Objective: To produce representative cross-sectional blood pressure reference centiles for children and young people living in Great Britain.


Methods: Blood pressure was measured using the Dinamap 8100 with the same protocol throughout. Weight and height were also measured. Data for 11,364 males and 11,537 females aged 4–23 years were included in the analysis, after excluding 0.3% missing or outlying data. Centiles were derived for systolic, diastolic, mean arterial and pulse pressure using the lambda-mu-sigma (LMS) equations method.

Results: Blood pressure in the two sexes was similar in childhood, rising progressively with age and more rapidly during puberty. Systolic pressure rose faster and was appreciably higher in adult men than in adult women. After adjustment for age, blood pressure was related more to weight than height, the effect being stronger for systolic blood pressure. Pulse pressure peaked at 18 years in males and 16 years in females.

Conclusions: These centiles increase our knowledge of blood pressure norms in contemporary British children and young people. High blood pressure for age should be defined as blood pressure above the 98th centile, and high-normal blood pressure for age as blood pressure between the 91st and 98th centiles. The centiles identify children and young people with increased blood pressure, and will be of benefit to both clinical practice and research.

Abbreviation: SDS, standard deviation score
pressure data for 22 901 participants, 11 364 male and 11 537 female, aged 4–23.9 years were analysed.

Sex-specific smoothed centiles were derived using the lambda-mu-sigma (LMS) method for age and sex. The LMS method summarises the age-changing frequency distribution of blood pressure in terms of three curves: the L curve defines the skewness, the M curve the median and the S curve the coefficient of variation as functions of age. Centile charts were drawn with centiles spaced two-thirds of an SD score (SDS) apart, ranging from the 0.4th centile (−2.67 SDS) through to the 99.6th centile (+2.67 SDS), consistent with other anthropometric charts in current use in the UK.

The relationship of systolic and diastolic blood pressure, weight and height was investigated through the multiple regression of blood pressure on weight and height, after adjusting the three variables for age and sex by converting them to SDS. The British 1990 reference was used for height and weight, and the internal reference for blood pressure. For measuring weight and height in subjects age >23 years was taken as 22.99 (the upper limit of the British reference). Sex effects were tested for in the regression by including sex and its interactions with height and weight.

RESULTS
Table 2 summarises the data for 22 901 participants with both systolic and diastolic blood pressure. Mean arterial pressure, height and weight were missing for 8%, 1% and 2% of participants, respectively. By year of age the sample consisted of 114 participants aged 4 years, 1181–1581 per year between 5 and 16 years, and 715–950 per year between 17 and 23 years. Height was very similar to the British 1990 reference (mean SDS 0.0), while weight and body mass index (weight (kg)/height2 (m2)) were slightly increased (mean SDS 0.3–0.4).

The data were used to construct blood pressure centile charts for systolic, diastolic, mean arterial and pulse pressure (figs 1–4). Blood pressure in the two sexes was similar before puberty, but the pubertal rise was more marked in boys. Pulse pressure peaked at 18 years in male participants and at 16 years in female participants, corresponding to the end of puberty.

Table 3 summarises the multiple regression of blood pressure on weight and height, each adjusted for age and sex by

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Table 1 Demographic characteristics of 22 974 participants aged 4–23.9 years from seven national health and social surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>Year</th>
<th>England</th>
<th>Scotland</th>
<th>Wales</th>
<th>Age range (years)</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health Survey for England</td>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td>5–23</td>
<td>3485</td>
</tr>
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<td>Health Survey for England</td>
<td>1996</td>
<td></td>
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<td>5–23</td>
<td>4198</td>
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<tr>
<td>Health Survey for England</td>
<td>1997</td>
<td></td>
<td></td>
<td></td>
<td>4–23</td>
<td>3756</td>
</tr>
<tr>
<td>Scottish Health Survey</td>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td>16–23</td>
<td>707</td>
</tr>
<tr>
<td>Scottish Health Survey</td>
<td>1998</td>
<td></td>
<td></td>
<td></td>
<td>5–23</td>
<td>3043</td>
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<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22 974</td>
</tr>
</tbody>
</table>

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Table 2 Summary statistics for 22 901 participants with valid data

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men (%)</td>
<td>22 901</td>
<td>49.6</td>
<td>—</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22 901</td>
<td>13.1</td>
<td>5.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>22 676</td>
<td>148.9</td>
<td>21.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>22 485</td>
<td>46.4</td>
<td>19.9</td>
</tr>
<tr>
<td>Height SDS (British 1990)</td>
<td>22 676</td>
<td>-0.03</td>
<td>1.08</td>
</tr>
<tr>
<td>Weight SDS (British 1990)</td>
<td>22 485</td>
<td>0.27</td>
<td>1.14</td>
</tr>
<tr>
<td>Body mass index SDS (British 1990)</td>
<td>22 425</td>
<td>0.36</td>
<td>1.11</td>
</tr>
</tbody>
</table>

SDS, standard deviation score.

