Objective: To define, in a group of children with nasal obstruction, the anatomical differences that differentiate those with quiet, unobstructed nocturnal respiration from those with obstructive sleep-related breathing abnormalities (snoring and obstructive sleep apnea).

Design: Case series.

Patients: Fifty-nine children aged 3 to 13 years (35 boys and 24 girls) with nasal obstruction and without tonsillar hypertrophy, known craniofacial syndromes, or neuromuscular diseases were included in the study.

Main Outcome Measures: Each patient was categorized as to severity of nocturnal obstructive breathing symptoms. Angular and linear cephalometric measurements were used for assessment of craniofacial features. Clinical symptom scores were correlated with the cephalometric measurements.

Results: Significant craniofacial abnormalities were identified in patients prone to obstructive breathing patterns: increased flexure of the cranial base and bony nasopharynx, opening of the gonial angle, shortened mandibular length, dorsocaudal location of the hyoid, reduced posterior airway space, and increased velar thickness.

Conclusions: A number of anatomical abnormalities may contribute to sleep-related abnormal breathing in otherwise normal children with nasal obstruction. Our results suggest that symptomatic children show some of the same skeletal and soft-tissue configurations that are found in adults with obstructive sleep apnea. While adenoidectomy is generally an effective treatment in children with obstructive sleep-related breathing abnormalities, the underlying craniofacial variances that remain after adenoidectomy may predispose these patients to redevelopment of obstructive breathing abnormalities in adulthood.

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MANIFESTATIONS of upper airway obstruction are common in children. An estimated 12% of children exhibit habitual snoring,1 and about 1% suffer from obstructive sleep apnea.2 Snoring and other sleep-related breathing abnormalities (SRBAs) may be associated with deleterious effects, including impaired daytime psychomotor performance, enuresis, hyperactivity, and poor sleep quality.1,3,4 Several predisposing anatomical and physiologic factors have been identified in children with SRBAs. These include localized sites of narrowing in the upper airways, neuromuscular disorders, and major craniofacial abnormalities, such as Stickler syndrome, Crouzon syndrome, Treacher Collins syndrome, and Pierre Robin syndrome.

The broadest subset of children with SRBAs comprises those with obstructive adenotonsillar hypertrophy. Children with adenoidal hypertrophy have nasal obstruction with consequent chronic mouth breathing. However, some of these children present with mouth breathing as an isolated manifestation, while others develop SRBAs of varying severity, from snoring to obstructive sleep-disordered breathing. In most of these children, snoring and SRBAs are cured if the obstruction of the nose is removed, usually by adenoidectomy. In our experience and according to reports in the literature, parents report that, after surgical treatment, “they now have a different child” who is more alert and active in all respects.5

It is not yet known why some children with obstructive adenoidal hypertrophy develop SRBAs while others with identical nasal obstruction remain otherwise asymptomatic chronic mouth breathers. A lack of correlation between adenoid size and severity of apnea has also been docu-
PATIENTS AND METHODS

PATIENTS

Fifty-nine healthy children ranging in age from 3 to 13 years (mean ± SD, 8.6±3.1 years) were included in this study. There were 35 boys and 24 girls. Forty-six patients selected had nasal obstruction caused by adenoid hypertrophy and 3 patients had obstructions caused by severe chronic rhinitis with symptoms persisting at least 3 months. Exclusion criteria were tonsillar enlargement, personal or family history of neuromuscular disorder or craniofacial syndrome, and obesity.

