THE BRAIN OF THE MENTAL DEFECTIVE: A STUDY OF MORPHOLOGY IN ITS RELATION TO INTELLIGENCE

PART II.—THE CORPUS CALLOSUM IN ITS RELATION TO INTELLIGENCE *

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THE corpus callosum forms the most important connexion between the cerebral hemispheres, and although considerable uncertainty still surrounds the place of origin and destination of certain of its fibre bundles, and particularly those of the genu, the researches of Van Valkenberg ¹ and others have established the important fact that the bulk of the callosal fibres constitutes an important link between practically every region of the two hemispheres, thus associating both homotypical and heterotypical areas of grey matter in an extremely intimate way. It is also believed that its compact fasciculi are almost entirely made up of axis-cylinders coming from the small, medium and large pyramidal cells of the neopallium, and as we pass up the animal scale from marsupials to man its progressive enlargement can be correlated with the gradual increase of the grey matter constituting the neopallium. Measurement of the total area of the corpus callosum should, therefore, furnish in an indirect way valuable information concerning the cellular richness of the cortical grey matter; if its total area be smaller than normal, the number of cortical neurones may be expected to be proportionately fewer than normal, and if the callosal dimensions exceed the normal, the cortex will be correspondingly richer in its cellular elements.

Now it is widely held that the cells of the cerebral cortex, and particularly those of the supragranular layers, mediate the so-called higher psychical processes, and if this correlation between function and morphology does exist, obviously it might also be possible to estimate the degree of mental efficiency in any given case by the simpler expedient of measuring the area of the corpus callosum. That this is feasible has indeed been claimed by Spitzka,² from whose monograph the following striking quotation is taken:

‘Special studies in the form and size of the callosum in various brains prompt me to introduce some remarks concerning the prevailing ideas about the relative importance of white and grey matter (or, using more appropriate

* Towards the expenses of this research a grant was made by the British Medical Association.

terms, the alba and cinerea). So much has been said of the grey matter and its constituent nerve-cells that the very notable researches of Flechsig and his co-workers in the field of myelin-development are often overlooked.

'Were it not for the manifold connexion of such cells with each other as well as with the periphery by means of the millions and millions of fibres, such a brain, as already pointed out, would be as useless as a multitude of telephone or telegraph stations with all interconnecting wires destroyed.

'The bulk of (normal) white matter in the brain therefore signifies elaborate grey matter and hence the significance of brain weight in relation to brain-powers; for even though there be, as has been computed, over nine billion cells in the cortex, their weight is probably less than 1 per cent. of the total brain weight.

'But if there is still more intricate interconnexion of nerve-cells, out of proportion as it were (by means of untold numbers of association fibres) the mass of white matter must necessarily be greater. So characteristic is this preponderance of white matter in the brain of man, and so needful is such an elaboration and amplification of the cerebral architecture to the workings of the human mind, that it is only necessary to glance at the cross-sections of the brains of lower animals as compared with that of man while we pause to think that, after all, it is this enormous coordination of the separate units of thought and action which constitutes the somatic basis of the highest mental functions. And in the mammalian series, as we ascend from the small-brained marsupial with few callosal fibres to the great neopallial commissure which the brain of man exhibits, we may perceive an indication of the elaboration of at least one development of the great complex of association systems: I refer now to the bilateral coordinations exclusively. But beyond the fact that the fibres of the callosum connect like regions in the two hemispheres little more is expressed, and yet every case of deficiency or disease of this structure is attended by more or less weak-mindedness or downright idiocy, not to speak of hemiparetic and other affections. And the examination of the brains of those notable men, possessing large capacity for doing and thinking much more than their fellows, shows the converse to be quite as true. Compared with ordinary men, individually and collectively, they have larger callosa. The callosum of Joseph Leidy exceeds in cross-section area that of any other in this series or recorded in literature. Here again, then, we have an index in somatic terms of how we may distinguish the brain of the genius or talented man from that of persons of only ordinary abilities.'

