THE RELATIVE WEIGHT OF THE GRAY AND WHITE MATTER
OF THE NORMAL HUMAN BRAIN

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ABSTRACT

The relative proportion of gray and white matter of the normal human brain
was determined to be approximately 60% and 40% respectively in the cerebral
hemispheres and in the brain as a whole, by calculations based on the water
content of these tissues. With this technique, the value for gray matter is an
approximate measure of a myelin-free abstraction, rather than of the actual
anatomic gray structures; e.g. structures such as the globus pallidus which
contain many myelinated fibers would act as a mixture of tissues, and would
not be included entirely with the gray matter. This abstraction may have
pathological significance.

INTRODUCTION

When the water content of gray matter, white matter, and the brain as a
whole are known, the proportion of gray and white matter can be calculated if
the values are truly representative of the tissues under consideration. This
study attempts to determine this proportion in the normal human brain by this
means.

METHOD

A series of brains, either normal or with changes considered minor and irrelevant, were
removed at autopsy within two days of death and fixed for 1–2 weeks in 20% formalin-1%
acetic acid, the standard in this laboratory. These, and three similar freshly removed,
unfixed brains, were divided by a mid-line sagittal section. Each half was sectioned
coronally for pathological study. One half, from which the leptomeninges and major vessels
had been removed, was finely diced and mixed to form a uniform mass, and in the case of the
unfixed brains, homogenized; duplicate samples, approximately 100–200 mgs., were
weighed, and then dried to constant weight at 56°C over an approximately 100 hour period.
The decrement in weight was interpreted as representing water, and the water content was
calculated as percent of wet weight. In some instances, the cerebellum and brain stem were
separated from the cerebrum by section through the colliculi, and each was separately
weighed, homogenized and dried so that the weight and water content of each were
separately determined. In these instances, the water content of the whole brain was
calculated by combining these values. No tissue was removed for histologic study from this
portion of the brain, but samples of the cerebral cortex and of the deep white matter of the
frontal lobes were taken from the other half of the brain, as were blocks for histologic
study. These samples were weighed and dried in a similar manner to determine the water
content of cortex and white matter.

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The proportion of gray matter, \( x \), was calculated by the equation \( ax + b(1 - x) = c \), where \( a \) represents the water content of gray matter; \( b \), the water content of white matter; and \( c \), the water content of the brain as a whole, all expressed as a decimal fraction of 1, so that the equation represents the equality, water in gray plus water in white equals water in the whole of a 1 gram sample of brain. The equation can be simplified to read \( x = c - b/a - b \).

The data given in Table 1 represent the average of the two duplicate values; these duplicate values were in close agreement in each instance, tending to exclude technical error.

No distinction is drawn between the determinations on fixed and unfixed brains, since prior studies (1, 8) indicated that fixation in 20% formalin—1% acetic acid does not significantly alter the water content; no essential differences are evident in these data in the present report.

Case 1 was a 59 year old man with a normal brain. Case 2 was a 76 year old man whose brain was normal except for the presence of a small subependymal astrocytoma, 7 mm. in diameter, in the left lateral ventricle. Case 3 was a 7 year old boy with a normal brain. Case 4 was a 61 year old man with changes in the mammillary bodies indicative of old Wernicke's disease. Case 5 was a 30 year old man with a normal brain. Case 6 was a 79 year old man whose brain did not appear atrophic, and contained a few scattered ischemic neurons and some neurofibrillary tangles. Case 7 was a 53 year old man whose brain did not

**TABLE 1**

<table>
<thead>
<tr>
<th>Case</th>
<th>% water gray (a)</th>
<th>% water white (b)</th>
<th>% water total brain (c)</th>
<th>Gray as % whole brain</th>
<th>Cerebrum as % whole brain</th>
<th>% water cerebrum (c^1)</th>
<th>% water cerebellum &amp; brain stem</th>
<th>Gray as % cerebrum</th>
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<tbody>
<tr>
<td>1a</td>
<td>84.3</td>
<td>69.4</td>
<td>78.5</td>
<td>61.1</td>
<td>80.1</td>
<td>78.5</td>
<td>78.8</td>
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<tr>
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<td>74.5</td>
<td>79.5</td>
<td>51.0</td>
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<tr>
<td>3a</td>
<td>83.7</td>
<td>68.7</td>
<td>78.6</td>
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<td>78.6</td>
<td>78.6</td>
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<tr>
<td>5</td>
<td>84.3</td>
<td>73.1</td>
<td>80.6</td>
<td>67.0</td>
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<tr>
<td>6</td>
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<td>73.1</td>
<td>80.7</td>
<td>63.9</td>
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<td></td>
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<td>69.4</td>
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<td>62.4</td>
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<td>80.6</td>
<td>81.1</td>
<td>61.4</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>84.0</td>
<td>71.3</td>
<td>78.9</td>
<td>60.0</td>
<td>87.0</td>
<td>78.1</td>
<td>78.8</td>
<td>60.3</td>
</tr>
</tbody>
</table>

