Age-related dendritic changes in human occipital and prefrontal cortices: a quantitative Golgi study

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Age-related Dendritic Changes in Human Occipital and Prefrontal Cortices: A Quantitative Golgi Study

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Qualitative (Scheibel, 1992) and quantitative (Jacobs & Scheibel, 1993) research indicates a general decline in dendritic neuropil with increasing age. The present study extends previous human dendritic research by examining quantitatively age-related changes in 2 cortical areas: prefrontal cortex (area 10) and occipital cortex (area 18). Tissue blocks were obtained from the left hemisphere of 10 neurologically normal subjects, ranging in age from 23 to 81 years. Blocks were stained with a modified rapid Golgi technique. Supragranular pyramidal cells were quantified on a Neurolucida computer/microscope interface system (Microbrightfield, Inc.). Dendritic system complexity was determined by several dependent measures: total dendritic length, mean dendritic length, dendritic segment count (DSC), dendritic spine number, and dendritic spine density. All dependent measures, except DSC, decreased with age, with a substantial (approximately 50%) decrease in dendritic spines. Although area 10 exhibited greater dendritic aborizations than area 18, dendritic declines were slightly more pronounced in area 10 than in area 18. The present results quantitatively document the ongoing, dynamic refinement of dendritic systems across the human life span, and suggest that higher order cortical areas (e.g., area 10) may be more susceptible to age-related changes.

Other age-associated histological changes have been observed across several cortical areas. Declines in brain weight, cortical thickness, and in the number of large neurons have been observed in midfrontal, superior temporal, and inferior parietal areas of aged human brains (Terry, DeTeresa, & Hansen, 1987). More specifically, a 13-20% reduction in soma area, which appears to be related to a reduction in dendritic systems, has been revealed in individuals between the ages of 70 and 85 years in the superior temporal gyrus (Anderson, Hubbard, Coghill, & Slidders, 1983). Similar decreases in neuron density have been observed in human somatosensory and visual cortices (Flood &...
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Coleman, 1988).

Several indirect measures further suggest decreases in dendritic systems with age. Chugani, Phelps, and Mazziotta (1987) found lower local cerebral metabolic rates for glucose (CMRGlc) in adults than in children. These changes were specifically associated with age-related alterations in dendritic systems (Jacobs et al., 1995; Jacobs & Scheibel, 1993). Age-related decreases in mean CMRGlc (Yoshii et al., 1988) and decreases in cerebral blood flow (Kety, 1956; Leenders et al., 1990; Melamed, Lavy, Bentin, Cooper, & Rinot, 1980) have been documented along with decreases in blood volume. Such metabolic changes parallel declines in synaptic density with increasing age (Leenders et al.). More directly, age-related decreases in the synaptophysin content have been observed in older rat brains (Saito et al., 1994), a decrease that correlates closely with loss of synapses (Masliah, Terry, Alford, DeTeresa, & Hansen, 1991). Bondareff and Geinisman (1976) and Feldman (1976) found a decrease in deafferented dendritic spines, indicating a correlation between loss of synapses and decreases in dendritic spine number.

Apart from Huttenlocher's (1979) intensive developmental work, the present study is the first to examine quantitatively age-related changes in dendritic spines across the human life span. The current project extends previous human dendritic research (Jacobs & Scheibel, 1993; Larsen, Swanson, Wainwright, & Jacobs, 1994) by specifically examining age-related changes in two cortical areas: prefrontal cortex (area 10) and occipital cortex (area 18). These two regions were chosen because preliminary results (Baca et al., 1995) indicate that cortical areas higher in the information processing hierarchy—as determined by Benson's (1994) functional schema—may be preferentially susceptible to age-related changes. Age-related decreases in dendritic complexity and especially in dendritic spine number/density are expected in both cortical areas. However, it is predicted that unimodal association cortex (area 18), which is involved in basic visual processing, will be less affected by aging than supramodal association cortex (area 10), which is involved in executive (cognitive) control of mental functions. The magnitude of age-related decreases is expected to be greater in supramodal cortex because, with increasing age, higher order cortical areas may not be as fully utilized as cortices involved in more basic (e.g., visual) processing.

