SUMMARY

In fifty-two children aged between 7 and 598 weeks the segmental spread of caudal epidural analgesia was measured. The effects of age, weight and height on dose requirements were studied by multiple regression techniques. The highest correlation existed to the age variable, the next highest to weight, and the lowest but still highly significant correlation to the height in this patient group. It is shown that the age variable alone is sufficient for establishing an optimum model for prediction. Further, it is confirmed that dose requirements increase with age in a linear manner. The regression equation can be used for the determination of dose requirements in clinical practice.

For small children and infants a form of anaesthesia is desirable which largely avoids postoperative vomiting and the subsequent risk of dehydration. At the same time it should permit oral fluid administration within the first hour after surgery is completed. Regional anaesthesia, as used in adults, can be applied to children with some modifications and it would seem to fulfil the above requirements. The modifications have to take into account a mostly unco-operative patient as well as a somewhat different anatomical situation. A combination of light general anaesthesia induced prior to regional blockade presents a useful technique. This is practised in a number of institutions. The most frequent regional techniques performed in this manner are brachial plexus and both lumbar and caudal epidural anaesthesia. (Bromage, 1962, 1969; Davenport, H. T., 1963, personal communication; Fortuna, 1967; Quan, M., 1964, personal communication; Ruston, 1964).

It is obvious that the dosage of local analgesics has to be guarded closely, particularly in infants and small children. The maximum dosage for plain lignocaine of 7 mg/kg body weight and 10 mg/kg for solutions with adrenaline, as found by Bromage and Robson (1961) for adults, presumably applies to children as well. Bromage (1962, 1969) discussed the various intrinsic and extrinsic factors governing the spread of solutions in the epidural space. In several graphs he showed the relationship of age, height and segmental dose for 2 per cent solutions of lignocaine, mepivicaine and prilocaine for the ages from 4 to 102 years. He stated: "In childhood the capacity of the space is small but it increases steadily with growth until full height and development are reached at about 16–20 years." Through these observations we became interested in the dose requirements of young children. But in order to reduce the total dose of lignocaine we used a 1 per cent solution with adrenaline 1:100,000 and tried to ascertain the quantity required to block a single spinal segment. In Bromage's patients, both adults and children, lumbar epidural block was employed. It could therefore not be assumed per se that the spread would be similar when caudal blocks were used.

METHODS

Fifty-two children from 7 to 598 weeks in age, who were to undergo lower abdominal or genitourinary surgery, were induced with inhalation anaesthesia using nitrous oxide, oxygen and halothane in a partial rebreathing system whilst lying on their side. Once the lid reflex had disappeared, the sacral region was prepared with thiomersal.

O. SCHULTE-STEINBERG, M.D., Department of Anaesthesia, Kreiskrankenhaus, Starnberg, Germany; V. W. RAHLFS, PH.D., Institut für Datenanalyse und Versuchsplanung, Munich, Germany.
Following identification of the sacral cornua a 20-
gauge needle was inserted through the skin over-
lying the sacral hiatus pointing in upward direc-
tion at an angle of 65–70° while the bevel was
turned toward the feet (see fig. 1). When the
needle pierced the sacrococcygeal ligament there
was a characteristic give. The epidural space had
now been entered. Care was taken not to advance
the needle into the sacral space, which extends
lower down in children than in adults. On no
occasion was spinal fluid obtained on aspiration
with this technique nor did any high spinal block-
ade occur.

One per cent lignocaine with adrenaline
1:100,000 was used in all cases. The dosage was
calculated at 0.1 ml per 1 dermatome to be
blocked per 1 year of age. (For example, 0.3 ml
per 1 dermatome for a 3-year-old.) This amounted
to dosages between 2 and 5 mg/kg and never
exceeded 6 mg/kg. The injection was made at
about 1 ml/sec. Records were kept of the amount
of anaesthetic solution used in each case and of
the age, weight and height of the patients.

