Quality measurement in the shunt treatment of hydrocephalus: analysis and risk adjustment of the Revision Quotient

Clinical article

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Object. The Revision Quotient (RQ) has been defined as the ratio of the number of CSF shunt revisions to the number of new shunt insertions for a particular neurosurgical practice in a unit of time. The RQ has been proposed as a quality measure in the treatment of childhood hydrocephalus. The authors examined the construct validity of the RQ and explored the feasibility of risk stratification under this metric.

Methods. The Kids’ Inpatient Database for 1997, 2000, 2003, 2006, and 2009 was queried for admissions with diagnostic codes for hydrocephalus and procedural codes for CSF shunt insertion or revision. Revision quotients were calculated for hospitals that performed 12 or more shunt insertions annually. The univariate associations of hospital RQs with a variety of institutional descriptors were analyzed, and a generalized linear model of the RQ was constructed.

Results. There were 12,244 admissions (34%) during which new shunts were inserted, and there were 23,349 admissions (66%) for shunt revision. Three hundred thirty-four annual RQs were calculated for 152 different hospitals. Analysis of variance in hospital RQs over the 5 years of study data supports the construct validity of the metric. The following factors were incorporated into a generalized linear model that accounted for 41% of the variance of the measured RQs: degree of pediatric specialization, proportion of initial case mix in the infant age group, and proportion with neoplastic hydrocephalus.

Conclusions. The RQ has construct validity. Risk adjustment is feasible, but the risk factors that were identified relate predominantly to patterns of patient flow through the health care system. Possible advantages of an alternative metric, the Surgical Activity Ratio, are discussed.

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Key Words • CSF shunt • hydrocephalus • quality • Revision Quotient

The dominant historical theme of clinical research in the treatment of childhood hydrocephalus has been technique: how to perform an operation, how to minimize complications, how to keep children out of the hospital. The implicit assumption of this line of work has been that, if the optimal operation could be defined, then all surgeons would agree on the indications for it, all surgeons would perform the procedure equally well, and all surgeons would exercise the same judgment about whether treatment has failed. This assumption cannot be true, but it has remained unexamined until relatively recently.

In the multicenter, prospective, randomized trials of the 1990s, precise definitions of shunt failure and shunt infection were critical. Interobserver reliability in recognition of these end points proved to be good but not perfect.4 Homogeneity of surgical skill was examined as well and was judged to be sufficient to support the conclusions of the trials.5,8

In the last decade the behavior of surgeons and the experiences of patients have been examined outside the context of prospective clinical trials through studies of large registries and administrative data sets. In 2002 Cochrane and Kestle reported a population-based analysis of CSF shunt surgery for childhood hydrocephalus based on data from the Canadian Institute for Health Information.3 Variations...
tion in shunt survival and shunt infection rates was noted to be linked to the experience of the operating surgeon. In related work, Kestle, Cochrane, and Drake documented seasonal variation in adverse shunt outcomes peaking in July and August in data from the Shunt Design and the Endoscopic Shunt Insertion Trials and from the Canadian Hospital Discharge Database. Smith et al. used the Nationwide Inpatient Sample to study admission mortality rates for children undergoing CSF shunt surgery between 1998 and 2000. The authors documented wide variation among hospitals in rates of failure of first CSF shunts. Hospitals with higher volumes of initial shunt insertions had lower revision rates. In a multivariate analysis, revision rates in the Midwest were higher than in other regions.

Variation in the quality of surgical care for children with hydrocephalus appears to be real. A quality metric that can be calculated consistently from readily accessible data and adjusted for risk would be useful for neurosurgeons and neurosurgical practices that wish to compare their experiences with national benchmarks, but no such metric exists. The Revision Quotient (RQ) has been defined as the ratio of the number of CSF shunt revisions to the number of new shunt insertions for a particular neurosurgical practice in a unit of time. Wide variation in the RQ has been demonstrated among hospitals in the US. Whether this variation can be attributed to case mix, surgeon skill, surgeon judgment, hospital practice patterns, or other factors is unknown. In this report we examine epidemiological aspects of CSF shunt surgery as they relate to the RQ, develop a statistical model for risk adjustment, and consider whether the RQ fulfills the requirements for a useful, acceptable quality metric.

