1542/peds.2011-3846
doi:10.1542/peds.2011-3846
Accepted for publication Dec 12, 2012

Address correspondence to Anne Monique Nuyt, MD, Division of Neonatology, Department of Pediatrics, Sainte-Justine University Hospital and Research Centre, University of Montreal, 3175 Côte Sainte-Catherine, Montreal, PQ, H3T 1C5, Canada. E-mail: anne-monique.nuyt@recherche-ste-justine.qc.ca

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275). Copyright © 2013 by the American Academy of Pediatrics

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDED: Supported by the Canadian Institutes of Health Research (CIHR) and the Ontario Ministry of Health and Long-term Care. Dr Barbier was supported by a Fondation du CHU Ste Justine fellowship, Dr Boivin by a Quebec Training Network in Perinatal Research fellowship, and Drs Nuyt and Platt by Fonds de la Recherche en Santé du Québec (FRSQ) Senior Scholar Awards. The Coordinating Center of the Canadian Neonatal Network is supported by funds from the CIHR and the Ministry of Health and Long-term Care, Ontario. Dr Platt is a member of the Research Institute of the McGill University Health Centre, and Dr Nuyt is a member of the CHU Ste Justine Research Center, which receive core support from the FRSQ.
The measurement of head circumference (HC) at birth is part of the initial basic clinical assessment of newborns. HC reflects brain volume and brain development in utero. Plotted onto reference curves, the HC measurement is indicative of in utero growth of the brain for the child’s gestational age (GA). It is thus a major diagnostic and prognostic marker used to help identify symmetric or asymmetric growth, microcephaly (<2 SDs below the mean or <10th percentile) and macrocephaly (>2 SDs above the mean or >90th percentile), all of which are associated with a number of etiologies that require additional investigation. It is therefore essential that the clinician be provided with trustworthy and representative reference growth curves. Because of improvement of antenatal and postnatal care, including better assessment of GA, it is important that measurement curves be updated, especially for preterm infants.

However, despite the clinical importance of HC, few recent growth curves are available in the literature. Indeed, measurements of HC are often not included in birth registries and databases used in cohort studies. Figure 1 shows the main HC curves currently in use in North America. Those by Usher and McLean are commonly referenced in Canada despite the fact they were published in 1969 and their small underlying sample size (300 total). The Fenton growth chart is more recent and based on a larger sample of 30,000 Australian and 380,000 Swedish (but not North American) infants. In addition, few infants born before 30 weeks’ gestation were included (only 274 infants), because the larger Swedish data set did not include births before 29 weeks. More recently, Olsen et al published HC intrauterine growth curves based on data of a large number of infants born in 33 US states; however, the Canadian newborn population might differ because prematurity rate and socioeconomic disparities are lower, and universal health care and obstetric coverage prevails.

The objective of the current study was to create up-to-date HC reference charts that are representative of today’s Canadian neonatal (including very pretermly born) population.

**METHODS**

We merged weight and HC data from 2 existing birth databases: the database of the Canadian Neonatal Network (CNN) and the McGill Obstetric and Neonatal Database (MOND). The curves presented in the current study were generated with CNN data for births at 23 to 34 weeks’ completed GA and MOND data for births at 35 to 41 weeks’ completed GA.

We first used these databases to generate growth curves for weight and verified that they were consistent with existing reference curves for Canadian newborns. We then developed HC curves and compared them with existing reference charts.

**Population**

The CNN (http://www.canadianneonatlenetwork.org/portal/) was established in 1995 and links researchers from 30 hospitals and 17 universities across Canada. The CNN maintains a database of all infants admitted to affiliate NICUs in Canada, from which we obtained data for patients born between 2003 and 2007. The MOND database includes all children born at a tertiary care university hospital in a major urban center (Royal Victoria Hospital of the McGill University Health Centre, Montreal, Quebec, Canada),

![FIGURE 1](image_url)

Main reference curves currently in use in Canada and the United States for birth weight, length, and HC, by GA (completed weeks). Data are from Lubchenco et al, Usher and McLean, Blidner et al, Arbuckle et al, Kramer et al, Fenton, and Olsen et al.
which includes ~3700 births per year. Data collected between January 1995 and June 2006 were obtained for the current study. Data collection was incomplete between April 1, 1997, and March 31, 1998, and these data were therefore excluded. The Royal Victoria Hospital NICU is part of the CNN database.

