Functional Outcome Measures in Stroke Rehabilitation
Frank Vanclay, MSocSci

I examine statistical considerations in the analysis of functional outcome following stroke and discuss the mathematical relation between improvement in function and discharge functional score. I demonstrate mathematically that the predictor variables of improvement and discharge functional score are the same and that the regression coefficients for improvement and discharge functional score will be equal, except for the admission functional score, for which a mathematically defined relation exists. I argue that the relation between admission functional score and discharge functional score must be positive and strong and that the relation between admission functional score and improvement must be negative for the stroke population. I believe that an ignorance of statistical concepts, especially confounding, and of the differences between raw correlations, partial correlations, and predictors have led to much confusion in functional outcome research. (Stroke 1991;22:105–108)

Jongbloed1 critically reviewed 33 studies that examined factors associated with functional outcome following stroke. Since the studies reviewed had different goals, methods, and measurement tools, she encountered difficulties in comparing the results. However, Jongbloed stated that "discharge function and improvement are very different measures" and that the "variables which predict improvement in functional status differ from variables which predict functional status on discharge." I show that the predictors of improvement and outcome are the same, that there is a mathematical relation between improvement and discharge functional score, and that considerable confusion has resulted because of a misunderstanding of the purposes of the different measures of outcome, the mathematical relations among the different measures, the effect of confounding in statistical analysis, the difference between predictors and correlates of outcome, and the statistical methods of examining predictors/correlates of the different measures.

Measures of Functional Outcome

The three most common functional outcome measures used in stroke research are improvement in function, discharge functional ability, and functional ability at a specified time after stroke. However, a number of other measures, including rehabilitation effectiveness (proportion of maximum potential improvement actually obtained) and rehabilitation efficiency (average daily improvement) are also used.2–4

These outcome measures can be based on any functional assessment scale. However, technically, if improvement, rehabilitation efficiency, or rehabilitation effectiveness are to be calculated from a scale or if the discharge functional score is to be used in regression analysis or other forms of statistical analysis, that scale should be of interval or ratio level. Many functional outcome scales are only ordinal in nature, and much statistical violation occurs with their use in multivariate analyses. Jongbloed further criticized many of the authors she reviewed for failing to use standardized measures, for using self-developed scales, and for using scales with unknown reliability and validity. The Barthel Index, recognized as the best measure of functional ability,5–7 is arguably of ratio level, although it needs modification to increase its sensitivity.8

Functional independence scales measure functional ability at one point in time. Functional score on discharge from rehabilitation, or at any specified time after stroke, can be used alone as one measure of stroke outcome. For the argument that follows, I consider a score of functional ability assessed at a fixed time after stroke, even following discharge from rehabilitation, to be equivalent to the discharge functional score. While Jongbloed1 may prefer consistency in results by measuring outcome at some fixed point in time, recovery patterns may change following discharge from rehabilitation. Functional assessment at a fixed point in time following the onset of stroke is not free from the influence of the
length of rehabilitation. Functional outcome following discharge from rehabilitation is an issue separate from functional recovery during rehabilitation and should be treated separately.

The improvement in functional score from commencement of rehabilitation to discharge, or any other point in time, can be calculated. Discharge functional score is useful in providing information as to the suitability of discharge placements, while improvement score provides information about the success of rehabilitation. Each measure has its own merits and disadvantages, and neither is inherently superior.

The maximum potential improvement score for patients with high admission scores is lower than that for those with lower admission scores due to the maximum possible score on the scale. One measure of improvement that adjusts for admission score is rehabilitation effectiveness, which can be interpreted as the percentage achievement of the maximum potential improvement. Rehabilitation effectiveness is calculated as actual improvement divided by maximum potential improvement times 100% to reflect the proportion of potential improvement actually obtained during rehabilitation. That is, rehabilitation effectiveness = (discharge score − admission score)/(maximum score − admission score) × 100%. For the Barthel Index, the maximum score is 100.