Methods

Study Sample

The Kids’ Inpatient Database (KID) is a compilation of deidentified discharge data from a sample of all hospital discharges of patients in the pediatric age range from community, nonrehabilitation hospitals in the US. The sampling is stratified and the files are weighted to allow extrapolation of incidences on a nationwide or regional basis or on the basis of hospital size, location, teaching status, or categorization by the National Association of Children’s Hospitals and Related Institutions (NACHRI). The KID is prepared every 3 years by the Healthcare Utilization Project of the Agency for Healthcare Research and Quality in cooperation with participating states. Each KID includes roughly 10% of all discharges of uncomplicated in-hospital live births and roughly 80% of discharges of complicated births and other pediatric cases from each sampled hospital. This study used the KIDs for 1997, 2000, 2003, 2006, and 2009. Except for the 1997 KID, which was limited to children from birth through 18 years of age, these data sets included children from birth through 20 years of age. Each admission file incorporates between 15 and 25 fields for ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) diagnostic codes and 15 fields for ICD-9-CM procedure codes.

Code Inclusions and Exclusions

Admissions were extracted for study on the basis of the concurrence of diagnostic codes for hydrocephalus (331.X, 742.3, 741.XX) and procedure codes for insertion or revision of a CSF shunt (02.32–02.35, 02.41, 02.42, 03.71, 03.72, 03.79, 03.97, and 54.95). The intention was to capture admissions of patients with active hydrocephalus who were managed with the goal of discharge with a working shunt. Endoscopic third ventriculostomy (ETV) was not considered in this study because the procedure code, 02.2, can be used imprecisely for external ventricular drainage and because there is no code for revision ETV. Review of the raw data indicated that procedure code 02.31 was used commonly for insertion of ventriculostubgaleal shunts; this code was excluded from study. Likewise, the code 02.39 was used commonly for external ventricular drainage; it too was excluded.

Attention to context was critical to identify admissions during which CSF shunt treatment was undertaken for the first time and to count insertions and revisions. If the principal diagnosis field for an admission contained the code for shunt malfunction (996.2), all the shunt surgery codes during that admission were counted as revisions. Likewise, if the principal procedure field contained a code for shunt revision or removal (02.41, 02.42, 02.43, 03.97, 03.98, and 54.95), all the shunt surgery codes during that admission were counted as revisions. Finally, if any diagnosis field contained a code for shunt infection (996.63), all the shunt surgery codes during that admission were counted as revisions. Procedures to remove shunts were not counted (02.43, 03.98). If an admission was coded for multiple shunt insertions, all but 1 of these procedures were counted as revisions.

Limited etiological classification of hydrocephalus was undertaken in a stepwise fashion. Admissions with a diagnostic code for myelomeningocele (741.XX) were so classified. Then admissions with a code for a brain or spinal cord tumor were classified as “neoplastic.” Next, admissions with codes for intraventricular hemorrhage, birth-related intracranial hemorrhage, prematurity, low birth weight, neonatal respiratory distress syndrome, bronchopulmonary dysplasia, retinopathy of prematurity, or necrotizing enterocolitis were classified as posthemorrhagic hydrocephalus. Remaining admissions with a code for congenital hydrocephalus (742.3) were so classified, and all the rest were classified as “other.” Identification of cases of posthemorrhagic hydrocephalus in this fashion by context with other diagnoses related to prematurity appeared plausible only in infancy, so, where specified, etiological analysis was stratified by age.

Statistical Analysis

Associations between categorical variables were analyzed by cross-tabulation and the chi-squared test. Differences between distributions of continuous variables
were compared by analysis of variance and by t-tests for independent samples. Where p values are not specified, denotation of significance implies \( p < 0.05 \). Variables that exhibited significant univariate associations with the RQ were entered into a generalized linear model for multivariate analysis. Variables were incorporated into the generalized linear model if they retained significance at the \( p < 0.05 \) level. Excel (Microsoft Corporation) and SPSS (version 19, IBM Corp.) were used for data organization and statistical testing. This study was supervised by the Nemours Delaware Valley Institutional Review Board.

Results

Epidemiology of Shunt Surgery

In the convenience sample extracted from the KID, there were 35,593 admissions coded for hydrocephalus and insertion or revision of a CSF shunt. Females accounted for 45% of admissions. Infants less than 12 months of age accounted for 34% of admissions. Data on race were available for only 27,888 admissions (78%). The racial distribution of admissions was 57% white, 16% black, 19% Hispanic, and 7% other. The primary payer was listed as commercial in 48% of admissions. A new CSF shunt was inserted during 12,244 admissions (34%). The diagnoses of patients undergoing initial shunt insertion were myelomeningocele in 14.6% of admissions, neoplastic hydrocephalus in 12.6%, posthemorrhagic hydrocephalus in 14.4%, congenital hydrocephalus in 20.4%, and other in 38.0%.