We included birth weight, HC, and GA for all singletons born between 23 +0 and 41 +6 weeks’ GA, excluding stillbirths and infants with major congenital anomalies. Before plotting the curves, we excluded data on children whose weight or HC measurements were at more than ±4 SD from the mean.

In accordance with recommendations by the World Health Organization, we truncated GAs to completed weeks. In the MOND database, 89.7% of mothers of neonates born from 1995 to 2006 had their GA validated with ultrasound evaluation; although this information was not directly available from the CNN database, the health care system and rate of antenatal ultrasound use for the Canadian population in recent years were considered very similar. We therefore assumed that the majority of GAs of infants included in this study were accurate.

Data Selection: Validation With Birth Weight Curves

We first constructed growth curves for birth weight by GA for each database (MOND and CNN) separately and compared them with the curves for birth weight by GA developed by Kramer et al.12 These curves were selected because they were both recent and representative of the Canadian population, were based on live birth registries across Canada (except for Ontario), and included the largest Canadian sample of low-GA births. The CNN-derived birth weight charts for males and females were very similar to the smoothing spline from the fitted generalized additive models. Data were separated by gender, and tables and charts created for the 3rd, 10th, 50th, 90th, and 97th percentiles. Curves were drawn by using R software version 2.9.0 (http://www.r-project.org, Developed by the Statistics Department, University of Auckland, Australia; available at http:// cran.r-project.org/). Means and SDs were calculated from empirical distribution of HC values and were also tabulated to allow calculation of z scores.12

The new CNN-MOND HC curves were compared with the Lubchenko et al,14 Usher and McLean,6 Fenton,7 and Olsen et al10 curves for HC. The CNN-MOND HC data were classified according to the <10th, 10th to 90th, and >90th percentiles of the Lubchenko et al,14 Fenton,7 and Olsen et al10 curves, and according to the means ± 2 SDs of the Usher and McLean6 curve. The proportion of misclassification was calculated for GAs stratified as 23 to 26 weeks, 27 to 31 weeks, 32 to 36 weeks, and 37 to 41 weeks, and a likelihood ratio χ² was calculated to assess statistical differences.10

RESULTS

Population

From 2003 to 2007, data for 26,482 infants born between 23 +0 to 34 +6 weeks GA were collected in the CNN database. In the MOND database, 35,519 infants were born from 1995 to 2006 (excluding April 1997 to March 1998) between 35 +0 and 41 +6 weeks GA. Of those, 18,675 in CNN and 32,749 in MOND had both birth weight and HC recorded. After exclusion of nonsingletons, those with congenital anomalies, and infants with HC or birth weight values more than ±4 SDs from the mean for GA, the final sample included 10,272 infants <35 weeks’ GA.
(including 3121 births at GAs of <30 weeks [1668 boys, 1453 girls] and 2374 infants at GAs of ≤28 weeks [1252 boys, 1122 girls]) and 29 624 infants ≥35 weeks’ GA (Fig 2).

Data Selection: Validation With Birth Weight Curves

The birth weight curves at the 10th, 50th, and 90th percentiles obtained from our combined CNN-MOND data showed a high degree of observable similarity to the most recent Canadian gender- and GA-specific fetal growth standards,12 both for boys and girls (Fig 3 A and B). When CNN-MOND data were separated as <10th, 10th to 90th, and >90th percentiles and compared with the Kramer et al curve,12 the differences were small overall (see Supplemental Tables 2 and 3).

HC Curves

We then calculated average HC values at GAs of 23 to 41 weeks and at the 3rd, 5th, 10th, 50th, 90th, and 97th percentiles, including both the median and the mean ± SD (Table 1). The smoothed curves closely followed (within limits of random error) the empirical HC distribution at each GA. For example, at 35 weeks, the 90th percentile curve excludes 90.5% of males and 92.1% of females in our data set. At 40 weeks, the 10th percentile curve excludes 9.2% of males and 11.7% of females. Figure 4 shows the curves (raw and smoothed) for HC at birth, as obtained from our merged CNN-MOND data. Supplemental Table 4 shows the differences between our values and those obtained from previously published reference curves.

Comparison With Lubchenco et al

Although Lubchenco et al’s14 HC growth curve starts at 26 weeks’ GA and is not gender-specific, it is still used in many NICUs. CNN-MOND current HC curves

FIGURE 2
Study population. BW, birth weight.