METHODS

The determination of obesity was made according to pediatric growth charts. A thorough history was recorded for each patient following a structured interview format applied in a consistent fashion. Each patient was accordingly classified as to level of obstructive symptom severity:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Symptoms</th>
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<tbody>
<tr>
<td>0</td>
<td>Oral breathing with no snoring</td>
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<tr>
<td>1</td>
<td>Mild snoring or snoring only while sleeping on back</td>
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<tr>
<td>2</td>
<td>Habitual snoring in all positions</td>
</tr>
<tr>
<td>3</td>
<td>Habitual snoring associated with a history of mild to moderate apnea and/or restless sleep</td>
</tr>
<tr>
<td>4</td>
<td>Habitual snoring associated with a marked clinical presentation of apnea and restless sleep</td>
</tr>
</tbody>
</table>

Ears, nose, and throat examination was performed with special attention to mouth breathing, daytime loud oral breathing during wakefulness, adenoidal face (ie, long face), steep mandibular planes, and receding chin (Figure 1).

In addition, special attention was paid to malocclusion, mainly anterior open bites and overjet of the maxillary incisors.

Lateral cephalometric radiographs were obtained for all subjects. For 38 patients, the radiographs were taken in an authorized laboratory. Standard technique was employed: The patients were instructed to fix their distant gaze on an imaginary horizon to reproduce their habitual occlusion, with the lips together, and to allow the tongue to relax in the floor of the mouth. Exposures were taken with the patient slowly exhaling through the nose. Exposures were optimized to demonstrate both the bony landmarks and the superimposed soft tissues. For the remaining 21 patients, the cephalometric measurements were made from lateral head radiographs. To allow correction for projection enlargement of the linear measurements, these radiographs were made with a 10-mm round steel median calibration marker in place. The head was oriented in the Frankfurt plane.

The cephalometric landmarks, angles, and linear measurements are defined in Table 1 and shown in Figure 2.

STATISTICAL ANALYSIS

Mean ± SEM was calculated for each variable at each level of symptom severity. Correlation coefficients were determined by the Pearson method for the associations between the cephalometric variables and symptom severity. The Pearson correlation method was also used to test the relationships of the craniofacial variables with age and the relationships of each craniofacial variable with the others. Analysis of variance was used to determine statistically significant differences of individual cephalometric variables at each level of symptom severity. Between-sex differences were tested by independent t test.

Cephalometric analysis has been used to characterize skeletal and soft tissue relationships in adults with SRBAs. Cephalometry can provide extensive data on the landmarks pertinent to the upper airways. However, correlative data between cephalometric parameters and children with SRBA symptoms are sparse. Therefore, we studied a series of children with chronic nasal obstruction without tonsillar hypertrophy, without any known craniofacial anomaly, and without hypotonia or neuromuscular disease.

Our hypothesis is that specific anatomical patterns correlate with obstructive symptom severity in children with nasal obstructions. The present study was designed to define the anatomical markers by craniofacial cephalometric evaluation of nonsyndromic young patients who develop SRBAs in the presence of nasal obstruction. This is one component of our research program on development of a general structural analytic model of sleep-related upper airway obstruction.

RESULTS

The summary of patient clinical data for each symptom severity level is given in Table 2. A clear increase in likelihood of adenoid facies (Figure 1) and audible mouth breathing during wakefulness is noted with higher level...
els of sleep-related obstructive breathing. Thirty-one pa-
tients underwent adenoidec- tomy, and obstructive breath-
ing was relieved in all patients. However, 3 patients had
residual mild snoring after adenoidec-
tomy.

Correlations between symptom severity and indi-
vidual cephalometric measurements are given in Table 3.
Decreasing cranial base angles (BaSN [angle formed by
the intersection of lines drawn from the nasion to the sella
and from the sella to the basion] and BaSPNS [angle
formed by the line connecting the basion, sella, and pos-
terior nasal spine]) (compare Figure 3 with Figure 4)
were found to correlate with increasing levels of obstruc-
tive symptoms. The BaSN was found to be 5.3° smaller
in patients with severe obstructions than in asymptom-
atic patients, a statistically significant difference. Simi-
larly, the BaSPNS was an average of 5° smaller in the se-
verely affected group, indicating nasopharyngeal
narrowing. Increased gonial angle (ArGoGn) and hyoid
angle (GnGoH) were associated with higher symptom se-
verity scores (compare Figures 3 and 4). Protrusion of
the maxilla (SNA [angle from the sella to the nasion to
the subspinal point]) and mandible (SNB [angle from the
sella to the nasion to the supramental point]) did not cor-
relate with patient symptom severity.