Weighted nationwide estimates of the distribution of annual admissions for shunt surgery among various NACHRI categories of children's facilities are presented in Table 1. The NACHRI category "children's specialized hospital" accounted for a very small number of admissions and was excluded in this and following analyses. Facilities categorized as "not identified as a children's hospital" accounted for a very small number of admissions by transfer: 9.8%, 11.7%, and 14.7% at "not children's hospitals," children's units in general hospitals, and children's hospitals, respectively.

Revision Quotients were calculated for each hospital in the data set that had 12 or more shunt insertions in any particular year. Not every hospital was sampled in all 5 years of data collection. Three hundred thirty-four annual RQs were calculated for 152 different hospitals. The RQs varied between 0.06 and 10.92, with a median value of 2.53 and an interquartile range of 1.78–3.40. The mean RQ weighted by volume of new insertions was 2.72, and the weighted standard deviation was 1.26. Weighted RQs were normally distributed.

The premise of studying RQs is that practice patterns tend to persist over time; that is, such patterns must persist if the RQ is to have construct validity. As RQs were calculated by hospital and by year, and as many hospitals were documented in 2 or more years, construct validity was tested by ANOVA. Hospital identity accounted for a dominant proportion in the south. This pattern was also true for weighted estimates of new shunt insertions and total shunt operations (data not shown). Estimated nationwide totals were "not children's hospitals," 10,574 admissions (17%), children's units in general hospitals, 25,856 admissions (43%), and children's general hospitals, 24,365 admissions (40%). Thus, over the epoch of this study, the majority of admissions for CSF shunt surgery (60%) occurred at institutions not categorized by NACHRI as dedicated children's hospitals.

Another health system factor with potential impact on hospital RQs is how patients access care. Transfer from another medical facility accounted for 12.5% of all admissions for shunt surgery, but transfer accounted for 22.5% of admissions for insertion of a new shunt. Of admissions by transfer, 61.5% were coded for new shunt insertion, compared with 30.2% of admissions from other sources (\( p < 0.0005 \)). Thus, in the majority of instances, the occasion for transfer from another medical facility was initial treatment. Increasing degrees of pediatric specialization were associated with increasing proportions of admission by transfer: 9.8%, 11.7%, and 14.7% at "not children's hospitals," children's units in general hospitals, and children's hospitals, respectively.

The RQ

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Weighted RQs were analyzed with respect to hos-
The Revision Quotient and hydrocephalus

Hospital characteristics and with respect to case mix (the clinical characteristics of new patients undergoing initial shunt insertion). Hospital characteristics included year, annual volume of new patients, region, teaching status, and NACHRI category. On a univariate basis, only NACHRI category had a significant association with RQ: the mean RQs at children’s hospitals, children’s units in general hospitals, and “not children’s hospitals” were 3.01, 2.53, and 1.95, respectively (overall p < 0.0005; pairwise comparisons all p < 0.05, ANOVA with orthogonal contrasts). The case mix of the hospital practices were analyzed on the basis of the proportions of admissions for initial shunt insertion coded for the following: infant age group, female sex, commercial insurance, lower two median-income-of-home-ZIP-code quartiles, and origin of hydrocephalus. The following factors had significant correlations with RQs: infant age group (Pearson correlation coefficient = -0.554, p < 0.0005), posthemorrhagic hydrocephalus origin (Pearson correlation coefficient = -0.205, p < 0.0005), neoplastic origin (Pearson correlation coefficient = -0.165, p = 0.002), and low median-income-of-home-ZIP-code (Pearson correlation coefficient = -0.143, p = 0.009). Additionally, the proportion of all hospital admissions for shunt surgery arising from transfers from other acute care facilities correlated highly with weighted RQ (Pearson correlation coefficient = -0.233, p < 0.0005).