FIGURE 3
Reference curves (10th, 50th, and 90th percentiles) for birth weights by GA by using combined CNN-MOND data (solid lines; see Methods) compared with reference charts from Kramer et al12 (dashed lines) for boys (A) and girls (B).
TABLE 1  HC (in cm) at Birth by GA for Singleton Boys and Girls

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender and GA</td>
<td>3rd</td>
<td>5th</td>
</tr>
<tr>
<td>23</td>
<td>48</td>
<td>17.9</td>
</tr>
<tr>
<td>24</td>
<td>154</td>
<td>19.0</td>
</tr>
<tr>
<td>25</td>
<td>188</td>
<td>20.0</td>
</tr>
<tr>
<td>26</td>
<td>245</td>
<td>21.1</td>
</tr>
<tr>
<td>27</td>
<td>262</td>
<td>22.1</td>
</tr>
<tr>
<td>28</td>
<td>357</td>
<td>23.1</td>
</tr>
<tr>
<td>29</td>
<td>416</td>
<td>24.1</td>
</tr>
<tr>
<td>30</td>
<td>503</td>
<td>25.1</td>
</tr>
<tr>
<td>31</td>
<td>549</td>
<td>26.1</td>
</tr>
<tr>
<td>32</td>
<td>710</td>
<td>27.1</td>
</tr>
<tr>
<td>33</td>
<td>886</td>
<td>28.2</td>
</tr>
<tr>
<td>34</td>
<td>1296</td>
<td>29.1</td>
</tr>
<tr>
<td>35</td>
<td>262</td>
<td>30.1</td>
</tr>
<tr>
<td>36</td>
<td>512</td>
<td>30.9</td>
</tr>
<tr>
<td>37</td>
<td>1238</td>
<td>31.5</td>
</tr>
<tr>
<td>38</td>
<td>2938</td>
<td>32.1</td>
</tr>
<tr>
<td>39</td>
<td>4252</td>
<td>32.6</td>
</tr>
<tr>
<td>40</td>
<td>3894</td>
<td>32.9</td>
</tr>
<tr>
<td>41</td>
<td>1839</td>
<td>33.3</td>
</tr>
</tbody>
</table>

a GA in completed weeks.

b n = sample size at each GA, after exclusions.

for boys and girls versus the unisex Lubchenco et al curves are presented in Supplemental Fig 6 A and B. The classification of current reference curves using the Lubchenco et al curves (Supplemental Table 5) showed a significant proportion of GAs $\geq$32 weeks with a small HC (SHC) and of GAs $\leq$36 weeks with a large HCs (LHC) classified as having an appropriate HC (AHC) for GA (32% to 87% misclassification). For 38 weeks of gestation and older, Lubchenco et al’s 50th percentile tended toward the CNN-MOND 10th percentile (Supplemental Fig 6 A and B).

Comparison With Usher and McLean (Montreal, Canada, 1959–1963)

The unisex Usher and McLean6 curves were generated from 300 infants born in 1959 to 1963. A comparison of birth weight CNN-MOND curves versus Usher and McLean curves are presented in Supplemental Fig 7 A (boys) and B (girls). With regard to HC, differences between these unisex curves were present for boys mainly for values at +2 SDs from the mean, where current measures were higher than Usher and McLean’s throughout GAs (Supplemental Fig 8A). In girls, the HC curves were similar, except our +2 SD values were lower, particularly at GAs of $\geq$37 weeks (differences ranged between 0.6 and 0.7 cm) (Supplemental Fig 8B). The classification of current references using the Usher and McLean curves (Supplemental Table 6) shows a significant proportion of all SHC and LHC infants.
classified as AHC (26% to 74% misclassification).

**Comparison With Blidner et al (Hamilton, Canada; 1974–1975)**

Blidner et al’s growth curves were developed from a random sampling of 1231 infants in Ontario, Canada, in 1974 to 1975, and present unisex HC values for GAs of ≥31 weeks and gender-specific values for GAs ≥36 weeks. Our proposed reference matches closely with Blidner et al’s, with differences of ≤0.5 cm at all percentiles for boys and girls (Supplemental Table 4).