Method

Subjects

Tissue was removed from the left hemisphere of 10 neurologically normal subjects, ranging in age from 23 to 81 years ($M = 50.1 \pm 19.5$; see Table 1). The average autolysis time was 10.4 ± 4.6 hours. Brains were divided into a younger group ($n = 5$; 23-48 years of age; $M = 33.8 \pm 9.0$) and an older group ($n = 5$; 51-81 years of age; $M = 66.2 \pm 10.8$). Brains were obtained from the County Coroner's office and a local hospital. The research protocol was approved by The Colorado College Human Subjects Institutional Review Board (#H94-004).

Apparatus

All cells were quantified on a Neurolucida computer/microscope interface system (Microbrightfield, Inc.) with an Olympus BH-2 microscope under a 40X (.70) dry objective.

Histological Techniques

Tissue was immersion fixed in 10% neutral buffered formalin for 2-4 weeks before staining. One 3-5 mm tissue block was removed from the frontal pole (area 10) and the lateral surface of the occipital lobe (area 18). Coded tissue blocks were stained using a modified rapid Golgi technique (Scheibel & Scheibel, 1978). Adjacent cortical blocks were stained with a cresyl echt violet technique (Gridley, 1960) to determine laminar depth and cortical thickness. Golgi-

### Table 1

**Subject summary**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Gender</th>
<th>Race</th>
<th>Autolysis time (hours)</th>
<th>Cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>M</td>
<td>C</td>
<td>12.0</td>
<td>Motor vehicle accident (chest trauma)</td>
</tr>
<tr>
<td>32</td>
<td>F</td>
<td>C</td>
<td>20.0</td>
<td>Bulimia</td>
</tr>
<tr>
<td>32</td>
<td>M</td>
<td>C</td>
<td>9.0</td>
<td>Suicide (asphyxia)</td>
</tr>
<tr>
<td>34</td>
<td>F</td>
<td>C</td>
<td>14.5</td>
<td>Heroin overdose</td>
</tr>
<tr>
<td>48</td>
<td>F</td>
<td>C</td>
<td>4.0</td>
<td>Myxoid leiomyosarcoma</td>
</tr>
<tr>
<td>51</td>
<td>F</td>
<td>C</td>
<td>6.0</td>
<td>Respiratory distress/emphysema</td>
</tr>
<tr>
<td>64</td>
<td>F</td>
<td>C</td>
<td>11.0</td>
<td>Myocardial infarction</td>
</tr>
<tr>
<td>66</td>
<td>M</td>
<td>C</td>
<td>9.0</td>
<td>Pneumonia/cardiac arrest</td>
</tr>
<tr>
<td>69</td>
<td>M</td>
<td>C</td>
<td>7.0</td>
<td>Prostate cancer</td>
</tr>
<tr>
<td>81</td>
<td>M</td>
<td>C</td>
<td>11.0</td>
<td>Gastro-intestinal bleeding</td>
</tr>
</tbody>
</table>
stained tissue was serially sectioned at 120 μm on a vibratome such that sections were perpendicular to the long axis of the gyrus. Tissue sections were then serially mounted on glass slides with permount and coverslipped.

**Cell Selection Criteria and Quantification Techniques**

Supragranular pyramidal cells from each tissue block were chosen based on accepted criteria (Jacobs & Scheibel, 1993): (a) The soma-apical dendrite orientation is perpendicular to the pial surface. (b) The soma is located centrally within the 120 μm section depth. (c) The apical shaft is at least 100 μm in length. (d) At least three primary basilar dendritic shafts are present, each with at least two secondary branches and their consequent branch systems. (e) Neurons show no obvious evidence of incomplete impregnation. (f) Cells are relatively unobscured by adjacent neuronal structures. (g) Higher order branches should have natural terminations, either characterized by naturally tapered ends, growth cone-bearing tips, or by terminal clusters of dendritic spines. The last criterion was not absolute because some dendrites had been sectioned during processing. Cells with incomplete endings were included in the present study because exclusion of these neurons would have biased the sample towards smaller neurons (Buell & Coleman, 1981).

