Age-Matched Normal Values and Topographic Maps for Regional Cerebral Blood Flow Measurements by Xe-133 Inhalation

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SUMMARY The relationship between normal aging and regional cerebral blood flow (rCBF) computed as initial slope index (ISI) by Fourier method was investigated in 105 right-handed healthy volunteers (132 measurements) by Xe-133 inhalation method, and age-matched normal values were calculated. Mean brain ISI values showed significant negative correlation with advancing age \((r = -0.70, p < 0.001)\), and the regression line and its 95% confidence interval was \(Y = -0.32 (X-19) + 63.5 \pm 11.2 (19 \leq X \leq 80)\). Regional ISI values also showed significant negative correlations for the entire brain \((p < 0.001)\). The regional reductions of ISI values with advancing age were significantly greater in the regional distribution of the middle cerebral arteries bilaterally, compared with regions in the distribution of the other arteries \((p < 0.05)\). Therefore, measured rCBF values for patients must be compared to age-matched normal values for mean hemispheric and each region examined. Two kinds of topographic maps, brain map showing rCBF compared to age-matched normal values and showing hemispheric differences were made by dividing patient's values by the 95% confidence limits for age-matched normal values and displaying laterality index calculated as follows, respectively.

\[
\text{Laterality index} = 100 \left(1 + \frac{\text{Right flow} - \text{Left flow}}{\text{Right flow} + \text{Left flow}}\right)
\]

These maps were useful for evaluating significantly decreased or increased regions and regional hemispheric differences.

Materials and Methods

One hundred and thirty two measurements of rCBF were performed in 105 right-handed (judged by Edinburgh handedness questionnaire) healthy volunteers free from cardiovascular and pulmonary diseases and risk factors of atherothrombotic stroke including hypertension, diabetes mellitus and hyperlipidemia. There were 57 males and 48 females, aged 19 to 80 years old (mean 42 years) (table 1). The old age group above 60 was subjected to psychometrical testing (Hasegawa scale) and diagnosed normal. Hematocrit was determined in all subjects.

The measurements were carried out in a room where the ambient noise level was 61 dB (A) derived from inhalation system and blowers and illumination intensity was 3 lux at rest and in the eye closed state. Xe-133 inhalation system (Meditronic Novo Diagnostic Systems, Inhalation Cerebrograph, Denmark) consists of 32 scintillation detectors placed in parallel. One pair of the detectors was mounted in a position over the brain stem and cerebellar region (fig. 1).

The data were analyzed by Fourier method and initial slope index (ISI, computed on the period 30 to 90 seconds from the beginning of inhalation) was used in this presentation as the index of rCBF. The relation between age and regional hemispheric percent values, which are obtained by dividing the regional values by hemispheric mean values, was also studied. Besides, two kinds of topographic maps, brain map showing rCBF compared to age-matched normal values and showing hemispheric differences were made for the purpose of evaluating significantly decreased or increased regions and regional hemispheric differences, respectively. These maps were made by divid-
ing patient's values by the 95% confidence limits for age-matched normal values and displaying laterality index calculated as follows.

\[
\text{Laterality index} = \frac{(\text{Right})\text{flow} - (\text{Left})\text{flow}}{(\text{Right})\text{flow} + (\text{Left})\text{flow}} \times 100
\]

The values of laterality index more and less than 100 denote the dominancies of the right and left hemisphere, respectively.

End expired air PECO\textsubscript{2}, (PECO\textsubscript{2}, calculated as follows\textsuperscript{17}) was recorded from the face mask during the measurements along with the mean arterial blood pressure (MABP). PECO\textsubscript{2} = (Barometric pressure - 47) mmHg x %CO\textsubscript{2}. ISI values were not corrected for changes in PECO\textsubscript{2}.

### Results

PECO\textsubscript{2} and MABP were 37.8 ± 2.9 and 83.7 ± 12.0 mmHg (mean ± 1 standard deviation (s.d.)) respectively, and didn't significantly correlate with aging (r = 0.03 and r = 0.18, respectively, p > 0.05). Mean brain ISI values showed significant negative correlations with advancing age (r = -0.70 (total), r = -0.72 (males), r = -0.61 (females), p < 0.001), and the regression lines were Y = -0.32 (X - 19) + 63.5 (total), Y = -0.37 (X - 19) + 64.1 (males) and Y = -0.26 (X - 19) + 62.5 (females) (19 ≤ X ≤ 80).