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Figure 1 Systolic blood pressure centiles in male (A) and female participants (B). The centiles are spaced two-thirds of a standard deviation score apart. Systolic pressure rises progressively with age, but rises more steeply in puberty, particularly in boys.
converting to SDS. This adjustment allowed the data for both sexes and all ages to be combined. Results are also given by sex, although they do not differ significantly; hence the combined results are valid. Weight had a large and positive effect on blood pressure (p < 0.001), whereas height had a smaller negative effect (0.005 < p < 0.001). A 1 SD increase in weight was associated with a 0.3 SD increase in systolic pressure and a 0.08 SD increase in diastolic pressure, whereas a 1 SD increase in height was associated with a 0.03 SD reduction in both systolic and diastolic pressure. Thus, on average, for any given weight, a taller (and hence thinner) individual had lower blood pressure. Analysing the data in separate age groups showed the associations in late puberty to be stronger than before or after.

These results suggest that body size (ie, weight) and obesity (weight adjusted for height) both play a role in raising blood pressure, particularly systolic blood pressure, 8% of the variation of which was explained by weight and height. The effect on diastolic blood pressure (0.5% of variance explained) was much smaller.

Using the British Hypertension Society cut-offs for hypertension, 23% of men and 6% of women exceeded the systolic cut-off, and 1.0% of men and 0.8% of women exceeded the diastolic cut-off by age 24 years.

**DISCUSSION**

The blood pressure centiles presented here are based on data collected using a consistent and rigorous method in representative samples of nearly 23 000 children and young people living in Great Britain. As such, we believe they are the most accurate characterisation of normal blood pressure in any country to date.

It is well recognised that children’s blood pressure tends to "track" over time. Moreover, high blood pressure in children is associated with the development of atherosclerosis, especially in those with additional risk factors, notably obesity. The charts will aid the timely recognition and monitoring of individuals with high blood pressure and hypertension, and facilitate the detection of children with secondary hypertension, consequent on renal, endocrine or other disease. Blood pressure monitoring is also important in children at risk of hypertension and/or vascular disease, such as those with obesity, diabetes, renal disease, or those receiving...
steroids or stimulant drugs and where a family history of hypertension is present.

We have used a standard nine-centile format consistent with other charts in use in the UK.7 The charts show a progressive rise in systolic and diastolic pressure with increasing age, the rise being more marked in males during puberty. This is consistent with an effect of body size (indicated by weight) and obesity (weight adjusted for height) on blood pressure, the effect being stronger for systolic blood pressure. Thus males, who gain more weight at puberty than females, have significantly higher blood pressures, with almost a quarter satisfying the British Hypertension Society definition of hypertension,1 defined as systolic pressure >140 mm Hg and/or diastolic pressure >90 mm Hg, by the age of 24 years. The high systolic pressures in older teenagers and young adults, particularly men, are of special concern. However, blood pressure measurements on a single occasion are insufficient for the determination of high or high-normal blood pressure for age,21 22 in the absence of evidence of a pathological cause or end organ damage, especially in children, who are more prone to “white coat” hypertension.23 Repeated measurements typically show that the majority of children with increased blood pressure on a single occasion subsequently have normal blood pressure.24

Pulse pressure25 26 and mean arterial pressure27 have been found to be significant determinants of morbidity and mortality in adults. The significance of these measures in children is unknown, but pulse pressure may be an indicator of early arterial disease, as has been found in young adults with type 1 diabetes.27 Of note, we found that pulse pressure peaks at the end of puberty in both sexes, before falling in young adult life (fig 4) in contrast with systolic, diastolic and mean arterial pressures, which rise progressively with age (figs 1–3). A knowledge of normal ranges for pulse pressure and mean arterial pressure should aid research in this area.