Ten cells were randomly selected from each block and traced if they met the above criteria. First, the soma was traced at its widest extent. Then, at least 100 μm of the apical shaft was traced for orientation purposes. Finally, the basilar dendrites, including dendritic spines, were traced. Unlike Horner (1993), no distinction was made between thin, stubby, or mushroom-shaped spines because of time-constraints.

**Intra- and Inter-rater Reliability**

Cells were traced by six different raters: KC = 60 cells; Serapio Baca = 10 cells; Bob Jacobs = 20 cells; Lori Larsen = 50 cells; Rebecca Swanson = 20 cells; Marcy Wainwright = 40 cells. Intrarater reliability was determined by having each rater trace the same dendritic system (including somata and dendritic spines) ten times. The average coefficient of variation across all raters for TDL, soma size, and DSN was 0.053, indicating little variation in tracings. The first five tracings were compared with the second five tracings in a split plot design (α = 0.5). There was no significant difference within raters for any of these measures. All raters were normed before quantification to maximize interrater reliability. In tracings of ten different dendritic systems, Pearson product correlations across TDL, soma size, and DSN averaged 0.98, indicating high agreement between raters. An ANOVA (α = 0.5) indicated no significant difference between raters on these measures.

**Design**

Cortical area (10 & 18) and age group (younger vs. older) constituted the independent measures for the present study. Age-related changes in dendritic systems across each individual were also noted.

Dendritic system complexity was determined by several dependent measures: total dendritic length (TDL), mean dendritic length (MDL), dendritic segment count (DSC), dendritic spine number (DSN), and dendritic spine density (DSD). Dendritic systems were further broken down by proximal (1st-3rd) and distal (4th order and higher) segments and by segment order to determine where on the dendritic tree age-related changes were most pronounced. Dependent values are provided as an average per cell per group (±SEM).

Because of the small sample size, only descriptive statistics were used for the present study. Pearson product-moment correlations between age and the dependent variables were also performed.

**Results**

As expected, all dependent measures, except DSC, decreased with age, with the greatest decline observed in spine measurements (see Table 2). Area 10 exhibited greater dendritic systems than area 18 (see Figure 1). In comparing the younger and older age groups, area 10 exhibited a greater decrease in dendritic measures (MDL: 17.7%, DSN: 51.8%, DSD: 53.3%) than did area 18 (MDL: 11.7%, DSN: 49.1%, DSD: 48.1%). Dendritic values tended to be 12.8% higher for males than for females.

**Summary of Neuronal Population**

Measurements from Nissl stains revealed that sampled cells originated in cortical layers II and III. There was little difference in cortical and laminar thickness between age groups (see Table 3), or between cortical areas. Area 10 was characterized by greater laminar and cortical thickness than area 18. Soma size tended to decrease slightly from the younger (M = 230.8±9.92 μm) to the older (M = 200.9±10.10 μm) group (r[200] = -0.21; p < 0.003). A decline in soma size was associated with a decrease in MDL (r[200] = 0.45; p < 0.01), TDL (r[200] = 0.22; p < .002), DSC
Table 2
A Breakdown of Dependent Measures across Individuals

<table>
<thead>
<tr>
<th>Age</th>
<th>TDL</th>
<th>MDL</th>
<th>DSC</th>
<th>DSN</th>
<th>DSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>4000.66</td>
<td>61.94</td>
<td>64.55</td>
<td>1724.40</td>
<td>0.38</td>
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<td>32</td>
<td>3313.76</td>
<td>71.18</td>
<td>48.17</td>
<td>1311.53</td>
<td>0.29</td>
</tr>
<tr>
<td>34</td>
<td>3466.45</td>
<td>63.02</td>
<td>54.35</td>
<td>985.35</td>
<td>0.27</td>
</tr>
<tr>
<td>48</td>
<td>3518.27</td>
<td>64.14</td>
<td>55.05</td>
<td>896.90</td>
<td>0.19</td>
</tr>
<tr>
<td>51</td>
<td>3008.72</td>
<td>54.31</td>
<td>55.25</td>
<td>586.00</td>
<td>0.14</td>
</tr>
<tr>
<td>64</td>
<td>3427.49</td>
<td>57.70</td>
<td>59.75</td>
<td>549.90</td>
<td>0.12</td>
</tr>
<tr>
<td>66</td>
<td>3301.50</td>
<td>53.40</td>
<td>61.65</td>
<td>718.35</td>
<td>0.16</td>
</tr>
<tr>
<td>69</td>
<td>3648.73</td>
<td>57.24</td>
<td>63.65</td>
<td>543.00</td>
<td>0.12</td>
</tr>
<tr>
<td>81</td>
<td>3667.01</td>
<td>56.68</td>
<td>64.60</td>
<td>678.70</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Grand mean</td>
<td>3482.60</td>
<td>61.08</td>
<td>57.52</td>
<td>930.57</td>
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<tr>
<td></td>
<td>23-48 mean</td>
<td>3554.58</td>
<td>66.29</td>
<td>54.06</td>
<td>1245.94</td>
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<tr>
<td></td>
<td>51-81 mean</td>
<td>3410.61</td>
<td>55.87</td>
<td>60.98</td>
<td>615.19</td>
</tr>
</tbody>
</table>