Rehabilitation efficiency relates to the amount of improvement averaged over the duration of rehabilitation and can be regarded as the average increase in functional ability per day. That is, rehabilitation efficiency = (discharge score − admission score)/duration of rehabilitation.

Rehabilitation effectiveness and rehabilitation efficiency provide a basis for measuring the success of rehabilitation, in terms of both individual patient performance and rehabilitation center performance.

Statistical Considerations

When analyzing a relation between two variables, there are three considerations: significance, strength, and confounding. While significance and strength are concepts that are widely understood by people with even minimal statistical training, confounding, the most important of these three considerations, is the most ignored and least understood.

Confounding occurs when the observed relation between two variables is only a product of the effect of another variable. Confounding may be reinforcing (i.e., the third variable accentuates the real relation between the two variables) or suppressing (i.e., the effect of the third variable hides the real relation between the two variables). It is important to consider the causal relation between the confounding variable and the other variables being considered. These causal relations are classified into three types: antecedent, intervening, and spurious.

To identify the true independent effect of one variable on another, a partial correlation, which controls for the confounding variable, is computed. Some of the confusion identified by Jongbloed has occurred because the issue of confounding has been ignored in stroke outcome research. Confounding is particularly likely to occur and influence the results of research in studies that have ad hoc samples.

Raw correlations describe the relation between two variables without taking into account potential confounding by other variables. Partial correlations describe the relation between two variables while controlling for the influence of one or more other variables. Correlations, both raw and partial, do not imply a causal direction. Correlates are variables that have observed correlations with other variables.

While much research has attempted to find the correlates of functional outcome, it is possible that many of the reported correlates do not have a nonspurious effect on functional outcome. That is, after controlling for some logically antecedent variable, such as admission functional score, these correlates do not continue to have a unique effect on outcome. In that case, they are not very important in any analysis of functional outcome. Theoretically, only those variables that have nonspurious correlations with functional outcome are important. Nonspurious means that the relation is not artificial and not only due to confounding by a key variable, such as age or admission score.

Predictors are those variables that alone or in combination with other variables can be used to estimate the value of another variable and that are usually selected by some form of multivariate analysis. Predictors are variables that have an independent correlation with the dependent variable after controlling for potential confounding by the other predictor variables being considered.

Many variables are correlated with functional outcome. However, much intercorrelation exists among the correlates of functional outcome, causing a great deal of potential confounding. For example, given that admission functional status is correlated with discharge functional status and that age is correlated with admission functional status (unpublished data), the research question should not be whether age is correlated with discharge functional status, but whether age has an independent effect on discharge functional status after controlling for admission functional status. In other words, does age have a nonspurious correlation with discharge functional ability and is age useful as a predictor of discharge functional ability? Research suggests that after controlling for admission functional status, age continues to have an effect on outcome. Jongbloed's difficulties in comparing different studies' results arose partly because some researchers reported raw correlations while others reported nonspurious correlates and/or predictors.

Admission Functional Score and Outcome

The relation (correlation) between admission functional score and discharge functional score can only be positive and strong for the population of
stroke patients simply because those with high admission scores will have high discharge scores regardless of the effectiveness of rehabilitation (unless the patients suffer extended strokes or other complications) and because at least some of those with low admission scores will have discharge scores less than those with high admission scores. The only situation for which the correlation between admission score and discharge score could be less than moderate (i.e., weak correlation, no correlation, or negative relation) is one in which only those stroke patients with high admission scores suffered extended strokes or did not improve and only those with low admission scores exhibited substantial, near perfect, improvement. It is impossible for this to happen unless the sample is nonrepresentative of the population or there is considerable confounding by other variables.

By definition, the correlation between improvement and admission functional score can only be negative for the population of stroke patients. Those with high admission scores can experience only limited improvement since there is a maximum value that can be obtained. For the Barthel Index, individuals whose admission score is 90 can have a maximum potential improvement of only 10, while those whose admission score is 40 can have a maximum potential improvement of 60. The strength of the relation depends on the distribution of scores for the sample being considered.

Researchers who find contrary results will discover that their data are confounded by other variables, that their sample is not representative of the population, or that their sample examines only a restricted range of admission function.

