asked about any case, both for information and to establish why an unusual procedure has been carried out. Most cases are not discussed in detail as they are uncomplicated and not of particular clinical interest. Important complications and misdiagnoses are, however, discussed in considerable depth when the case warrants it. Radiological investigations are also reviewed. A free and open discussion then takes place to discover if and when errors of judgement took place. Deaths are treated in a similar fashion, and particular attention is paid to those cases where the underlying condition was not fatal. Two examples that were freely discussed in this way during the last year were acute appendicitis in a young patient who later developed fatal septic shock and a patient who died from a duodenal fistula. This developed in a chronically malnourished man after simple closure of a large perforated duodenal ulcer.

Results

In the first year of the review the general surgeons in the Salford Area reported the admission of 5774 patients, including patients admitted as day cases. There were 4440 operations carried out with a reported complication rate of 5.8%. The 215 patients who died during the year included those admitted to the wards for terminal care.

On reviewing the misdiagnoses, we found that very few had serious implications. Thus the confusion of acute gynaecological disorders with acute appendicitis, a commonly recognised diagnostic problem, was reported on 15 occasions. Only rarely were serious misdiagnoses reported.

Initially the audit was somewhat subdued because all surgeons, especially the junior ones, felt that open discussion was critical of both themselves and their colleagues. This inspired a rather defensive reaction to begin with, but as the weeks passed and members of surgical teams realised that the discussion was essentially fair and non-aggressive, the atmosphere changed. Junior surgeons commented that it was useful to hear the more experienced surgeons indicating their own approach to problems such as haematemesis, the management of abdominal injuries, and whether certain investigations were valuable in some crises.

Discussion

"No clinician should be averse to some form of feedback of performance that permits an external critique."² The complex auditing procedures carried out in the United States are not at present applicable in this country, for they demand expensive and extensive administrative machinery and their value has yet to be proved. Nevertheless, the type of examination of surgical practice we have described is possible in both district general

and teaching hospitals. It can be carried out only by doctors who understand the problems being discussed, and for this reason it should be open only to the staffs of the units concerned. Occasionally, however, visiting surgeons may be invited to join in the audit and discuss the cases. The attendance of anyone else would undoubtedly inhibit the frank discussions that take place. It is important that those in charge of the auditing procedure must not be aggressive, especially to the junior staff, who may have had to make difficult decisions in less than ideal circumstances. An audit such as we have described undoubtedly has a positive educational role as the experience of the more senior surgeons is pooled during discussion of difficult problems. The main difficulty would appear to be that of boredom and repetition, yet there is usually sufficient variety of material each week to provide a lively clinical discussion on the week's work.

One further advantage is that an audit such as this gives the opportunity for differences in surgical practice to be aired without fear or favour. For example, some surgeons routinely carry out sigmoidoscopy under general anaesthesia—is this necessary? Another example is the treatment of pilonidal sinus—is wide surgical excision, leaving the wound to granulate, justifiable now that minor procedures, such as Lord's operation, are available? Finally, difficult ethical decisions, such as the wisdom and efficacy of operating on very old patients with ruptured aortic aneurysms, may also be freely discussed.

To undertake an audit less frequently than once a week would mean that many cases would be left undiscussed simply because of the volume of work that passes through the units. Regular monitoring of the clinical work load should not, however, detract from or replace normal postgraduate activities such as clinico-pathological conferences to discuss in detail the more interesting cases. With the establishment in a hospital of such a group a way is open for the health authorities to refer statistics derived from the Hospital Activity Analysis for discussion.

We acknowledge the co-operation of our surgical colleagues Mr J R N Curt, Mr A W Hargreaves, Mr G Ingram, and Mr R W Marcuson, and their junior staff, without whose help this venture could not have been started.

References

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- ² Dudley, H A F, *Proceedings of the Royal Society of Medicine*, 1975, **68**, 634.

Statistics at Square One

XIX—Correlation (continued)

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Calculation of correlation coefficient

When making the scatter diagram (Part XVIII, fig 18.2) to show the heights and pulmonary anatomical dead spaces in the

15 children he was studying, Dr Green set out the figures as in cols (1), (2), and (3) of table 19.1. It is helpful to arrange the observations, as he has done, in serial order of the independent variable when one of the two variables is clearly identifiable as independent. The corresponding figures for the dependent variable can then be examined in relation to the increasing series for the independent variable. In this way we get the same picture, but in numerical form, as appears in the scatter diagram.

The calculation of the correlation coefficient is as follows, with x representing the values of the independent variable (in this case height) and y representing the values of the dependent variable

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(in this case anatomical dead space). The formula to be used is

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

The computation is as follows:

Note number of observations of x	..	..	..	..	n
Find the sum of the x observations	..	..	..	..	$\sum x$
Find the mean of the x observations	..	..	..	..	$\bar{x}$
Find the sum of the squares of the x observations	..	..	..	..	$\sum x^2$
Find the square of the sum of the x observations	..	..	..	..	$(\sum x)^2$
Divide this by n	..	..	..	..	$\frac{(\sum x)^2}{n}$

Find the sum of the squared differences of the observations from the mean, $\sum(x - \bar{x})^2$, from the identity $\sum x^2 - \frac{(\sum x)^2}{n}$.

This procedure is exactly the same as in finding the standard deviation, except that we here stop at finding the sum of the squared differences between the observations and their mean, $\sum(x - \bar{x})^2$.