Note. Dependent variable values represent mean measurements per neuron for the 20 cells quantified for each individual. Abbreviations: TDL = total dendritic length; MDL = mean dendritic length; DSC = dendritic segment count; DSN = dendritic spine number; DSD = dendritic spine density.

\( r(200) = 0.32; p < 0.01 \), and DSN \( r(200) = 0.31; p < 0.01 \).

Dendritic Measures

Dendritic Length Measures. There was an inverse relationship between age and measures of dendritic length. TDL was 4.2% higher in the younger group (3,555±108.0 μm) than in the older group (3,411±102.8 μm) and 15% higher in area 10 (3,725±115.0 μm) than in area 18 (3,240±89.0 μm; see Figure 2). MDL was 19% greater in the younger group (66.3±1.29 μm) than in the older group (55.9±0.91 μm) and 2.5% higher in area 10 (61.8±1.34 μm) than in area 18 (60.3±1.04 μm). Overall, distal segments contributed 61% more to TDL and 104% more to MDL than did proximal segments. TDL increased from first to fourth order and tended to decrease thereafter. MDL increased from first to higher order segments but remained stable from fourth to sixth order, averaging 78.3 μm (see Figure 3). There was a general decrease in MDL with age \( (r(200) = -0.37; p < 0.01) \), but not in TDL.

Dendritic Segment Count. Unlike dendritic length measures, the number of segments tended to increase with age (see Figure 4). DSC was 11% lower in the younger group (54.1±1.41) than in the older group (61.0±1.48) and 12% higher in area 10 (60.9±1.55) than in area 18 (54.2±1.35). For the total population, DSC was 5.1% higher in the distal part of the dendritic tree than in the proximal part.

There were 17.9% more distal segments in the younger group over the older group, but only 5.0% more proximal segments. An order by order analysis

Table 3
Depth of Cortical Layers and Sampled Cells (μm)

<table>
<thead>
<tr>
<th></th>
<th>Younger group</th>
<th>Older group</th>
<th>Area 10</th>
<th>Area 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer I/II junction</td>
<td>294</td>
<td>282</td>
<td>305</td>
<td>271</td>
</tr>
<tr>
<td>Layer I/III junction</td>
<td>573</td>
<td>571</td>
<td>596</td>
<td>548</td>
</tr>
<tr>
<td>Sampled cells</td>
<td>850</td>
<td>842</td>
<td>844</td>
<td>848</td>
</tr>
<tr>
<td>Layer III/IV junction</td>
<td>1407</td>
<td>1385</td>
<td>1429</td>
<td>1363</td>
</tr>
<tr>
<td>Gray/white matter junction</td>
<td>3092</td>
<td>3353</td>
<td>3387</td>
<td>3064</td>
</tr>
</tbody>
</table>
Figure 2. Total dendritic length (TDL in µm) for the younger versus the older group broken down by (a) area and (b) distal/proximal segments. TDL is also displayed for individuals broken down by area (c). Note the higher dendritic values in area 10 and in distal segments. Bars represent SEM.