In support of his contention Spitzka supplies two illustrations. In the first of these (fig. 1) the area of cross-section of the corpus callosum in the brains of ten eminent men is contrasted with similar measurements made on the brains of ten ordinary labourers, and from this chart it is clear that without exception the ten eminent men possess larger corpora callosa than the manual workers selected for comparison.

In the second diagram, which presents an outline drawing of the corpus

callosum of a man of genius, an eminent neurologist, a white labourer and a negro, the fall off in size in the order named is equally striking, the man of genius having a corpus callosum whose area on cross-section is no less than twice that of the negro.

Another anatomical method of approach is to be found in a study of acallosal brains in the human subjects. According to Baker and Graves³ there are now on record 82 cases of complete or partial agenesis, and in the majority of these the intellectual status has ranged from profound idiocy to a moderate degree of mental impairment.

In a few instances acallosal brains have been recorded in subjects who during life exhibited little or no intellectual defect, a finding which would

FIG. 1.—Chart showing the cross-section area of the corpus callosum in square cm. in the brains of 10 eminent men, compared with ten such of ordinary labourers, mechanics, etc. The largest callosum is that of Professor Leidy, the eminent morphologist; the smallest is that of a labourer of ordinary intelligence. After Spitzka.

appear to be inconsistent with the hypothesis that the corpus callosum is of importance in relation to intelligence; in such cases, however, the question of compensatory tracts, such as the *Balkenlangsbündel* of Probst,⁴ must be entertained.

On the experimental side it has been shown by Muratow,⁵ Seletzky and Gilula⁶ that in cats and dogs division of the callosal fibres, especially those of the genu, causes apathy and inactivity in the animals under observation; but perhaps the most convincing evidence of the importance of an intact corpus callosum for the proper performance of psychical functions is to be obtained from the study of pathological lesions. In the view of many recent writers, among whom Ironside and Guttmacher,⁷ Alpers and Grant,⁸ may be specially mentioned, in callosal tumours the mental symptoms are of exceptional severity and overshadow all other signs. From the first, patients show

an inability to concentrate and to maintain attention for even a short time. In addition, motor disturbances such as hemiparesis and apraxia are often present. How profoundly the intelligence can be affected by callosal lesions has been well expressed by Collier ⁹ in his address on localization of function in the nervous system. 'Mentality,' he states, 'should be a function of the nervous system as a whole. Very widely spread destruction or isolation of the cortex anywhere and in either hemisphere will, for a time at least, result in grave depression of this function. What has struck me forcibly in my clinical experience is that lesions of the prefrontal region involving the cortex are so much less potent in this respect than destructive lesions of the prefrontal white centre, extending as these often do backwards to catch the forward fibres of the corpus callosum and part of the radiation from the temporal isthmus, and the obvious inference is that by such lesions of the white matter so much more of the cortex is functionally isolated, so many more of the transcortical paths are severed, and the possibility of compensation by other regions of the cortex is thereby defeated. I have seen the gravest disturbances of mentality from cortical and from subcortical lesions in every part of the brain, but more from subcortical lesions; of all lesions producing mental reduction those of the corpus callosum, however, have been the most striking and constant, and especially when the splenium is destroyed. One can well realize why the great anatomist Willis was convinced that the seat of the soul was in the corpus callosum. He had doubtless seen, as I have seen several times, a lesion of this structure associated with such loss of memory from moment to moment, such disorientations of association in consciousness, the more striking for the complete absence of hebetude, as to convince one for all time of the high potency of transcortical lesions in breaking up higher nervous functions. It is to such transcortical lesions rather than to any cortical lesions that the phenomena of apraxia, agnosia and disorientation are attributable.'

With these considerations in view we have investigated the question of a possible correlation between size of the corpus callosum and mental age in normal controls and in a series of aments, whose mental ages had been determined during life.

METHOD

The area of medial cross-section of the corpus callosum was measured in 69 of our 71 brains from aments and from normal controls. The brains had all been fixed in 10 per cent. formol-saline. Of several methods of measurement examined, we found the most suitable and accurate to be that in which an image of the corpus callosum is projected on to white paper and then measured with Amsler's planimeter (an instrument which measures directly the area of an irregular shape).

