

Use of Discharge Abstract Databases to Differentiate among Pediatric Hospitals Based on Operative Procedures

Surgery in Infants and Young Children in the State of Iowa

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Introduction: A pediatric hospital may aim to show governmental agencies, charitable organizations, and philanthropic individuals how its clinical services differ from those of non-pediatric surgical facilities and of other pediatric hospitals. Yet, it is unknown how to use existing databases to quantify where infants and young children undergo surgery, and to use that information to differentiate among facilities.

Methods: Discharge abstracts were used to study inpatient and outpatient operative procedures performed between January and June 2001 in children 0–2 yr old at hospitals or hospital-affiliated outpatient surgery centers in Iowa.

Results: Of the 93 facilities performing at least one procedure, the 90 performing 15 or fewer different types of procedures provided surgical care for 80% of procedures. Among procedures performed at these 90 facilities, less than 0.15% were physiologically complex (more than seven American Society of Anesthesiologists' basic units). In contrast, at the larger and smaller pediatric hospitals, the percentages were 26% and 7%, respectively. These pediatric hospitals performed 181 and 73 different types of procedures, respectively; 64% of the physiologically complex procedures performed statewide were performed at the larger pediatric hospital. The smaller pediatric hospital was no more similar to the larger pediatric hospital in its relative volumes of each type of procedure than it was to the other 91 facilities.

Conclusions: Statewide discharge abstract data can be used by a hospital to quantify how its surgical practice differs from that of other hospitals (e.g., to show that it provides a more diverse, comprehensive, and physiologically complex selection of procedures in younger patients).

A PEDIATRIC hospital may seek to differentiate itself from other facilities with respect to the types of services that it provides, both to attract more patients and to secure more financial support from governmental agencies, charitable organizations, and philanthropic individuals. Yet, little^{1,2} is known about the demographics of pediatric surgery and the types of procedures performed in pediatric *versus* nonpediatric hospitals. For example, pediatric hospitals may not perform much of the pedi-

atric surgery in a state. In California, more than 85% of hospitals providing inpatient surgical care for infants performed less than one operation per week on infants.¹ In a rural state such as Iowa, pediatric hospitals are located far from many patients. Children may have routine surgery at closer facilities that perform few procedures each year, or they may undergo physiologically complex procedures at nonpediatric³ facilities.

Even if information were available about where children undergo surgery, little is known about how to differentiate types of procedures performed among surgical facilities. Criteria do not exist for quantifying differences among facilities in the types of procedures performed.

This article describes our results in using inpatient and outpatient state discharge abstracts to quantify the operative services provided for children 0–2 yr old by pediatric and nonpediatric surgical facilities throughout Iowa. The American Academy of Pediatrics' guideline is that each facility should have minimum volumes for pediatric surgery in this age group.⁴ Our goals were twofold. First, we evaluated how to use statewide discharge abstracts to quantify where infants and young children have surgery in a state. Second, we investigated the volume, diversity, and physiologic complexity of operative procedures to learn how a pediatric hospital can differentiate itself from nonpediatric facilities and from other pediatric hospitals.

Methods

Databases

We used the State of Iowa inpatient and outpatient discharge abstract database, January 1, 2001, to June 30, 2001. This database included all cases performed in the 117 hospitals and two hospital-affiliated freestanding outpatient surgery centers statewide.

Procedures and diagnoses were coded by each facility using the *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM). Some of the outpatient procedures were coded using Current Procedural Terminology codes. These were converted to the corresponding ICD-9-CM as specified by the Iowa Hospital Association's Statewide Outpatient Database's Outpatient Procedure Dictionary.

Population sizes for Iowa and its counties were from the year 2000 census.

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A hospital was considered to be a pediatric hospital if it sponsored an accredited pediatric residency or had major participation with an accredited pediatric residency.³ This was determined from the pediatric residency section of the American Medical Association's Fellowship and Residency Electronic Interactive Database (accessed on September 1, 2002).