**Comparison With Fenton (Sweden, Australia; 1977–1995)**

In 2003 Fenton published practical growth curves that assembled on 1 sheet Canadian birth weight curves (from Kramer et al) and HC curves generated by combining Swedish and Australian databases. Comparisons of current HC curves with Fenton’s are presented in Fig 5 A (boys) and B (girls). Current HC values for boys at the 90th percentile were higher overall (Supplemental Table 4). This finding was particularly apparent at GAs of 23 to 28 and 33 to 37 weeks (differences ranged between 0.6 and 1.3 cm). At the 50th percentile (median), our proposed reference was closer but still higher than Fenton’s (differences ranged between 0.5 and 0.9 cm at weeks 33–38).
and tended to converge at 39 weeks. At the 10th percentile, current values were higher from 33 weeks and older (differences ranged between 0.6 and 1.1 cm). For girls (Supplemental Table 4), our and Fenton’s curves were similar (differences <0.5 cm), except that our 10th percentile values were lower at GAs <28 weeks (differences estimated on the published curves ranged between 0.7 and 0.8 cm). The classification of current reference using the Fenton curves (Supplemental Table 6) showed a significant proportion of 32 to 36 and 37 to 41 GA weeks SHC and of 37 to 41 GA weeks LHC infants classified as AHC (26% to 41% misclassification).

**Comparison With Olsen et al (Multiple Sites, United States; 1998–2006)**

Two trends emerged when we compared current curves with Olsen et al10 (Fig 5). For both genders, HC values were consistently higher than Olsen et al’s at the 90th percentile (differences ranged between 0.6 and 1.4 cm) for GAs younger than ∼31 weeks (Supplemental Table 4). The 50th percentile of current curves and Olsen et al’s curves overlapped. For the 10th percentile, current HC measures were higher for GAs >32 weeks (differences ranged between 0.5 and 1 cm). The classification of current references using the Olsen et al curves (Supplemental Table 6) showed a significant proportion of 32 to 36 (41%) and 37 to 41 (66%) GA weeks SHC infants misclassified as AHC.

**DISCUSSION**

We have produced a set of new, up-to-date reference curves for HC at birth that were based on a large Canadian population, are gender-specific, and are valid for births between 23 and 41 weeks’ gestation. Overall, measures in boys were higher than in girls. We also note that Canadian newborn HCs at the 10th and 90th percentiles differed from recent North American US references.

For the development of these curves, we merged 2 complementary databases to achieve a good sample size of both preterm and term neonates: the CNN database, which comprises most of the NICUs in Canada, and the MOND database of a tertiary care maternity hospital in a large urban center (Montreal, Quebec, Canada). We verified our methodology by plotting birth weight curves on the basis of our combined data and comparing them with the reference charts of Kramer et al,12 which were based on a 1994 to 1996 Canadian (except for Ontario) population study. We then generated HC curves and compared them with existing charts with specific attributes: historic (Lubchenco et al,14 Usher and McLean,6 and Blidner et al15), frequently used (Fenton7), and recent (Olsen et al10).

One particular advantage of our reference curves is that they were based on the population of a single country that is relatively affluent and with free access to prenatal care. The importance of a geographical link between optimal birth weight and lowest perinatal and neonatal mortality was revealed by the EuroNatal Working Group.16 The same would be expected to hold true for HC. The second advantage is that our data for preterm births under 35 weeks’ gestation dated from 2003 to 2007, which was recent enough to reflect some of the latest advances in the rapidly changing field of perinatology17 and can be related to the recent birth weight curves. The third advantage is the better GA assessment of the current cohort compared with those of historical curves.

**FIGURE 5**

Reference curves (10th, 50th, and 90th percentiles) for HC at birth by GA by using combined CNN-MOND data (see Methods; black lines) compared with reference curves from Fenton7 (long dashed lines) and from Olsen et al10 (dotted dashed lines) for boys (A) and girls (B).
Another major strength of our HC reference curves is the large number of very preterm births included in the database, which was an order of magnitude greater than that of any other HC curve based on a Canadian population (Fig 1). Of the other HC curves currently in use in Canada, those of Fenton7 were based on a non-Canadian population and those of Olsen et al10 on a US population. Our large sample allowed for the segregation of preterm births by gender, a major determinant of fetal growth.18,19