\( a = \% \) water in middle portion of cortex of frontal lobe. \( b = \% \) water in deep white matter of frontal lobe. \( c = \% \) water in sample of hemisection of whole brain. \( c^1 = \% \) water in sample of hemisection of cerebral hemisphere, separated at colliculi. \( d = \) In case 1, 2 and 3, the brains were examined unfixed. In all others, the brain were fixed before study. \( e = \) In cases 7, 8 and 9, representative samples of parietal white matter contained 67.8, 67.3 and 66.9% water respectively, and in two other cases, 68.0 and 69.3% in instances in which the frontal white matter contained 69.7 and 70.5% respectively. For all 5 cases, the average water content was 67.9% parietal and 69.3% frontal.
appear atrophic but contained senile plaques, neurons with neurofibrillary tangles and granulovascular degeneration in moderate numbers. Case 8 was a 55 year old woman with a normal brain. Case 9 was a 69 year old man with a normal brain. Case 10 was a 83 year old woman whose brain did not appear atrophic, but contained senile plaques and neurons with neurofibrillary tangles in moderate numbers.

DISCUSSION

If the water values are truly representative, these data indicate that the cerebrum and the brain as a whole consist of approximately 60% gray matter and 40% white matter. However, the water content of the cerebral white matter varies, with a thin, outer, arcuate zone containing considerably more water, and the corpus callosum slightly more water, than the deep white matter which was used for this study (1), although histologically, these tissues appear fundamentally the same. Other differences may exist; in five instances in which frontal and parietal white matter were separately evaluated, the latter contained slightly less water than the former, averaging 67.9% compared to 69.3%. If the true average water content of white matter were lower than that used in our calculations, the true proportion of gray matter would be higher than that calculated; if higher, the reverse would be true.

The water content of gray matter also varies considerably (8) but this may have a different significance. The lowest concentrations of water are observed in those gray matter tissues which contain the greatest number of myelinated fibers, such as the globus pallidus or the spinal gray matter. In a sense, these really constitute a mixed tissue, with elements of gray and white matter intimately admixed. A very few myelinated fibers are present even in the cortical gray matter, the area with the highest measured water content, so that “pure” gray matter, completely free of myelin, would have a very slightly higher water content than that used in our calculations, and the proportion of gray to white would be slightly less than calculated.

The concept of a “pure” gray matter, completely free of myelin, is an abstraction, probably not completely applicable to any real structure, not even the cerebral cortex, and certainly not to such structures as the corpus striatum or the spinal gray matter. With respect to our calculations, such tissues would act as if they were partly gray and partly white matter. If one chooses to view these as all gray matter, then the gray matter of the brain would have a higher value than that reported. The abstract concept of a “pure” gray matter may not be realistic from a gross anatomic point of view, but it may have pathologic significance. For example, the corpus striatum and the spinal gray matter have a greater tendency to become edematus than the cerebral cortex, though much less than white matter, possibly reflecting the inclusion of tissues that may be viewed as white matter (8).

Other, more direct studies reflect the usual gross anatomic relationships, rather than this abstract concept. Kappers (7) physically excised the cortex from sections of formalin fixed brains, and determined that this constituted 50.6% of the weight of the hemisphere. The basal gray structures are not
included in this estimate; if they were, the proportion of gray matter in the hemisphere would be much greater. Donaldson (2) measured the surface area and average depth of the cerebral cortex to obtain its volume, multiplied by specific gravity to obtain its weight, and determined that this constituted 58.3% of the hemisphere in one series, and 61.85% in another. In a similar study, Henneberg (4) reported an average value of 49.2%. Jäger (6) determined the volume of cortex in 1 cm. coronal slices planimetrically, and calculated that the cortex constituted 55% of the weight of the hemisphere. Donaldson (2) also employed an indirect method utilizing values for the specific gravity of cortex and white matter, and the weight and volume of the hemisphere excluding the striatum, and calculated that the cortex constituted 54.8 of the hemisphere. This indirect study is theoretically more like that which we have employed, but like the others, it excluded the basal gray structures from consideration, and referred only to the cerebral cortex. Høedt-Rasmussen and Søinhøj (5) equilibrated radioactive xenon with homogenized samples of gray matter, white matter, and homogenized samples of the entire hemisphere; in three individual cases, the gray matter (including the basal gray) constituted 50%, 58% and 43% of the hemisphere. These investigators had earlier analyzed data on cerebral blood flow in these same individuals when alive, and concluded then that the gray matter constituted 46%, 49% and 27% of the brain respectively. The cerebral blood flow indicated by xenon clearance was analyzed mathematically into a fast component, representing blood flow through gray matter, and a slow component for the white matter, which determined the proportion of each. They expressed the opinion that the in vivo studies were more valid, the in vitro studies being in error because of autolysis. It has been suggested (3) however, that figures based on cerebral blood flow change under altered physiologic conditions, and should not be interpreted on a strictly morphological basis, reflecting the actual percentage of gray matter.

REFERENCES