The procedure is then repeated for the y observations, so that from the identity $\sum(y - \bar{y})^2 = \sum y^2 - \frac{(\sum y)^2}{n}$ we likewise have the sum of the squared differences of the y observations from their mean.

Multiply $\sum(x - \bar{x})^2$ by $\sum(y - \bar{y})^2$ and take the square root

This gives us the denominator of the formula.

To obtain the numerator we proceed as follows:

Multiply each value of x by the corresponding value of y and add these products together

Multiply the sum of the x observations by the sum of the y observations

Divide this product by the number of pairs of observations

Subtract (3) from (2)

This is identical to $\sum(x - \bar{x})(y - \bar{y})$ (4)

Finally, divide (4) by (1) to give the correlation coefficient, r.

The calculations on Dr Green's data follow—see also table 19.1, columns (4), (5), and (6). In practice the separate values for $\sum x^2$, $\sum y^2$, and $\sum xy$ are not written down as they are in the table but accumulated in the calculator to form the totals given at the foot of those columns.

n = 15	n = 15
$\sum x = 2169$	$\sum y = 1004$
$\bar{x} = 144.6$	$\bar{y} = 66.93$
$\sum x^2 = 318889$	$\sum y^2 = 75030$
$(\sum x)^2/n = 313637.4$	$(\sum y)^2/n = 67201.07$
$\sum(x - \bar{x})^2 =$	$\sum(y - \bar{y})^2 =$
$\sum x^2 - \frac{(\sum x)^2}{n} = 5251.6$	$\sum y^2 - \frac{(\sum y)^2}{n} = 7828.93$
$\sum xy = 150605$	
$(\sum x)(\sum y)/n = 145178.4$	
$\sum(x - \bar{x})(y - \bar{y}) = \sum xy - \frac{(\sum x)(\sum y)}{n} = 5426.6$	
$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} = \frac{5426.6}{\sqrt{5251.6 \times 7828.93}} = 0.846$	

The correlation coefficient of 0.846 indicates a strong positive correlation between size of pulmonary anatomical dead space and height of child. But in interpreting correlation it is important to remember the familiar adage, *correlation is not causation*. There may or may not be a causative connection between the two correlated variables. Moreover, if there is a connection it may be indirect, so that their mutual variation has a common cause elsewhere.

A part of the variation in one of the variables (as measured by

TABLE 19.1—Correlation between height and pulmonary anatomical dead space in 15 children

Child number (1)	Height in cm (2)	Dead space in ml (3)	Col (2) squared x^2 (4)	Col (3) squared y^2 (5)	Col (2) $\times$ col (3) xy (6)
1	110	44	12100	1936	4840
2	116	31	13456	961	3596
3	124	43	15376	1849	5332
4	129	45	16641	2025	5805
5	131	56	17161	3136	7336
6	138	79	19044	6241	10902
7	142	57	20164	3249	8094
8	150	56	22500	3136	8400
9	153	58	23409	3364	8874
10	155	92	24025	8464	14260
11	156	78	24336	6084	12168
12	159	64	25281	4096	10176
13	164	88	26896	7744	14432
14	168	112	28224	12544	18816
15	174	101	30276	10201	17574
Total	2169	1004	318889	75030	150605
Mean	144.6	66.93			

its variance) can be thought of as being due to its relationship with the other variable and another part as due to undetermined (often "random") causes. The part due to the dependence of one variable on the other is measured by r^2 . In Dr Green's investigation $r^2 = 0.716$. So we can say that 72% of the variation in size of the anatomical dead space is accounted for by the height of the child.

Standard error

The correlation coefficient also has a standard error, which for large samples is approximately $\frac{1-r^2}{\sqrt{n}}$.

However, to test the deviation of r from 0, or nil correlation, it is better to use the t test in the following calculation:

$$t = r \sqrt{\frac{n-2}{1-r^2}}$$

The t table is entered at $n-2$ degrees of freedom.

For example, the correlation coefficient for Dr Green's figures was 0.846. The number of pairs of observations was 15. Applying the above formula, we have

$$t = 0.846 \times \sqrt{\frac{15-2}{1-0.846^2}} = 5.72$$

Entering the t table at $15-2=13$ degrees of freedom we find that, at $t=5.72$, $P < 0.001$. So the correlation coefficient may be regarded as highly significant.

Exercise 19. In a part of Kenya the incidence of kala-azar in homesteads was related to the proximity of termite hills.¹ Presumably this was because the sandfly that transmits the protozoon causing the disease found shelter there. A doctor wanting to know whether this relationship was also true for another part of Kenya visited 16 homesteads in which 40 or more people lived and for each homestead made two measurements: (1) the percentage of people suffering from kala-azar; (2) the mean distance of the five nearest termite hills. The two observations for each homestead were as follows: (1) 21%, 68m; (2) 12%, 103m; (3) 30%, 17m; (4) 8%, 142m; (5) 10%, 88m; (6) 26%, 58m; (7) 42%, 21m; (8) 31%, 33m; (9) 21%, 43m; (10) 15%, 90m; (11) 19%, 32m; (12) 6%, 127m; (13) 18%, 82m; (14) 12%, 70m; (15) 23%, 51m; (16) 34%, 41m. What is the coefficient of correlation between percentage of kala-azar cases and mean distance of termite hills? *Answer:* $r = -0.848$.

Reference

¹ Southgate, B A, and Oriedo, B V E, *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 1962, **56**, 30.