Figure 3. Mean dendritic length (MDL in µm) broken down by order. MDL tended to increase with each subsequent segment order. Segments 8 and 9 were not graphed because there were only one or two segments each. Bars represent SEM.

indicated an increase in DSC up to the fourth order and then a decrease in subsequent segments. There was a significant increase in DSC with age (r[200] = 0.23; p < 0.001).

Dendritic Spine Measures. As with length measures, spine measures decreased as a function of age. DSN was 50.6% less in the older group (615±25.3) than in the younger group (1,246±52.2) and 31% higher in area 10 (1,056±58.5) than in area 18 (805±40.4; see Figure 5). DSD was 50% less in the older group (0.14±0) than in the younger group (0.28±0.01) and 10% greater in area 10 (0.22±0.01) than in area 18 (0.20±0.01). An order by order analysis revealed greater DSN and DSD for all orders in the younger group than in the older group (see Figure 6). DSN and DSD were 89% and 155% greater in distal segments than in proximal segments, respectively. Figure 7 illustrates a decline in DSN with age, with area 10 consisting of more dendritic spines than area 18 across all but one individual. There was a significant decrease in DSN (r[200] = -0.63; p < 0.01) and DSD (r[200] = -0.77; p < 0.01) with age.

Discussion

The results of the present study revealed a general decline in dendritic systems with age. This decrease in dendritic systems was slightly more pronounced in area 10 over area 18. Interpretation of these findings, however, is constrained by methodological limitations.
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Figure 4. Dendritic segment count (DSC in μm) for the younger versus the older group broken down by (a) area and (b) distal/proximal segments. DSC is also displayed for individuals broken down by area (c). The older group has more dendritic segments than the younger group, and area 10 exhibits more dendritic segments than area 18. Bars represent SEM.

Methodological Limitations

Limited availability of human brain tissue with short autolysis time and detailed biographic information, especially from young individuals, places crucial restraints on quantitative dendritic studies. Such limitations make it difficult to obtain multiple subjects of the same age, which is required for statistical analyses to be meaningful (Flood, 1993). Without such large sample sizes, it is difficult to rule out factors (e.g., educational level and personal history) that also influence dendritic systems (Jacobs, Batal, et al., 1993).

Figure 5. Dendritic spine number (DSN) for the younger versus the older group broken down by (a) area and (b) distal/proximal segments. DSN is higher in the younger group and in area 10. Distal segments consist of more dendritic spines than proximal segments. Bars represent SEM.
Figure 6. An order by order analysis for the younger and older group: (a) Dendritic spine number (DSN). (b) Dendritic spine density (DSD). DSN and DSD are consistently greater in the younger group than in the older group. Segments 8 and 9 were not graphed because there were only one or two segments each. Bars represent SEM.

Figure 7. Dendritic spine number (DSN) per individual broken down by area. Bars represent SEM.

Several studies have reported variable results due to different Golgi techniques, especially between the Golgi-Cox and the rapid Golgi method. Rapid Golgi stains tend to be more sensitive to post-mortem fixation delay than the Golgi-Cox method (Buell, 1982). This delay tends to have adverse effects, particularly on dendritic spines (deRuiter, 1983). To avoid degenerative changes in brain tissue, deRuiter suggested that fixation delay should not exceed four hours. Although the average autolysis time in the present study was 10.4 hours, there was no correlation between autolysis time and TDL, which is in agreement with previous findings (Jacobs & Scheibel, 1993), nor did dendritic spines appear to decrease as a result of increased autolysis time. Nevertheless, the number of dendritic segments did appear to decrease with increased autolysis time ($r(200) = -0.23; p < 0.01$).

In spite of the potential problems associated with the rapid Golgi technique, it remains particularly useful for formalin-fixed tissue (Buell, 1982). Furthermore, within our laboratory, the rapid Golgi method has provided more complete impregnations and more detail of dendritic structures (Jacobs & Scheibel, 1993) than any other silver technique. Because the rapid Golgi technique has been consistently applied in our previous studies, it is essential to continue with the same methodology if the present results are to be compared with past findings.