For projection, we used an epidiascope, with a mirror arranged at an angle of 45 degrees in front of the lens and some distance from it so as to throw the image vertically downwards on to the table (fig. 2). The cut hemisphere was then placed in a padded dish with its mesial surface upper-

most and in contact with a sheet of glass in the epidiascope. In this way a brilliant image of the corpus callosum with all its details magnified about three diameters was thrown on to the sheet of white paper on the table. The actual magnification was measured accurately by projecting an inch scale from the same position in the epidiascope and measuring the size of the magnified image. It was found that by the use of a magnified image the accuracy of measurement of the corpus callosum is considerably increased.

In using Amsler's planimeter considerable error may be introduced by not starting and stopping at the same place. Errors due to this were avoided

FIG. 2.—Sketch of the apparatus used for measuring the area of the corpus callosum. E, epidiascope containing brain hemisphere; M, mirror; T, drawing table.

by drawing a fine line across the paper. The image of the corpus callosum was then thrown across this line, thus giving a precise point at which to start and stop.

Since there is definitely some personal factor in deciding exactly what is corpus callosum and what is not, particularly at its anterior end, all measurements were made by one person so as to eliminate this source of variability. Furthermore, so that no unconscious bias could creep in, the observer was not allowed to have access to the clinical records of this series while the measurements were in progress.

SOURCES OF ERROR

Before proceeding, it will be as well to discuss other possible sources of error in technique.

(i) *Correlated Errors*.—We have considered the technique carefully, and are of the opinion that errors correlated with other variables, such as mental age, etc., could not arise.

(ii) *Biased Errors*, i.e., reading all the measurements too high or all too low, are of little interest here, since we are comparing group with group, all done with the same technique. Any bias would affect the groups equally and hence would cancel out.

For the present, we have postponed the question of how much error of technique may be considered permissible in our series in any particular measurement. In a later communication we shall assign limits to the scope of the investigation and hope to show that it will be valid between these limits, provided that the fraction variance between patients does not exceed 0.265. (Variance is a measure of the 'scatter' between different observations.)

In this case the above fraction equals 0.032, and we may, therefore, conclude that our experimental technique is sufficiently accurate.

The question 'are the numbers sufficient?' is really part of the above question and will be discussed fully at a later date.

STATISTICAL DATA

For the statistical analysis of the data, we have used the methods of correlation and regression.

There are some other points with regard to the statistical side of the data which must be mentioned here.

1. As, in our cases, mental age is not normally distributed, the correlation coefficient has a meaning different from its usual meaning. This, however, does not affect the coefficient as a test of significance, and it is the latter which is important for our purpose. Furthermore, it will be noticed in the graph that the residual variance does not appear to be constant. This must affect the test of significance to some extent, but here the latter gives quite straightforward results, so it is unlikely that the slight change makes any appreciable difference to the final result.

2. On testing the data for deviation from linearity in order to make sure that the use of linear regressions was justifiable, it was found by Fisher's method of the analysis of variance that no significant deviation from linearity existed.

To discover whether there were any other disturbing variables present, the multiple regressions for area of corpus callosum on mental age, brain weight and body weight were calculated and the expected values found for each patient. The residual deviations were then found and were examined for correlations with any of our other data. There appeared to be no other correlations affecting the area of the corpus callosum. In particular, they were tested for any effect of sex, Mongolism and epilepsy, but none of these

variables showed any particular connexion with the area of the corpus callosum. There did not, therefore, appear to be any other disturbing factors present.

THE RESULTS

The results are given in Table 1. We have dealt here exclusively with the square root of the area and not with the area directly, as throughout this investigation, wherever possible, we shall be examining linear quantities, so as to make volumes, areas, etc., comparable.

Table 1 gives the square root of the area of the corpus callosum (measured at first in square cm.) for each patient.

ANALYSIS OF THE DATA

The relation between the area of the corpus callosum and mental age for the 69 cases is shown in fig. 3, where each dot represents the result for one person.

In the series, 60 brains were from defectives and nine from normal adults.

FIG. 3.—Shows 69 results for (square root) area of the corpus callosum plotted against mental age.