Relation Between Improvement and Discharge Score

The mathematical derivation of improvement is

\[ \text{Improvement} = \text{discharge score} - \text{admission score} \]  
(1)

Accepting that admission score (A) is one of the predictors of discharge score,\textsuperscript{1,15} the regression formula for discharge score will be

\[ \text{Discharge score} = b \times A + f \text{ (other variables)} \]  
(2)

where f(other variables) is a linear function of other variables. Alternatively, f(other variables) could be replaced by \((x_1 + x_2 + \ldots + x_n)\) or by \((x + y + z)\) where \(x_1, x_2, x_n, x, y,\) and \(z\) represent other variables such as age, onset to hospital admission, hospital admission to rehabilitation commencement, and comorbidity that might contribute to the prediction of functional outcome.

Substituting Equation 2 into Equation 1,

\[ \text{Improvement} = b \times A + f \text{ (other variables)} - A \]  
(3)

Reducing Equation 3 provides

\[ \text{Improvement} = (b - 1) \times A + f \text{ (other variables)} \]  
(4)

Equation 4 establishes that the predictive variables for improvement are the same as the predictive variables for discharge score, \textit{by definition}, except that the raw regression coefficient for admission score in the improvement model will be equal to the coefficient in the discharge model minus 1.0.

Note that the logic of the above mathematical proof holds only when improvement or discharge functional ability is being estimated at the same point in time. It is possible to assess discharge functional score at any time prior to discharge, with variables relating to length of rehabilitation, extension of stroke, type of rehabilitation, etc. included as the potential predictors. However, if discharge functional score and improvement score are being assessed at the same point in time (such as at admission to rehabilitation) with the same set of potential predictors, there will be no difference in the variables selected.

Rehabilitation Effectiveness and Rehabilitation Efficiency

Rehabilitation efficiency is expressed as a rate of improvement and can be substantially influenced by the length of rehabilitation. Therefore, rehabilitation efficiency is not a true outcome measure and cannot be compared with other outcome measures. Rehabilitation effectiveness is a measure of improvement that adjusts for admission functional score. Consequently, there is no simple relation between improvement or discharge functional score and rehabilitation effectiveness, although admission functional score is correlated with it\textsuperscript{2} due to the influence of the non-linear relation between admission function and discharge function.\textsuperscript{15} Because rehabilitation effectiveness adjusts for admission score, in stepwise regression analysis the variables selected as predictors of rehabilitation effectiveness will differ from those selected as predictors of improvement and discharge score.\textsuperscript{2}

One problem with rehabilitation effectiveness as an outcome measure is that it is overly sensitive at the upper end. This becomes a problem in patients with an extension of the stroke, and extreme outliers occur. The impact of these outliers in terms of variable selection is difficult to determine; however, such outliers would partly explain the much reduced \(R^2\) of rehabilitation effectiveness (0.30)\textsuperscript{2} compared with discharge functional score (0.61).\textsuperscript{15} Since stroke extension can serve only to reduce the amount of explained variance and lower the expected outcome score, a preferable strategy would be to exclude patients with stroke extensions from analyses such as this. This was not done in the research of Shah et al.\textsuperscript{12,15} because of their population basis. However, in most situations, should a patient suffer an extension of the stroke, then a new admission score should be calculated and a new prediction made.
Conclusion

There is a mathematically defined relation between improvement in function and discharge functional score. Predictors of improvement must be the same as predictors of discharge functional score, by definition, with the regression coefficients being equivalent for all variables except admission functional score. For admission functional score, the regression coefficient in an improvement model will equal the coefficient in a discharge model minus 1.0.

Admission functional score theoretically must have a strong positive relation with discharge functional score and a negative correlation with improvement. However, experimentally, the relation between admission function and outcome is not linear, and a quadratic equation (admission score squared) is appropriate. 15

Confusion has occurred because of a misunderstanding of the difference between correlates and predictors and a misunderstanding of the importance of confounding.

References


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F Vanclay

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