Light microscopy. One restriction of light microscopy is the inability to see spines above and below dendrites. Because thicker branches tend to have more dendritic spines than smaller branches, spines on
thicker branches tend to be underestimated (Horner, 1993; Horner & Arbuthnott, 1991; but see Belichenko & Dahlström, 1995). Although correction equations (Feldman & Peters, 1979) and three-dimensional reconstructions of dendrites (Belichenko & Dahlström) attempt to compensate for this underestimation, such compensation techniques would not be practical in the current study because of the extensive nature of the data. Spine measures in the present project thus probably represent an underestimation. Nonetheless, the present cell selection criteria (Jacobs & Scheibel, 1993) and sampling procedure ensured that the degree of underestimation was constant across all samples.

An additional restriction of light microscopy is sectioning, which often truncates endings. Although 26% of dendritic segments were sectioned in the present study, cell selection criteria (Jacobs & Scheibel, 1993) minimized the number of incomplete endings. To avoid cut segments entirely, sections would need to approach a thickness of approximately 1,000 μm, making light microscopy impossible. Given the limitations of light microscopy, one solution would be to eliminate neurons with cut segments. However, exclusion of such neurons would result in an unrepresentative neuronal population (Buell & Coleman, 1981). A second solution would be to trace across sections. Because of the extensive nature of the present data and because the Golgi method stains several neurons simultaneously (unlike injection methods, cf. Belichenko & Dahlström, 1995), serial tracing would be impractical. Despite problems associated with dendritic truncation, incomplete endings were consistent across age group and area in the present investigation.

**Neuronal Shrinkage**

Soma size decreased from the younger to the older group. The present findings are consistent with previous studies (Anderson et al., 1983; Terry et al., 1987; Vaughan, 1977) documenting neuronal shrinkage. This decline in soma size is believed to result in an increase in the population of smaller neurons (Terry et al.). Although such a shift in neuron type was not examined in the current study, there did appear to be a direct relationship between soma size and the amount of dendritic systems, which would result in an apparent increase in the number of smaller neurons.

**Dendritic Regression**

The current findings document age-related, basilar dendritic regression in area 10 and area 18 supragranular pyramidal cells. The greatest decline was found in dendritic spines, which was expected because previous, qualitative work (Scheibel, 1992) had suggested such a decline with age. Continued reorganization of dendritic systems throughout the aging process might be responsible for the loss of dendritic spines because spines are resorbed if they lose their synaptic connections (Bondareff & Geinusman, 1976; Feldman, 1976; Vaughan, 1977). Resorption of proximal dendritic segments (Simonds & Scheibel, 1989) appears to be one aspect of this on-going reorganizing process. Such a resorption of dendritic segments throughout one's life span might account for the observed decreases in dendritic length observed in the present study.

Unlike dendritic length and spine measurements, the number of dendritic segments increased with age, which is consistent with previous studies. Jacobs and Scheibel (1993), for example, found an increase in DSC from the younger (< 50 years) to the older group (r(20) = 0.23) with the same magnitude of increase as the present results. Such an increase in dendritic segments would tend to increase TDL values. This would in turn reduce the observable loss in TDL (Jacobs & Scheibel) resulting from decreases in segment length. The addition of segments appeared to occur primarily in the distal part of the dendritic arbor (recall Figure 4b). This is to be expected because peripheral segments are believed to represent the most plastic portion of the dendritic tree (Carugh, Carpenter, & Diamond, 1989; Scheibel, 1988) and appear to be preferentially involved in higher-level cognitive functions (Jacobs, Batal, et al., 1993). An addition of segments to the dendritic tree with age might therefore provide a compensatory mechanism for dendritic resorption (Coleman & Flood, 1986).

The overall regression in dendritic systems can be seen as a normal part of the maturation process (Scheibel, 1992). Some synaptic connections may be lost, but other connections are enhanced. In essence, there is a refinement of dendritic systems with increasing age. This refinement is perhaps one reason why older individuals can still perform high-level mental tasks, but at a slower rate. Giaquinto (1988) performed experiments on younger and older individuals and found that the number of errors made was approximately the same for both groups, but that there was a decline in reaction time with age. With increasing age, there appears to be a general slowing of behavior (Giaquinto) and a decrease in the ability to recognize faces (Grady et al., 1995). Such changes may result from dendritic degeneration such as those observed in the present study.
Area 18 versus Area 10