The length of the mandibular plane (GnGo) and the
minimal posterior airway space (MPAS) were inversely
correlated with symptom levels. Mean mandibular short-
ening of 8.4 mm was found in the level-4 group com-
pared with level 0. Decreasing MPAS was significantly
correlated with increasing severity of obstruction; the pa-
tients with the most severe obstructions exhibited a mean
MPAS less than 10 mm, in contrast to 14.2 mm for the
asymptomatic group (Figures 3 and 4). Velar width tended
to be increased in patients with more pronounced symp-
toms, although the absolute difference was small, on the
order of a millimeter. Two derived measures, DTH/
GnGo (ratio between the dorsal tongue height and GnGo)
and MPH/GnGo (ratio between the distance from the man-
dibular plane to the hyoid and GnGo), were positively
correlated with worsening of symptoms.

Cross-correlation between cephalometric variables
demonstrated a number of statistically significant inter-
relationships (Table 4). With increasing age, GnGo and
DTH were increased. With decreasing BaSN, there was
a tendency of BaSPNS and GnGo to decrease and of SNA
and SNB to increase. With increasing GnGoH, there was
a tendency of MPH and GnGo to increase (Figures 3 and
4). With decreasing GnGo, there was a tendency of DTH
and GnGoH to increase.

The mean±SD age of the boys (7.8±3.0 years) was
significantly lower than that of the girls (10.1±2.6 years).
The boys (127.7°±5.5°) had a more acute BaSN than the
girls (130.4°±4.7°) and a more open ArGoGn
(132.9°±6.0°) than the girls (128.7°±6.3°).

In this study of children with SRBA, obstructive symp-
toms were found to correlate with the following cranio-
facial (and velolinguopharyngeal) differences demon-
strated by cephalometry: skull base angles (BaSN and
BaSPNS), GnGo and ArGoGn, hyoid position as given
by MPH and GnGoH, and MPAS at the level of the tongue
base. Some of these factors are directly interrelated, yet
each individually contributes a component of potential
upper airway compromise. These results are based on mul-
tiple statistical correlations and cannot directly prove
causal relationships. Individual statistically significant re-
Results are useful to the extent that they can be confirmed in subsequent studies and contribute to a coherent anatomical model of obstructed upper airway breathing. Cranial base components (BaSN and BaSPNS) are considered to be of primary importance in facial equilibrium and do not change greatly from childhood to adult form. Excessive flexure or relatively acute angulation of the skull base refers to a decreased BaSN measurement. We found that nearly all the reduction of BaSN in patients with severe obstructions was caused by re-