Except for Blidner et al15 at the higher GAs (with which our values matched well) and Olsen et al,10 none of the other curves were gender-specific. The reference curves proposed by the current study indeed showed higher measures of HCs in boys versus girls, as also observed for birth weight. Overall, when comparing our HC curves with recent others, we noted 2 major trends, both of which were seen more particularly in boys: a consistent upward shift in the 90th percentile at most GAs and an overall upward shift at the 10th percentile starting at 34 weeks. When classifying current data according to <10th, 10th to 90th, and >90th percentiles of other published curves, a significant underestimation of infants with HCs <10th percentile was particularly present with all comparison curves, both historical6,14 and more recent.7,10

It has been suggested that birth weight has been steadily increasing in developed countries, including in the Canadian population.20,21 Current CNN-MOND birth weight curves differed little from the previous Canadian reference curves that date from the mid-1990s; this finding could be due to a “slowing” of increasing birth weights in newborns or to the fact that not enough years separated the 2 study periods to unravel differences (MOND data used for the current study and Kramer et al12 data overlap for the years 1995–1996). Increases in birth weight could reflect increases in average weight and incidence of overweight in the population, rather than “improved” overall fetal growth and health resulting from improved life habits (less smoking) and improved prenatal obstetric care: HC data, in addition to birth length, would be essential to study these possibilities. However, birth lengths and HC are not variables currently collected in most administrative birth registries. Indeed, most recent Canadian neonatal anthropometric curves concerned only birth weight.12,22 Length data in newborns are a measure with high interobserver variability if not realized with the use of a well-calibrated and reproducible procedure; however, HC has a lower inter- and intraobserver variability.23,24

HC curves, like weight curves, can be based on longitudinal or cross-sectional measurements. Intrauterine growth charts (based on measurements made by ultrasound examination either cross-sectionally or longitudinally) represent the whole population of healthy pregnancies as well as those at risk of premature delivery.25 Nevertheless, ultrasound assessments remain less precise than direct measures taken on the infant; and growth charts based on measures taken at birth (ie, cross-sectional) of infants of all GAs remain an important reference for clinicians in the evaluation of size for GA at birth. For preterm infants, however, these curves do not well represent, by definition, growth through a normal pregnancy because a preterm delivery may reflect an underlying pathologic pregnancy. Preterm infants are more likely to suffer from intrauterine growth restriction or other health issues compared with fetuses who remained in utero.26–28 Despite these limitations, growth charts based on direct measures taken at birth, such as the ones produced in the current study, are used in most NICUs to assess size at birth as well as to monitor growth up to term.

The identification of infants with SHC for GA is an important element for the complete assessment of a newborn and for the determination of specific investigations as well as medical and neurodevelopmental follow-up requirements. With the historical and the more recent curves, a number of newborns in the current cohort would be classified with an appropriately grown HC when in fact it is below the 10th percentile, and would therefore not be identified for additional medical attention.

One limitation of our study stemmed from the fact that the MOND database (data for the 35–41 weeks) was single site. However, this limitation was offset by the sheer number of patients in the database (close to 30 000 after exclusions), the multiethnic nature of the Montreal population, and by comparing birth weight for the GAs taken from MOND with data published by Kramer et al.12 Another limitation came from the fact that the CNN was based on neonates who were admitted to NICUs and that therefore a selection bias could be suspected. Indeed, this database did not include stillbirths and deaths in the delivery room, but these represent a very small proportion of newborns. Some late preterm infants (33–34 weeks) might not be automatically admitted in all of the NICUs; however, the comparison of the birth weight in Kramer et al’s population-based curves revealed that this bias was unlikely.

CONCLUSIONS

The current study presents recent and gender-specific HC curves. These Canadian newborn HCs showed some differences compared with recent North American US references. To accurately
acknowledge fetal growth and overall newborn population health, complete anthropometric measures are required, including birth HC and length.