All dependent measures were higher in area 10 than in area 18, which is consistent with preliminary results (Larsen et al., 1994). This finding may reflect differences in the computational and processing demands placed on dendritic systems in area 10 (Baca et al., 1995). According to Benson's (1994) functional hierarchical schema, supramodal association cortex (prefrontal area 10), the phylogenetically newest part of the cortex, is perhaps the most functionally complex area of the brain. It has executive control over other cortical functions, thus enabling it to select or inhibit cognitive activity. Moreover, area 10 appears to be responsible for high-level cognitive functions (e.g., discrimination, recognition, recall, attention, visual and tactile learning; Roland, 1993). Even though area 10 does monitor some sensory information, most of this information (e.g., visual) is analyzed by unimodal association cortex (occipital area 18), which specifically analyzes visual patterns (i.e., orientation, color, spatial frequencies, motion; Roland). In summary, area 10 is responsible for high-level cognition, and area 18 is responsible for processing visual impulses (Benson).

Because distal segments appear to be preferentially involved in high-level cognitive functions, it seems reasonable to expect that area 10 would have more distal segments than area 18, which was the case in the present study. Jacobs, Batal, et al. (1993) found that Wernicke's and Broca's areas, which are involved in high-level functions, also exhibited a distal over proximal advantage in dendritic length and suggested that distal segments might be involved in higher order cortical activities. Such a distal advantage was not observed in the motor strip areas, which represent primary cortex in Benson's (1994) schema. Similar findings have been observed in prefrontal cortices of rhesus monkeys (Cupp & Uemura, 1980).

A greater decline in dendritic systems in area 10 may be due to decreased utilization of the prefrontal cortex with increasing age or due to preferential sensitivity of these higher cortical areas to the effects of aging. Involvement of area 18 in basic visual processing may make it less susceptible to age-related changes because the visual system may be more consistently utilized throughout the life span than higher order areas. Additional support for the current findings is provided by studies of local cerebral blood flow (Tachibana et al., 1984), which found a greater decline in cerebral blood flow in prefrontal cortical areas than in visual areas with age.

Individual Variations

When the personal history of each individual is unknown, one cannot determine the extent to which other factors (e.g., education and environment) influence the results. In the present study, the 81-year-old male, who was a physician by occupation, exhibited greater TDL than all but the youngest subject and greater spine number than the 69-year-old male, whose occupation was unknown. Perhaps, the 81-year-old's educational achievements were responsible for his relatively higher TDL and spine measures. Such a possibility was suggested by Jacobs, Schall, and Scheibel (1993), who found a relationship between educational level and dendritic values. They believed that a higher educational level coupled with continued, intellectual activity could contribute to a proliferation in dendritic systems. Over 30 years of nonhuman animal research investigating the effects of differential environments on the brain have yielded similar results (Diamond, Krech, & Rosenzweig, 1964). For example, plasticity in response to a challenging environment has been shown in 904-day-old male rat brains (Diamond, Johnson, Protti, Ott, & Kajisa, 1985), which is equivalent to an 80-year-old human brain. These rats were placed in an enriched environment at 766 days of age and, after 138 days, showed an increase in cortical thickness, presumably as a result of increased dendritic arborizations. Such findings indicate continued plasticity throughout the life span of the organism and suggest that dendritic system degeneration may be diminished in older rats, and possibly humans, in the face of a challenging environment.

Conclusion

The current study quantitatively documented life span changes in dendritic systems and is the first to document life span decreases in spine number in human brain tissue. The results of the present investigation revealed: (a) A decline in total dendritic length, mean dendritic length, dendritic spine number, and dendritic spine density from the younger to the older group, with the greatest decline in spine number. (b) Greater dendritic systems in area 10 than in area 18. (c) A slightly more pronounced decrease in dendritic systems with age in area 10 over area 18. Importantly, the present project reconfirms previous qualitative observations (Scheibel, 1992) by providing quantitative data. Despite the loss in dendritic systems with age, human (Jacobs, Schall, & Scheibel, 1993) and nonhuman (Diamond et al., 1985) animal studies have
indicated continued plasticity throughout the aging process and suggest that challenge can at least partially attenuate the effects of aging. The overall findings stress the importance of maintaining a mentally active life into old age.

References


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