### Table 1. Definitions of Cephalometric Landmarks, Angles, and Measurements

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<td><strong>Landmarks</strong></td>
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<tr>
<td>A</td>
<td>Subspinal: the deepest point on the premaxillary outer contour between the anterior nasal spine and the central incisor</td>
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<tr>
<td>Ar</td>
<td>Posterior ramus plane: the intersection of a line along the posterior border of the mandible and the inferior border of the basilar occipital bone (basicranium)</td>
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<tr>
<td>ANS</td>
<td>Anterior nasal spine: the most anterior part of the nasal floor</td>
</tr>
<tr>
<td>B</td>
<td>Supramental: the deepest point on the outer contour of the mandible between the point of the chin and the incisor teeth</td>
</tr>
<tr>
<td>Ba</td>
<td>Basion: the midpoint of the anterior border of the foramen magnum</td>
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<tr>
<td>Gn</td>
<td>Gnathion: the most anterior point in the contour of the chin</td>
</tr>
<tr>
<td>Go</td>
<td>Gonion: the most posterior and inferior point on the convexity of the angle of the mandible</td>
</tr>
<tr>
<td>H</td>
<td>Hyoid: the most anterior-superior point on the body of the hyoid bone</td>
</tr>
<tr>
<td>N</td>
<td>Nasion: the sagittal junction of the frontal-nasal suture line</td>
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<tr>
<td>PNS</td>
<td>Posterior nasal spine: the most posterior part of the contour of the hard palate</td>
</tr>
<tr>
<td>S</td>
<td>Sella: the center of the hypophyseal fossa (sella turcica)</td>
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<td>DT</td>
<td>The highest point of the outline of the dorsum of the tongue</td>
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<tr>
<td><strong>Angles</strong></td>
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<tr>
<td>ArGoGn</td>
<td>Angle formed by the line connecting the articulate, gonion, and gnathion</td>
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<td>BaSN</td>
<td>Cranial base flexure: angle formed by the intersection of lines drawn from the nasion to the sella and from the sella to the basion</td>
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<tr>
<td>BaSPNS</td>
<td>Angle formed by the line connecting the basion, sella, and posterior nasal spine</td>
</tr>
<tr>
<td>GnGoH</td>
<td>Hyoid angle: angle formed by the line connecting the gnathion, gonion, and hyoid</td>
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<tr>
<td>SNA</td>
<td>Angle from the sella to the nasion to the subspinal point</td>
</tr>
<tr>
<td>SNB</td>
<td>Angle from the sella to the nasion to the supramental point</td>
</tr>
<tr>
<td>ANB</td>
<td>Angle from the subspinal point to the nasion to the supramental point</td>
</tr>
<tr>
<td>BaN-ANSPNS</td>
<td>Angle formed by the line connecting the nasion and basion (which we call the basal plan) and the line connecting the anterior nasal spine and the posterior nasal spine (which we call the palatal plan)</td>
</tr>
<tr>
<td>BaN-GnGo</td>
<td>Angle formed by the basal plan and the line connecting the gnathion and the gonion (which we call the mandibular plan)</td>
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<td><strong>Linear Measurements</strong></td>
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<tr>
<td>MPAS</td>
<td>Retrolingual posterior air space: the minimal distance (in millimeters) between the base of the tongue and the nearest point on the posterior pharyngeal wall</td>
</tr>
<tr>
<td>MPH</td>
<td>The distance between the mandibular plane and the hyoid</td>
</tr>
<tr>
<td>GnGo</td>
<td>The length of the mandibular plane</td>
</tr>
<tr>
<td>Uw</td>
<td>Maximal uvular width: the width of the uvula measured on cross-section at the widest point</td>
</tr>
<tr>
<td>MPH/GnGo</td>
<td>Relative hyoidal distance: the ratio between the hyoidal distance from the mandibular plane and the length of the mandibular plane</td>
</tr>
<tr>
<td>DTH/GnGo</td>
<td>Relative tongue height: the ratio between the tongue height and the length of the mandibular plane</td>
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</tbody>
</table>

**Figure 2.** The cephalometric landmarks, angles (left), and linear measurements (right) used in the present study. MP indicates mandibular plane. See Table 1 for expansions of additional abbreviations and definitions.
duction of the BaSPNS, which defines the bony limits of the nasopharyngeal space. Bacon et al noted a similar reduction of BaSPNS in adults with obstructive sleep apnea. They found that the reduction in BaSPNS was associated with decreased sagittal facial length, which they interpreted as facial and pharyngeal “compression.” Thus, it appears that acute angulation of the skull base is associated with posterior displacement of the facial skeleton and shortening of the anteroposterior dimensions of the pharynx. In addition, excessive cranial base flexure may play a role in the development of SRBA; the decreased operating length of the pharyngeal dilator muscles compromises their efficiency. It is well documented that adenoidectomy is effective in relieving snoring in children because it relieves nasopharyngeal obstruction. Therefore, it is interesting to note that 3 of our young patients who had some residual snoring after adenoidectomy all had excessive cranial base flexure (117°, 119°, and 119.5°) and reduction of the BaSPNS (45°, 50°, and 45°). These findings suggest that excessive flexure of the cranial base is a risk factor for incomplete clinical response to adenoidectomy.