In multivariate analysis, the following generalized linear model accounted for 40.8% of the total variance of RQ:

\[
\text{MODEL} = 6.081 - 0.768 \cdot N_1 - 0.431 \cdot N_2 - 7.181 \cdot FR_{\text{TUMOR}} - 6.671 \cdot FR_{\text{INFANT}}
\]

in which \(N_1\) takes the value 1 for NACHRI category “not children’s hospital” and 0 otherwise (p = 0.001); \(N_2\) takes the value 1 for NACHRI children’s unit in a general hospital and 0 otherwise (p = 0.001); \(FR_{\text{TUMOR}}\) represents the fraction of initial cases with neoplastic hydrocephalus (p < 0.0005), and \(FR_{\text{INFANT}}\) represents the fraction of initial cases in the infant age group (p < 0.0005). For the purpose of evaluating the power of the model, hospitals were characterized as “high RQ” or “low RQ” if their RQs were more than 1 standard deviation above the mean or less than 1 standard deviation below, respectively. For the model’s prediction of high RQ status, the area under the receiver operating characteristic curve was 86%. For prediction of low RQ status the area under the receiver operating characteristic curve was 85%. Measured and predicted RQs are presented in Fig. 2.

**Discussion**

The current study establishes the construct validity of the RQ, in which the RQ of a particular hospital in a particular year is more closely related statistically to the RQs of that hospital in other years than to the RQs of other hospitals. Whatever factors may contribute to the determination of the RQ, they tend to persist over time.

The NACHRI category accounted for a small but significant proportion of the observed variance in RQ: increasing degrees of pediatric specialization were associated with higher RQs. One might hypothesize that difficult, complex patients who require more frequent shunt revisions tend to drift up the ladder of specialization and that these challenging patients contribute to the higher RQs of children’s general hospitals. As noted, analysis of patient ages was inconclusive but not supportive on this point. The senior author’s personal impression has been that distressing clusters of shunt revisions at short intervals tend to precede rather than to follow removal of care to a new practice or hospital. Nevertheless, the hypothesis of drift to increasing pediatric specialization is plausible and cannot be dismissed on the basis of evidence developed in this study.

The NACHRI category and other health care system
factors accounted for most of the explicable variation in RQ. The small contribution of neoplastic etiology to hydrocephalus is easily understood. Patients who die of their brain tumors require no more shunt revisions, and patients who are cured of their tumors are often cured of their hydrocephalus as well. Furthermore, patients with brain tumors tend to continue in follow-up at the institutions where they receive initial treatment. Those institutions capture credit for the initial shunt insertion, which augments the denominator of the RQ. The substantial contribution of infant age group and its negative correlation with RQ is less self-evident, but it is easily explained: infants account for the great majority of new diagnoses of childhood hydrocephalus. We hypothesize that parents exercise little control over the setting of their infant’s initial care. Many newborns, for instance, undergo initial shunt insertion at the hospital where their mothers happened to receive obstetrical services. After discharge from initial care, however, parents may exercise the opportunity to transfer their child to a more highly specialized center. The initial operation at the hospital of birth may even be performed by a neurosurgeon from an affiliated children’s hospital, in which case transfer of care to the more specialized facility can be expected to occur in the natural course of follow-up. In this scenario, the denominator of the RQ is augmented at the first hospital, and all subsequent shunt revisions augment the numerator of the RQ at the second hospital. This hypothesis is consistent with the higher proportion of infants in the initial case mix of NACHRI “not children’s hospitals” than at hospitals with greater pediatric specialization (data not shown, p = 0.036). As NACHRI category retained significance in the multivariate analysis, transfer of care after the initial hospitalization does not explain all of the association of greater pediatric specialization with higher RQ. Although it did not retain significance in the multivariate model, the influence of the structure of the health care system on RQ is apparent as well in the negative correlation between RQ and proportion of patients admitted by transfer. As most transfers result in new shunt insertions, they tend to augment the denominators of the RQs of the receiving institutions.

The Surgical Activity Ratio

The statistical model of RQ developed in this study rests almost entirely on health care system phenomena rather than clinical phenomena. Furthermore, there is no assurance that the current model accounts for all of the variance arising from system factors. A quality metric that categorizes neurosurgical performance to such a substantial yet uncertain degree on the basis of practice setting is not optimal. A related metric, the Surgical Activity Ratio (SAR), may be more to the point. The SAR of a neurosurgical practice is defined as the ratio of operations performed for treatment of hydrocephalus in a period of time divided by the total number of patients with hydrocephalus in follow-up during that period of time. In a simulation it exhibited less random variation from year to year than the RQ. The SAR ought also to be less sensitive to health care system factors, such as the mix of new and previously treated patients entering a neurosurgical practice, and to be more reflective of neurosurgical skill and

![Fig. 2. Risk adjustment of RQs. Observed RQs (black circles) are plotted with their corresponding ranked model scores (confluent gray squares) ± 2 standard deviations (gray lines).](image-url)
strategy. Unfortunately, SARs cannot be calculated from the KID or from other data sets that are limited similarly to hospital activity.