As we have assumed that a mental age of 14 years represents the mental level of a normal adult, the brains of the normal controls are at the extreme right-hand end of the figure, while the imbeciles and idiots occupy its left-hand side.

On examining the figure, we note that at first sight there seems to be a slight shifting up of the right-hand (normal) end. Calculating the correlation

TABLE I

Patients' no. in our series.	Sq. root area of corpus callosum.	Patients' no. in our series.	Sq. root area of corpus callosum.
1	2.26	36	2.46
2	2.37	37	2.12
3	1.79	38	2.34
4	1.36	39	2.76
5	1.41	40	1.62
6	2.38	41	1.93
7	2.51	42	2.76
8	2.53	43	2.24
9	1.93	44	2.30
10	2.08	45	2.07
11	2.02	46	2.58
12	2.21	47	2.16
13	2.41	48	2.33
14	1.35	49	2.14
15	2.28	50	2.45
16	2.02	51	2.10
17	2.07	52	2.23
18	2.35	53	2.18
19	1.77	54	2.36
20	2.51	55	2.33
21	—	56	2.20
22	2.28	57	2.21
23	2.34	58	2.24
24	2.58	59	2.75
25	2.30	60	—
26	2.48	61	2.47
27	2.49	62	1.79
28	2.16	63	2.56
29	2.53	64	2.55
30	1.99	65	2.46
31	1.62	66	2.26
32	2.50	67	2.50
33	1.22	68	2.59
34	2.47	69	2.68
35	2.15	70	2.46
—	—	71	2.24

coefficient we find it to be $+0.247$. Testing its (statistical) significance, using Fisher's method of the analysis of variance, we find it to be probably significant ($P = 0.035$). But while the area of the corpus callosum seems, therefore, to show a tendency to increase with mental age, yet we may notice the three largest corpora callosa belonged to three idiots.

But before we draw any conclusions, there are some complicating factors which must be disentangled. The area of the corpus callosum proves in our series to be correlated to some extent with body weight and with brain volume, and both these latter variables are themselves correlated with mental age.

Table 2 gives the necessary intercorrelations.

TABLE 2

	Area of corpus callosum.	Body weight.	Brain weight.
Body weight	$+0.3583$	—	—
Brain weight	$+0.7101$	$+0.2380$	—
Mental age	$+0.2466$	$+0.6160$	$+0.1527$

By using the method of partial correlations, it is found that when we eliminate the effect of body weight and the effect of brain weight the correlation between the area of the corpus callosum and mental age falls off from its first value of $+0.247$, which was just significant, to $+0.041$, which is quite insignificant.

From these considerations the important fact emerges that the area of the corpus callosum has no direct connexion with mental age, but that the apparent connexion is due to the fact that it tends to vary with the body weight and the brain weight. Both these latter tend to vary with mental age and hence provide a connexion between the corpus callosum and mental age.

Since the present communication is concerned with the brains of mentally defective persons we are not in a position to discuss Spitzka's contention that eminent men are invariably endowed with large corpora callosa. History teaches us, however, that some of the ablest men of letters have possessed remarkably small brains—and presumably proportionately small corpora callosa—so that a relatively small brain may yet be an instrument of exceptional human success. The presence in our series of three profound idiots whose corpora callosa were larger not only than those of the imbeciles and feeble-minded but also than any of the nine normal controls, suggests that Spitzka's attempt to use the corpus callosum as a simple anatomical criterion of cerebral function goes further than the facts actually warrant.

SUMMARY

1. We have measured the area of the mesial cross-section of the corpus callosum in 69 brains, 60 being from mental defectives of known mental age, and nine from normal people.

2. The technique and possible sources of error are discussed.

3. On testing for correlation between area of the corpus callosum and mental age, a significant correlation is found.

4. It is known, however, that there is a general trend in body size in the sense that body size tends to fall off with mental age, and on closer analysis the change in size of the corpus callosum with mental age appears to be simply part of the general change in size. That is to say, in our series, there is no evidence of any specific correlation between area of corpus callosum and mental age.

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