We found no significant correlation between SNA or SNB and patient symptom severity scores. This is likely due to interdependence between BaSN and these measures of maxillary and mandibular protrusion. Future studies need to determine the compensation factor, which will be derived from BaSN, needed to establish norms for SNA and SNB.

The MPAS is another important measurement in the evaluation of patients with SRBA. In adults, uvulopalatopharyngoplasty failure has been shown to correlate with MPAS less than 1 cm. In our study of children, decrease in MPAS from a norm of 14 mm was associated with increased clinical symptoms. The most symptomatic children had an MPAS as low as 7 mm. We found that MPAS had a statistically significant correlation with ArGoGn and GnGo. In the children with a more obtuse ArGoGn and a shorter GnGo, the symptoms tended to be more pronounced. Since the genioglossus muscle has its origin at the internal surface of the anterior mandible, both shortening of the GnGo and an increase in the ArGoGn result in relative retrodisplacement of the tongue. Furthermore, these mandibular changes result in reduced protrusor mechanical efficiency of the genioglossus muscle, which could contribute to posterior airway obstruction, as the muscle tone is diminished during sleep.

Nasal obstruction induces mouth breathing, a characteristic of so-called adenoidal facies. Mouth breathing...
is associated with dorsocaudal rotation of the mandible about the temporomandibular joint. This mandibular repositioning in turn brings the origin of the genioglossus muscle into a more posterior and inferior position, with direct narrowing of the MPAS. Also, genioglossus protrusor mechanical efficacy may be reduced, as seen with an excessive ArGoGn or a shortened GnGo. These factors may explain the increased upper airway collapsibility documented by Meurice et al\textsuperscript{21} in mouth breathers. In other words, mouth breathing itself creates a propensity for pharyngeal airway narrowing and increased collapsibility. Thus, nasal obstruction of an acute or chronic nature can induce snoring and increases in apnea-hypopnea severity.\textsuperscript{22}

Inferoposterior (dorsocaudal) placement of the hyoid bone has repeatedly been shown to correlate with SRBA in both children\textsuperscript{5,13,14,17,18,24} and adults.\textsuperscript{5,13,14,17,18,24} In addition, in our study, MPH/GnGo and GnGoH were increased in patients with more severe obstructive symptoms. The overall effects of dorsocaudal hyoid placement include narrowing of the MPAS and decreased mechanical efficiency of the genioglossus muscle protrusor action. One reason children with SRBA are often found to sleep with extended-head postures\textsuperscript{14,25} may be to bring about elevation of the hyoid so as to relieve retrolingual airway obstruction.

There is a descent in hyoid position during life. A significant relationship was reported between age and the

**Figure 3.** Left, Cephalometric roentgenogram of a 15-year-old girl who underwent adenoidectomy at age 3 years and suffered from nasal obstruction because of severe rhinitis without snoring. All the craniofacial features are within the normal range. Note that the tongue is normally positioned and the velum rests on it. The facial morphologic characteristics are normal, and the lips are well balanced and competent at rest. She has a class I profile. Right, Cephalometric tracing and analysis. The reference contours, points, and lines used in the study are shown. Arrow indicates the competent lips. MP indicates mandibular plane; TB, tongue base. See Table 1 for expansions of additional abbreviations and definitions.