Following the injection the child was turned
into the supine position and skin preparation for
surgery was begun. Approximately 10 minutes
later, provided there was no alteration in pulse
rate, respiration and size of pupils due to surgical
stimulus, the initial concentration of halothane
was reduced from 1.5 to 0.5 per cent. The
lack of alteration of the above-named vital func-
tions was taken as an indication of a satisfactory
level of analgesia. Subsequently the halothane
concentration was maintained at a level just
sufficient to prevent movement; in some cases it
was discontinued. The concentrations required
with this method were much lower than those
needed in unblocked patients.

The children always reacted to painful stimuli
in unblocked areas at the end of the surgical pro-
cedure. Analgesia was tested using a 20-gauge
needle from the groin towards the head on each
side. Since there was no need for direct com-
unication with the arousing patient, we had
remarkably little difficulty in obtaining the exact
margin between sensitive and analgesic skin. The
pinprick test was done several times on each side
and the extent of analgesia judged by the start of
defensive movements when sensitive skin was
entered. Each time two to three observers were
present to confirm the findings and to avoid bias.

To permit a comparison with work by other
authors similarly dose requirements were defined
as:

<table>
<thead>
<tr>
<th>Dose of analgesic solution injected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of analgesic dermatomes</td>
</tr>
</tbody>
</table>

ANALYSIS OF DATA AND RESULTS

Purpose of the data analysis was to build a model
in the framework of which dose requirements
could be predicted from the observable age,
weight and height with optimum accuracy. This
could be done by fitting the standard multiple
regression model to the data. The regression
equation in its simplest form is

\[ Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \]

in which \( Y \) denotes the dependent variable to be
predicted and \( X_1, X_2, \ldots, X_n \), the independent vari-
ables. The coefficients \( b_0, b_1, \ldots, b_n \), are to be calcu-
lated from the data in such a way that prediction
is optimum. This may be accomplished by use of
the so-called least squares criterion. Accuracy of
prediction may be specified in per cent by help of
\( R^2 \), the coefficient of determination.
Fig. 2
The age distribution on normal probability paper.

Fig. 3
The logtransformed age distribution on normal probability paper.
Fig. 4  Distribution of dose requirements on normal probability paper.

Fig. 5  Distribution of logtransformed requirements on normal probability paper.
As a first step to analysis the distributions of the most important variables were investigated graphically. Deviations from a normal distribution are easily recognized if the cumulative distribution is plotted on normal probability paper. In figure 2 it may be seen that the age data do not fit the straight line well and that the curve sometimes has a staircase shape which naturally is the consequence of the fact that the data were collected under normal clinical conditions. Figure 3 shows that a logarithmic transformation of the age data will not improve the situation.

Figure 4 depicts the distribution of the dose requirement data on normal probability paper. The points show a slight curvature, a fact which may be prevented to some extent by a logtransformation (fig. 5). Thus a logtransformation of the data of this variable perhaps will improve the fit of the regression model.

The statistics of the four variables are as follows:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age (weeks)</td>
<td>157.80</td>
<td>130.00</td>
<td>147.18</td>
</tr>
<tr>
<td>2. Weight (kg)</td>
<td>14.50</td>
<td>13.10</td>
<td>8.36</td>
</tr>
<tr>
<td>3. Height (cm)</td>
<td>93.10</td>
<td>92.50</td>
<td>27.20</td>
</tr>
<tr>
<td>4. Dose ml/spin. seg.</td>
<td>0.35</td>
<td>0.25</td>
<td>0.29</td>
</tr>
</tbody>
</table>

The coefficients of correlation of the variables may be arranged in matrix form:

1. 2. 0.95
2. 3. 0.94 0.95
3. 4. 0.94 0.90 0.86

From these figures it may be derived that the dose (variable 4) has the highest correlation to the age (variable 1), the next highest to weight (variable 2) and the lowest but still high correlation to height (variable 3).