The number of subjects was so large that the 95% confidence interval of the regression line (total) was able to approximate to ±1.96 V/VE = ±11.2 (VE: mean residual square) (fig. 2). There were no significant differences in the correlation coefficients between males and females (p > 0.05). Regional ISI values also showed significant negative correlations with advancing age for the entire brain (p < 0.001) (fig. 3). Regional regression lines and their 95% confidence intervals were also calculated (fig. 4). There were no significant differences in the correlation coefficients obtained from parallel regions between the right and left hemispheres (p > 0.05). The regional reductions of ISI values with advancing age were significantly greater in the regional distribution of the middle cerebral arteries (MCA, corresponding detectors are 4, 5, 6, 7, 9, 10, 11, 13, 15, 20, 21, 22, 23, 25, 26, 27, 29, 31, see fig. 3) bilaterally, compared with regions in the distribution of the anterior cerebral (detectors, 1, 3, 17 and 19), the posterior cerebral (detectors, 8, 12, 16, 24, 28, 32) and vertebrobasilar (detectors, 2, 18) arteries (p < 0.05). Regional hemispheric percent values for frontal lobe (mean value of detectors, 1, 3, 4, 5, 6, 7, and 9, or of detectors, 17, 19, 20, 21, 22, 23 and 25) were greater than that of either parietal (mean value of 7, 9, 11, 13 and 15, or 23, 25, 27, 29 and 31), temporal (mean value of 6, 8, 10, 12 and 14, or 22, 24, 26, 28 and 30), occipital lobe (mean value of 14, 15 and 16, or 30, 31 and 32), or brain stem and cerebellar region (2 or 18) for the entire age (fig. 5). But, this hyperfrontal distribution became gradually lost with advancing age, because reductions of ISI values with aging were greater in the frontal lobe than in other regions.

Topographic patterns of rCBF as a brain-map, were made on a 64-year-old patient who suffered from left angular artery infarction after 102 days from the onset (fig. 6a) by dividing patient values with the lower 95% confidence limits for the age-matched normal values (fig. 6b, c, d). According to this map, it became clear that rCBF of extensive regions except for part of frontoparietal and brain stem and cerebellar regions fell within the lower normal limits or showed significant decreases for the left hemisphere (p < 0.05), while all regions were within normal limits for the right hemisphere.

There were no significant differences in the hemispheric mean ISI values between the right and left hemispheres (p > 0.05), on the other hand significant regional hemispheric differences were observed in superior frontal (right dominancy) and posterior inferior temporal (left dominancy) regions for these normal right-handed subjects (Student's t-test, p < 0.05). Mean and 1 s.d. values for laterality indices of hemispheric mean values were 100.3 ± 1.2 (fig. 7). Mean values for regional laterality indices were less than 100 (left dominancy) between the pairs of detectors at positions (see fig. 1) 7 and 23, 8 and 24, 10 and 26, 12 and 28, and 13 and 29, on the other hand more than 100 (right dominancy) between the other pair detectors, while 1 s.d. values for regional laterality indices were below 3 in all regions.

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### Table 1: Age Distribution of Healthy Volunteers

<table>
<thead>
<tr>
<th>Age</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-30</td>
<td>30(40)</td>
<td>8(10)</td>
<td>38(48)</td>
</tr>
<tr>
<td>31-40</td>
<td>9(14)</td>
<td>5(5)</td>
<td>14(19)</td>
</tr>
<tr>
<td>41-50</td>
<td>5(9)</td>
<td>11(16)</td>
<td>16(24)</td>
</tr>
<tr>
<td>51-60</td>
<td>5(6)</td>
<td>10(12)</td>
<td>15(18)</td>
</tr>
<tr>
<td>61-70</td>
<td>4(4)</td>
<td>12(12)</td>
<td>16(16)</td>
</tr>
<tr>
<td>71-80</td>
<td>4(4)</td>
<td>2(3)</td>
<td>6(7)</td>
</tr>
<tr>
<td>Total</td>
<td>57(77)</td>
<td>48(55)</td>
<td>105(132)</td>
</tr>
</tbody>
</table>

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**FIGURE 1. Location of 16 detectors over the right hemisphere.** Left hemisphere was identically covered by an additional 16.
regional laterality indices showed significantly greater values \((p < 0.05)\), that is the right hemisphere was dominant, in all regions except for part of frontal and temporal lobes (fig. 8).

**Discussion**

In analyzing head clearance curves by the Xe-133 inhalation technique, Fourier method has been reported to have the following three advantages in comparison with the conventional Obrist method.\(^{13-15}\) [1] In Obrist method, delayed start fit time has been used to avoid the artifacts from the air passages. The main disadvantage of this method is the omission of the first part of the clearance curve which contains information about the flow of the fast clearing gray matter. By contrast, Fourier method provides complete informa-

**Figure 2.** Correlation of mean brain ISI measured by Fourier method with age in 105 right-handed healthy volunteers. ISI values showed significant negative correlation with advancing age \((r = -0.70, p < 0.001)\). The regression line and its 95\% confidence interval was \(Y = -0.32X + 63.5 \pm 11.2 \) \((19 \leq X \leq 80)\). Limits of confidence were showed for regression line (---) and for the 95\% limits (…….) of ISI value for a given age.