**Figure 4.** Left, Cephalometric roentgenogram of the girl shown in Figure 1, showing a posteriorly and inferiorly displaced tongue base and an acute cranial base combined with a dorsocaudal position of the hyoid. Note the anterior open bite, large overjet, steep mandibular plane, large gonial angle, overjet, and high, ogival hard palate. She has a class II profile: a normally positioned maxilla and a retropositioned mandible. Her lips are parted at rest, with the upper lip incompetent or nonfunctional. Right, Cephalometric tracing and analysis. Black arrows indicate shallow palatal arch and narrow mandibular arch. MP indicates mandibular plane; TB, tongue base. See Table 1 for expansions of additional abbreviations and definitions.
MPH during childhood,\textsuperscript{26} from childhood to adult-
hood,\textsuperscript{26-28} and during adult life.\textsuperscript{14,28} While in children the hyoid position is related to the development of the ling-
uomandibular complex, in adults, the dorsocaudal shift-
ing of the hyoid is probably accentuated by increased body weight.\textsuperscript{14} Those young patients with SRBA and a dorso-
caudally located hyoid, even if cured by adenoidec-
tomy, certainly may be at higher risk to develop SRBA in their adult life as body weight increases.

Children are usually respond well to adenoidectomy, in contrast to adults, in whom relief from nasal ob-
struction is markedly less successful in curing SRBA. We believe that SRBA develops as a result of posterior tongue dis-
placement during mouth breathing. Accordingly, ad-
enoidectomy is effective in relieving SRBA because the children revert to nasal breathing with the mouth closed. In contrast, adults may exhibit SRBA despite patent na-
sal airway; this appears to be a consequence of cranio-
facial maturation, including increased nasomaxillary height, decreased ArGoGn, and hyoid descent.\textsuperscript{26-28} These changes correspond to vertical elongation of the phar-
ynx and increased tongue height,\textsuperscript{27,28} both of which im-
ply a more unstable mechanical arrangement of the tongue and velopharynx.\textsuperscript{14,23,25,28} independent of nasal or nas-
opharyngeal obstruction. Children exhibit relatively ob-
lique orientation of the pharynx and a superiorly placed hyoid, which enhance airway stability at the level of the tongue. These advantages disappear during transforma-
tion toward the adult craniofacial form.

Untreated chronic mouth breathing in children might lead to unfavorable developmental changes in the cranio-
facial complex that predispose the individual to SRBA in adulthood.\textsuperscript{26-28} Adverse developmental effects of chronic mouth breathing include increased height of the nasomaxillary complex, obtuse ArGoGn, and secondary dor-
socaudal shifting of the hyoid, as has been shown in hu-
mans\textsuperscript{26} and experimentally in monkeys.\textsuperscript{19,31} This means that children who are chronic mouth breathers develop secondary changes in craniofacial morphologic charac-
teristics that predispose them to adulthood obstructive sleep apnea.\textsuperscript{25} Thus, as Guilleminault\textsuperscript{30} concluded, main-
taining nasal breathing during childhood is important for preventing alterations of the facial skeleton that reduce upper airway stability during sleep. Nasal obstruction of long duration must be avoided throughout the growing process. Persistent nasal obstruction should be corrected surgically early in life, even if, in most cases, the original cause will be resolved spontaneously.\textsuperscript{38}

This cephalometric study of children with nasal obstruc-
tion found several structural parameters that correlated with the severity of the obstructive symptoms. The cepha-
ломetric findings indicate that regional sites of airway nar-
woring, as well as mechanically disadvantageous con-
figurations of the mandible and hyoid, appear to contribute to sleep-related upper airway collapse. Fortunately, relief of nasal obstruction by adenoidectomy is highly effective in improving obstructed breathing in chil-
dren. Nevertheless, cephalometric analysis reveals cranio-
facial patterns that may predispose the patient to a sub-
optimal surgical result or redevelopment of SRBA in adulthood. Cephalometric analysis may identify a sub-
set of patients who are at risk for continued obstruction. Future studies are needed to clarify whether early sur-
gical intervention for chronic mouth breathing can re-
verse some craniofacial substrates of SRBA.

**CONCLUSIONS**

Table 4. Interrelationships Among the Craniofacial Variables by Pearson Correlation*"}

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>BaSN</th>
<th>BaSPNS</th>
<th>ArGoGn</th>
<th>GnGoH</th>
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<th>SNB</th>
<th>ANB</th>
<th>BaN-ANSPNS</th>
<th>MPAS</th>
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* See Table 1 for expansions of abbreviations and definitions.

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