THE CRANIAL THICKNESS IN DOWN’S SYNDROME: FOURIER ANALYSIS*

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SUMMARY

Individuals exhibiting Down’s syndrome have been compared with normal controls to try to ascertain whether the cranial thickness from nasion to the occipital bone in the midsagittal plane is affected. A direct measurement of the cranial thickness is misleading since the cranial vault of the trisomics is significantly smaller and on allometric grounds, the cranial thickness can be considerably thinner and still fall within normal limits.

Fourier analysis, in opposition to the conventional metrical approach, was chosen because: (1) it can be used to accurately characterize complex irregular forms and (2) it allows for the control of size differences. A sample of 80 trisomics, controlled for age and sex, was matched with an equal number of normal controls. The cranial thickness in the trisomics was found to be significantly thinner after size had been controlled for. These results indicate that the cranial thickness in adult trisomics is relatively as well as absolutely thinner than that of normal controls, and reflects the accumulating effect of the abnormal growth process in Down’s syndrome.

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I. INTRODUCTION

Systematic morphological differences in the craniofacial region [7], the cranial base [2,8] and the cranial vault [5, 9] have been observed and quantitatively described in individuals exhibiting Down's syndrome when compared to normal controls.

Although measurements have established that the mongoloid cranial vault is smaller [9], the possibility that the thickness of the cranial bones is also affected has not been investigated. A direct measurement of the cranial thickness is misleading since the cranial vault is smaller in trisomy 21 cases in comparison to normals. Further, since the cranial thickness is correlated with size (allometry), a thinner cranial thickness would also be expected. Consequently, the cranial thickness in trisomics could be considerably thinner and still fall within normal limits. What is needed is a method that would correct for differences in size between comparison in this case a group of individuals with Down's syndrome and a group of normal controls.

As an accurate measurement of the cranial vault is a necessity, and since the conventional metrical approach based on lines and angles is insufficient, an alternative method is required.

In a previous study we have applied Fourier analysis as a curve-fitting procedure to characterize the shape of the mongoloid cranial vault and to attempt to detect the presence of statistically significant differences in shape between trisomics and controls [5]. Fourier analysis is particularly well-suited for accurately describing complex irregular forms and for effectively minimizing differences in size and maximizing differences in shape between comparisons.

II. MATERIALS AND METHODS

This study is based on 160 lateral cephalometric radiographs of which 80 are confirmed trisomy 21 cases, and 80 are normal controls. The individuals exhibiting Down's syndrome were of British ancestry living in Melbourne, Australia [8] while the normal controls were drawn from Southwestern Ohio whites enrolled in the longitudinal study administered by the Fels Research Institute, Yellow Springs, Ohio. Each group consisted of 40 males and 40 females of whom 20 were children (mean age 10.0 years) and 20 were young adults (mean age 21.8 years). The age distributions of the controls were matched as closely as possible to the ages of the trisomics.

The outer and inner margins of each cranial vault were traced onto acetate sheets for dimensional stability and the vectors numbered 0 to 52, were measured with a Helios dial caliper direct reading to an accuracy of 0.10 mm (Fig. 1). The 53 vector distances to the ectocranial and endocranial margins were separately measured. The choice of the vector center, C, was dictated by goodness-of-fit considerations [4, 5]. These vectors were then submitted as data to a specially written Fourier analysis program [6]. The output from this program consists of Fourier coefficients \(a_0, a_1, a_2, a_3, \ldots, a_n\) which uniquely describe the cranial vault for each individual case from nasion to the occipital region in the midsagittal plane. Two separate Fourier equations describe the vault, one for the ectocranium and one for the endocranium.

As more terms are added to the Fourier equation, a series solution, the closer the fit or convergence between the actual observed cranial outline and the predicted fit provided by the Fourier series. With the addition of 19 terms and the constant, \(a_0\) the difference or residual, defined as the average difference between the observed and predicted vectors to the cranial vault outline, is less than 0.30 mm on the average over
Fig. 1. The geometry and measurements used to define the ectocranial and endocranial margins from nasion to the occipital region in the midsagittal plane. N = nasion; ba = basion; S = sella; R = the midpoint of a perpendicular extended from sella to the nasion-basion line. The 55 vectors are constructed at 5° intervals.

the whole cranial vault. This figure is within the combined tracing and measuring errors.

Data derived in this fashion is still not suitable for analysis. Two further refinements are required. First, since comparisons are to be made between trisomics and normal controls, it becomes necessary that the cranial outlines be superimposed on a neutral center rather than the vector center, C (Fig. 1). This neutral center is the centroid. The choice of any other center results in a loss of information in the higher terms or harmonics [1].

Secondly, there remains the problem of size differences alluded to earlier. The cranial vault in individuals exhibiting the trisomy 21 syndrome is smaller, reflecting altered growth rates.

It is possible to «scale» the cranial vault up or down such that the area under the
ectocranial outline and bounded by the line from point 0 to point 52, is made the same. All cranial outlines have been adjusted to a constant area of 10,000π units. This effectively corrects for differences in size between comparisons.

Since the two Fourier functions, one for the ectocranial margin and the other for the endocranial aspect, are accurate representations or analogs of the actual observed cranial vault, it is a simple matter to calculate the cranial thickness. Conveniently, the constant or $a_0$ term in each series is also the mean of the vectors describing the cranial outline. Thus, the difference between constants yields an estimate of the average cranial thickness from nasion to the occipital region in the midsagittal plane.

Fig. 2. Within-group age differences uncorrected for size and area-standardized. Graphs show the mean cranial thickness as a function of age. Each sex is considered separately.
Fig. 3. Within-group sex differences uncorrected for size and area-standardized. Graphs depict the mean cranial thickness as a function of sexual dimorphism. Data controlled for age.

III. RESULTS AND DISCUSSION

The sample design facilitates within and between group comparisons, controlled for age and sex. Although the major concern is the presence of statistically significant differences in cranial thickness between trisomics and controls, within-group sex and age differences in cranial thickness are also of interest. The $t$-test results refer to the within-group comparisons in each case. For example, Figure 2 refers to the trisomic female children versus the trisomic female adults, etc. The sample size is 20 for each comparison. The cranial thickness increases with age in both groups, trisomic and controls, as expected; however, the increase in thickness with age is considerably less
in the trisomics when compared to normal controls. This applies equally to the female as well as the male trisomics.

Figure 3 depicts the within-group sex differences. Again, the $t$-tests refer to the within-group comparisons. While the cranial thickness is greater in males in each comparison, this is due, in part, to allometry. The area-standardized procedure makes this allometric effect apparent in the trisomics. That is, the statistically significant difference ($p<0.05$) between the male and female trisomic children disappears when size is corrected for. However, the within-group sex differences in the adult trisomics remain statistically significant after size has been corrected for. This would suggest
that the abnormal growth pattern is more pronounced in females (Fig. 3d). The reason for this sex difference is not readily apparent and, if valid and not due to sampling, merits further study.

The between-group differences for trisomics versus normal controls, corrected for age and sex, are shown in Figure 4. The systematic growth retardation in the trisomics is clearly evident. Again, once size has been controlled for by the area-standardization procedure, the statistically significant differences between the trisomic female children and the normal children become nonsignificant. In contrast, the between-group differences when corrected for size, remain statistically significant in the adult trisomics when compared to controls (Fig. 4d).

These results indicate that the cranial thickness in adult trisomics is relatively as well as absolutely thinner than that of normal controls. This retardation reflects the accumulating effect of the abnormal growth process in Down’s syndrome.

REFERENCES