The use of oscillometric blood pressure measurements was dictated by the nature of the health and social surveys, which required a reliable, reproducible and accurate method for determining blood pressure, using multiple observers.34 The Dinamap 8100 was subject to a rigorous calibration study3 to ensure its validity (although the calibration study did not include participants aged <16 years). However, the Dinamap monitor has been compared with direct radial artery pressure and central aortic pressure measurements in infants and children and was found to be superior to the auscultatory method.28 29 Moreover, particularly in young children, the conventional mercury sphygmomanometer can be difficult to use,42 0 with the Korotkoff sounds hard to distinguish, so, increasingly, automated oscillometric devices are being used in clinical practice.30

O’Brien et al31, using the British Hypertension Society protocol, graded the Dinamap 8100 B for systolic blood pressure and D for diastolic blood pressure compared with the conventional mercury sphygmomanometer in adults.32 Paediatric studies have generally found significant differences, particularly between diastolic pressure assessed by fourth-phase Korotkoff sounds.33–35 However, an Australian study of prepubertal children with type 1 diabetes using the British Hypertension Society protocol graded the Dinamap B for both systolic and diastolic pressure.36

The Dinamap 8100 and other oscillometric devices produce results that differ in comparison with the mercury sphygmomanometer. These differences have been attributed to

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**Figure 4** Pulse pressure centiles in male (A) and female participants (B). The centiles are spaced two-thirds of a standard deviation score apart. Pulse pressure rises progressively until the end of puberty and then falls again.

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**Table 3** Relationship of systolic and diastolic blood pressure with weight and height by sex (all variables expressed as standard deviation score)

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Sex</th>
<th>n</th>
<th>Weight (SDS)</th>
<th>Height (SDS)</th>
<th>$R^2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic blood pressure (SDS)</td>
<td>Men</td>
<td>11 153</td>
<td>0.279 (0.011)</td>
<td>0.033 (0.011)</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>11 272</td>
<td>0.258 (0.010)</td>
<td>0.039 (0.010)</td>
<td>7.6</td>
</tr>
<tr>
<td>Diastolic blood pressure (SDS)</td>
<td>Combined</td>
<td>22 425</td>
<td>0.268 (0.007)</td>
<td>0.035 (0.008)</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>11 153</td>
<td>0.070 (0.011)</td>
<td>0.033 (0.012)</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>11 272</td>
<td>0.081 (0.010)</td>
<td>0.032 (0.011)</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>22 425</td>
<td>0.076 (0.008)</td>
<td>0.033 (0.008)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

SDS, standard deviation score. The table gives regression coefficients (SEs).
What is already known on this topic

- Blood pressure rises through childhood and childhood blood pressure strongly predicts adult blood pressure.
- This rise in blood pressure is substantially determined by weight.
- As with growth, blood pressure is an important parameter of child health.
- Furthermore, atherosclerosis and hypertension may have their origins in childhood, particularly in those with additional risk factors—for example, obesity, renal disease or diabetes.

What this study adds

- These blood pressure centiles compiled from nationally representative data are the most comprehensive attempt to characterise normal blood pressure in childhood in Great Britain.
- The centiles complement existing charts for height, weight and body mass index and other parameters in evaluating the health of children.
- This information will contribute to a better understanding of blood pressure in childhood and aid further research.

inaccuracies but simply reflect the fact that different methods yield different results. However, in view of these differences, blood pressure results recorded with the mercury sphygmomanometer should be referenced to these centiles with caution.

ACKNOWLEDGEMENTS

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REFERENCES

A 7-year-old boy presented to paediatrics with a 3-week history of a worsening facial rash, which was intermittently itchy. He was otherwise well. He had two guinea pigs as pets. On examination, an extensive scaling erythema was noticed with a definite edge involving the upper eyelids, the bridge of the nose and extending onto both cheeks (see fig 1).

A provisional diagnosis of tinea faciei was made; however, cutaneous lupus was also considered. While mycology results were awaited, topical terbinafine was given, with little effect. Microscopy revealed a dermatophyte infection with _Trichophyton mentagrophytes_, and a 3-week course of oral terbinafine (125 mg oral dosage once daily) was given. The rash resolved completely, leaving post-inflammator hyperpigmentation only.

Tinea facialis/faciei is a dermatophytosis of the glabrous facial skin, characterised by a well-circumscribed, often asymmetric, erythematous patch with an elevated border and central regression. It may be asymptomatic or present with pruritus, or, occasionally, photosensitivity that may lead to diagnostic confusion with cutaneous lupus. It is the most commonly misdiagnosed dermatophytosis. Other differential diagnoses include eczema, seborrhoeic dermatitis and rosacea. It is most common in children, with predisposing factors including exposure to animals, chronic topical steroid use and spread from tinea capitis. The most frequent organisms involved are _T mentagrophytes_, _T rubrum_ and _T tonsurans_. However, cases caused by _Microsporum audouini_ and _M canis_ occur worldwide. Most cases are given short-term oral antifungal treatment, but milder cases may respond to topical imidazoles. Affected animals and family members should also be treated.

**REFERENCES**