ACKNOWLEDGMENTS

Site investigators of the Canadian Neonatal Network are as follows: Shoo K. Lee, Director, Canadian Neonatal Network and MiCare Research Centre; Prakash S. Shah, Associate Director, MiCare Research Centre, and site investigator Mount Sinai Hospital, Toronto, ON; Wayne Andrews (Janeway Children’s Health and Rehabilitation Centre, St John’s, NL); Barbara Bullied (Everett Chalmers Hospital, Fredericton, NB); Rody Canning (Moncton Hospital, Moncton, NB); Ruben Alvaro (St Boniface General Hospital, Winnipeg, MB); Kimberly Dow (Kingston General Hospital, Kingston, ON); Michael Dunn (Sunnybrook Health Sciences Centre, Toronto, ON); Suzanne Ferland (Hôpital St François d’Assise, Quebec City, QC); Adele Harrison (Victoria General Hospital, Victoria, BC); Andrew James (Hospital for Sick Children, Toronto, ON); Zarin Kalapesi (Regina General Hospital, Regina, SK); Lajos Kovacs (Jewish General Hospital, Montreal, QC); Jean Lachapelle (Hôpital Maisonneuve-Rosemont, Montreal, QC); David S.C. Lee (St Joseph’s Health Centre, London, ON); Francis Lefebvre (CHU Ste-Justine, Montreal, QC); Douglas D. McMillan (IWK Health Centre, Halifax, NS); Cecil Ojah (St John Regional Hospital, St. John, NB); Abraham Pelowski (Royal Alexandra Hospital, Edmonton, AB); Bruno Piedboeuf (Centre Hospitalier Universitaire de Québec, Sainte Foy, QC); Patricia Riley (Montreal Children’s Hospital, Montreal, QC); Royal Victoria Hospital, Montreal, QC; Nicole Rouvinz- Bouali (Children’s Hospital of Eastern Ontario, Ottawa, ON); Koravangattu Sankaran (Royal University Hospital, Saskatoon, SK); Mary Seshia (Health Sciences Centre, Winnipeg, MB); Sandesh Shivananda (Hamilton Health Sciences Centre, Hamilton, ON); Todd Sorokan (Royal Columbian Hospital, New Westminster, BC); Anne Synnes (Children’s and Women’s Health Centre of British Columbia, Vancouver, BC); Herve Walti (Centre Hospitalier Universitaire de Sherbrooke, Fleurimont, QC); and Wendy Yee (Foothill’s Hospital, Calgary, AB).

We thank the MiCare Research Centre, Mount Sinai Hospital, Toronto, Canada, for hosting the Canadian Neonatal Network database and for providing administrative and statistical support for this project. The MiCare Research Centre was funded by the Canadian Institutes of Health Research and the Ontario Ministry of Health and Long-Term Care. We thank the parents of newborns admitted to participating Canadian Neonatal Network centers (for sites and site investigators, see above) and the parents of infants born at the Royal Victoria Hospital, Montreal, Canada. We are grateful to Danielle Buch, medical writer/editor at the Applied Clinical Research Unit of Sainte-Justine University Hospital and Research Centre, for the translation, revision, and editing of the manuscript.

REFERENCES

10. Olsen IE, Grovenman SA, Lawson ML, Clark RH, Zemel BS. New intrauterine growth curves based on United States data. Pediatrrics. 2010;125(2): Available at: www.pediatrics.org/cgi/content/full/125/2/e214
New Reference Curves for Head Circumference at Birth, by Gestational Age
Alexandre Barbier, Ariane Boivin, Woojin Yoon, Danielle Vallerand, Robert W. Platt, François Audibert, Keith J. Barrington, Prakesh S. Shah, Anne Monique Nuyt and the Canadian Neonatal Network
Pediatrics; originally published online March 18, 2013;
DOI: 10.1542/peds.2011-3846

Updated Information & Services
including high resolution figures, can be found at:
/content/early/2013/03/12/peds.2011-3846

Supplementary Material
Supplementary material can be found at:
/content/suppl/2013/03/12/peds.2011-3846.DCSupplemental.html

Citations
This article has been cited by 4 HighWire-hosted articles:
/content/early/2013/03/12/peds.2011-3846#related-urls

Permissions & Licensing
Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at:
/site/misc/Permissions.xhtml

Reprints
Information about ordering reprints can be found online:
/site/misc/reprints.xhtml

PEDIATRICS is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. PEDIATRICS is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 2013 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 0031-4005. Online ISSN: 1098-4275.

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN™
New Reference Curves for Head Circumference at Birth, by Gestational Age
Alexandre Barbier, Ariane Boivin, Woojin Yoon, Danielle Vallerand, Robert W. Platt, François Audibert, Keith J. Barrington, Prakash S. Shah, Anne Monique Nuyt and the Canadian Neonatal Network
Pediatrics; originally published online March 18, 2013;
DOI: 10.1542/peds.2011-3846

The online version of this article, along with updated information and services, is located on the World Wide Web at:
/content/early/2013/03/12/peds.2011-3846