Study Limitations

Endoscopic third ventriculostomy was an invisible factor in the current study. In a data set with sufficient precision, ETV might be incorporated together with shunt surgery into calculation of comprehensive metrics that provide a more realistic and global picture of the management of hydrocephalus.

Large administrative data sets have many well-known limitations as material for clinical research. There is no identification of individual patients in the KID, so longitudinal study is impossible. Only limited clinical data are available in the KID, so of particular concern for this project was the precision of ICD-9 codes and the accuracy of the coding. The absence of a specific diagnostic code for posthemorrhagic hydrocephalus was a major obstacle, as it was probably the leading origin of childhood hydrocephalus during the study epoch. Identification of cases of posthemorrhagic hydrocephalus by association with other diagnostic codes specific to prematurity was a weak method and applicable only among infants. This method created an artificial linkage between posthemorrhagic hydrocephalus and infancy, and therefore between posthemorrhagic hydrocephalus and initial shunt insertion. Imprecision of procedural codes was problematic as well. The scope of the current study did not extend to ETV because of poorly defined coding practices during the study epoch. There is no ICD-9 code for removal of a shunt with replacement. Replacement of a shunt after a period of external CSF drainage could only be distinguished from initial insertion of a shunt by coding context, as described at length in the Methods. Compounding the structural limitations of the ICD-9 system was the unknown reliability of the coding process.

Not all states report race to the KID data. These missing data made extrapolations of analyses of race to a nationwide population base impossible. Furthermore, state-by-state decisions to report or not report data on race may correlate with state-by-state racial disparities in health care services and outcomes. Race was not considered in the current analysis.

For all its weaknesses the KID has notable advantages over the available alternative data sets for epidemiological study of childhood hydrocephalus in the US. The National Hospital Discharge Survey is conducted by the Centers for Disease Control and Prevention (http://www.cdc.gov/nchs/nhds.htm). Like the Healthcare Utilization Project databases, the National Hospital Discharge Survey is a survey of hospital discharges designed to permit nationwide extrapolation. The samples in this survey, however, are smaller than the KID samples by more than an order of magnitude, and the National Hospital Discharge Survey includes adults as well as children. At some expense, qualified researchers can obtain data regarding services provided through Medicaid from the Centers for Medicare & Medicaid Services (http://www.resdac.org). Medicaid sourcing of data necessarily excludes nearly half of the pediatric hydrocephalus population that has commercial insurance, but longitudinal tracking of individual patients is possible. Study of the Medicaid data set may shed light on hypotheses generated in the current study regarding flow of patients through the health care system. The PHIS contains extremely detailed and comprehensive clinical and financial information from 40 regionally noncompeting children’s hospitals (http://www.research.chop.edu/programs/cpe/docs/AdminDataforResearch.ppt). The PHIS supports longitudinal analysis as well, and this feature has been exploited in the study of CSF shunts.11–13 The PHIS is limited as a basis for study of practice variation, however, because of its restricted set of reporting hospitals. There are no control data from less specialized hospital settings. The Hydrocephalus Clinical Research Network maintains a dedicated and detailed registry supplied by neurosurgical units at 9 major children’s medical centers in North America (http://www.hcrn.org). The Hydrocephalus Clinical Research Network registry has been the basis for many useful investigations of focused clinical questions,7,9,10,15–17 but its very narrow base of contributing institutions makes it unsuitable for study of nationwide practice variation. Because its investigators have access to outpatient data, however, the Hydrocephalus Clinical Research Network could be an effective setting for pilot study of the SAR and comparison of the SAR and the RQ.

Conclusions

The RQ has construct validity, to the extent that institutional practice patterns tend to persist over time, and risk adjustment is possible. Practice setting and the patterns in which patients move through the health care system exert a substantial influence on the RQ that may blunt its sensitivity as a measure of neurosurgical performance. A related metric, the Surgical Activity Ratio, may overcome these limitations, but study of combined inpatient and outpatient data will be necessary to test it.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Piatt. Acquisition of data: both authors. Analysis and interpretation of data: Piatt. Drafting the article: Piatt. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Piatt. Statistical analysis: Piatt. Administrative/technical/material support: Piatt. Study supervision: Piatt.

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