**Figure 3.** Correlation of regional ISI values with age. Regional ISI values showed significant negative correlations with advancing age for the entire brain \((p < 0.001)\). In the right hemisphere, region of detector 4 indicated significant greater correlation than regions of detectors 2, 3, 12, 13, 15, 16 and 7 greater than 2, 3, 13, 15, 16. In the left hemisphere, regions of detectors 17, 20-23, 25-27, 30 indicated significant greater correlations than region of detector 18, and 20, 23 greater than 24 \((p < 0.05)\). There were no significant differences in the correlation coefficients obtained from parallel regions between the right and left hemispheres \((p > 0.05)\).

**Figure 4.** Regional regression lines and their 95\% confidence intervals. The 95\% confidence limits \((Y)\) of ISI values for a given age \((X)\) can be calculated by the equation of \(Y = A(X - 19) + B \pm C \) \((19 \leq X \leq 80)\).
The method has a faster computation time. We compared the reproducibilities of flow parameters, \( F_\text{r} \) and ISI between Fourier and Obrist methods by back-to-back measurements. 18 The coefficient variations (C.V.) of the change from first to second measurement were 5.1%, 3.3%, 6.4%, 3.4% for hemispheric mean values, 9.1%, 5.0%, 13.0%, 6.6% on average for regional absolute values, and 7.9%, 3.9%, 12.2%, 5.5% on average for regional hemispheric percent values in \( F_\text{r} \) by Fourier method, ISI by Fourier method, \( F_\text{r} \) by Obrist method, and ISI by Obrist method, respectively. ISI by Fourier method showed the best reproducibility and the values for C.V. were almost equal to the results obtained by intra-carotid injection method. 19-21 ISI by Fourier method was considered to be an excellent index of \( rCBF \) as Risberg et al. and Prohovnik et al. have reported previously.
It is concluded that measured rCBF values for patients with disease must be compared to age-matched normal values for mean hemispheric and each region examined, because rCBF inhomogeneously becomes reduced with advancing age. The brain map showing rCBF compared to age-matched normal values is useful for evaluating significantly decreased or increased regions.

Regarding hemispheric differences for CBF in normal subjects, opinions vary. Ingvar said that there were no significant hemispheric differences in hemi-

![Brain map showing rCBF comparison to normal values.](image)

**RIGHT**

- 117%
- 44
- 37
- 36
- 32
- 43
- 40
- 38
- 37
- 36

**LEFT**

- 101%
- 38
- 40
- 39
- 37
- 36
- 40
- 39
- 37

**RIGHT**

- 38
- 40
- 42
- 38
- 36
- 32
- 40
- 39
- 37

**LEFT**

- 44
- 45
- 42
- 42
- 41
- 40
Mean and 1 s.d. values for hemispheric mean and regional laterality indices in right-handed healthy volunteers. Laterality index is calculated as follows: Laterality index = 100 (1 + (Right)flow - (Left)flow) / (Right)flow + (Left)flow. The values of the index more and less than 100 denote the dominancies of the right and left hemisphere, respectively.

FIGURE 7. Mean and 1 s.d. values for hemispheric mean and regional laterality indices in right-handed healthy volunteers. Laterality index is calculated as follows: Laterality index = 100 (1 + (Right)flow - (Left)flow) / (Right)flow + (Left)flow.

FIGURE 6. Topographic map for rCBF was made by dividing the rCBF values for this 64-year-old patient with left angular artery infarction by the lower 95% confidence limits for age-matched normal values. Right and left hemispheric mean values of the patient were 117% and 101% of the lower limits, respectively. Topographic map showed regional percentages above or below the lower limits using the clock symbols in the circles (90° = 25%). In the left hemisphere, all regions except for part of frontoparietal and brain stem and cerebellar regions fell within the lower normal limits or showed significant decreases (p < 0.05). Regional laterality indices show significantly greater values, that is the right hemisphere is dominant, in all regions except for part of frontal and temporal lobes.

FIGURE 8. Brain maps of patient in Fig. 6. The image is displayed as either clock symbols in the circles (90° = 25%, above) or shaded squares including the regional indices (below). Stars in hemispheric mean and the circles denote the significance of the indices compared to normal values (p < 0.05). Regional laterality indices show significantly greater values, that is the right hemisphere is dominant, in all regions except for part of frontal and temporal lobes.
References

Age-matched normal values and topographic maps for regional cerebral blood flow measurements by Xe-133 inhalation.
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