Multiple regression technique showed that only one variable was sufficient for optimum prediction of dose requirement: the other coefficients were insignificant (P>0.05) and barely increased the power of prediction. This fact is not surprising because all the independent variables are highly interrelated. The regression equation was:

\[ Y = 0.0261 + 0.001969 \times \text{age in weeks} , \]

the coefficient of determination being 87.66 per cent. It is apparent that the prediction could not be improved by this procedure.

Another approach was attempted in which the dependent variable was logtransformed as had been suggested by figure 5. However, the degree of prediction turned out to be worse \( R^2 = 82.17 \) per cent. Because of the small number of data it seemed not worth while to try fitting a more complicated model such as, for example, a polynomial model of higher order.

It must be concluded, therefore, that the first regression equation represents the best model for these data. The correctness of this regression model was checked by examining the residuals, i.e. the differences between the predicted and the actual values of the Y-variable. The residuals were plotted against the predicted values as well as against the values of the independent variable. The diagrams did not indicate abnormalities so that the model does not appear to be invalidated.

The calculations have shown that a simple equation with one independent variable represents a model of optimum prediction. The coefficient of determination shows that the accuracy of prediction is good: 87.71 per cent of the variation of the dependent variable is explained by age. Figure 6 depicts the scattergram of the two variables, the linear relationship being represented by the straight line. So the best guess for dose requirement in individual cases may be made by help of the regression line.

The standard error of the estimate \( (s_{\hat{y}}) \) is 0.104. The parallel dashed lines in figure 6 at a vertical distance of 1.96 \times standard error of the estimate mark off the region within which we expect 95 per cent of the observed values to lie.
The calculated regression line gives an average estimate for prediction, the precision being inferred from the standard error of estimate. For practical purposes, however, in order to be more certain of the analgesic effect, we would recommend the use of the value interpolated from the line plus one standard error of estimate, i.e. plus 0.1.

Thus the dosage schedule is given in the following table:

<table>
<thead>
<tr>
<th>Year</th>
<th>Regression line</th>
<th>Regression line + SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.153</td>
<td>0.253</td>
</tr>
<tr>
<td>2</td>
<td>0.250</td>
<td>0.350</td>
</tr>
<tr>
<td>3</td>
<td>0.348</td>
<td>0.448</td>
</tr>
<tr>
<td>4</td>
<td>0.445</td>
<td>0.545</td>
</tr>
<tr>
<td>5</td>
<td>0.542</td>
<td>0.642</td>
</tr>
<tr>
<td>6</td>
<td>0.640</td>
<td>0.740</td>
</tr>
<tr>
<td>7</td>
<td>0.737</td>
<td>0.837</td>
</tr>
<tr>
<td>8</td>
<td>0.834</td>
<td>0.934</td>
</tr>
<tr>
<td>9</td>
<td>0.932</td>
<td>1.032</td>
</tr>
<tr>
<td>10</td>
<td>1.029</td>
<td>1.129</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Previously the dose requirements for epidural analgesia in children had to be calculated from the equation of Bromage (1969) which was based on the data from 25 subjects aged from 4 to 20 years, large majority (21 cases) being in the upper age range. Thus the regression equation in this study which has been calculated on the basis of data from 52 cases aged from 7 to 598 weeks allows a more precise estimation of dose requirements for infants and very young children.

Nevertheless the two regression equations are quite similar:

1. \( Y = 0.1063 + 0.07531 \times \text{age in years} \) (Bromage, 1969);
2. \( Y = 0.0558 + 0.09729 \times \text{age in years} \) (this paper).

The fact that Bromage made use of 2 per cent lignocaine with 1:200,000 adrenaline instead of 1 per cent with 1:100,000 adrenaline will not invalidate the comparison, as in the earlier work of Bromage it was shown that the 1.2 per cent
line is approximately parallel to the 2 per cent line (although from 20 to 80 years), so that at least the regression coefficients have to be quite similar.

It is interesting to note that the degree of determination or precision in prediction is the same in both studies: the coefficient of correlation between the two critical variables in both studies amounts to 0.94.

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REFERENCES