Two hospitals in Iowa sponsor or have major participation in accredited pediatric residencies.[§] We refer to them as the larger and smaller pediatric hospitals based on the number of hospital beds. These are also the only two children's hospitals listed by searching from the Children's Miracle Network's home page (www.cmn.org, accessed on January 17, 2003).

Operative Procedures

We limited consideration to the 1,558 inpatient admissions and 3,318 outpatient visits among children 0–2 yr old with an operating room and/or anesthesia charge. We studied operative procedures (*i.e.*, procedures that are frequently associated with operating room charges).⁵ For example, diagnostic procedures (ICD-9-CM 87.0 and greater) were excluded. We added the requirement that an incision be made for a procedure to be operative.⁵ For example, cardiopulmonary bypass (39.61) was excluded. We did not require that there be surgical closure for a procedure to be operative. For example, myringotomy with insertion of tube was included (20.01). With these definitions, there were 5,671 operative procedures performed during 462 inpatient admissions and 3,143 outpatient visits.

Comparison of Operative Procedures among Facilities

We explored six ways of assessing the characteristics and diversity of the operative procedures performed at different facilities: the number of procedures performed at each facility, the number of different types of procedures performed at each facility, the physiologic complexity of the procedures performed at each facility, the number (percentage) of different types of procedures for which each facility performed the most in the state, the internal Herfindahl index of the facility, and the similarity of the facility to other facilities in the state.

Physiologic Complexity of Procedures

The physiologic complexity of procedures was assessed using the American Society of Anesthesiologists' (ASA) Relative Value Guide (RVG) basic units.^{6–8} We considered a procedure to be "physiologically complex" if it had more than seven ASA RVG basic units.^{6,7} For example, repair of syndactyly (three units), repair of

inguinal hernia (four units), adenoidectomy (five units), and pyloromyotomy (seven units) were not considered to be physiologically complex.^{5–8} Repair of myelomeningocele (eight units), creation of ventriculoperitoneal shunt (10 units), craniectomy for craniosynostosis (11 units), posterior segmental instrumentation (13 units), Blalock-Taussig shunt (15 units), and complex pediatric cardiac surgery repairs (20 units) were considered to be physiologically complex.^{6–8}

Discharge abstracts use ICD-9-CM procedure codes. ASA RVG basic units are obtained from Current Procedural Terminology codes.⁸ As described in detail previously,⁶ we obtained the ASA RVG basic units from the ICD-9-CM procedure codes by modifying a Current Procedural Terminology to ICD-9-CM Crosswalk (ADP Context, Inc., Westmont, IL, 1999 edition). Although for each ICD-9-CM there were from one to 122 different Current Procedural Terminology codes, for almost all ICD-9-CM all of the relevant Current Procedural Terminology codes either had seven or fewer ASA RVG basic units or eight or more basic units.⁶ Exceptions were ICD-9-CM for which the relevant number of basic units depended on the anatomic location. For example, the basic units for "biopsy of lymphatic structure" (40.11) vary depending on whether these are internal mammary nodes, superficial nodes, and so forth. Then, we relied on the anatomic location determined from the patient's other diagnoses and procedures.

Number of Different Types of Procedures and Internal Herfindahl Index

The diversity or comprehensiveness of the types of procedures performed at a facility can be quantified by the number of different types of procedures performed at the facility.⁹ For example, outpatient surgery facilities are often classified based on whether they are single *versus* multiple specialty.¹⁰ Quantifying diversity using the number of different types of procedures is simple conceptually. However, it is a biased estimator with poor precision because it addresses only whether a type of procedure is performed, not how often.

The internal Herfindahl index of a facility is a statistically reliable measure of the same parameter, the diversity or comprehensiveness of the types of procedures performed at a facility. The internal Herfindahl index equals the sum of the squares of the proportions of all procedures at a facility that are accounted for by each type of procedure.⁹ That is, it equals the probability that if two procedures are selected at random, both will be of the same type of procedure. Whereas the number of different types of procedures only considers whether a type of procedure is performed at a facility, the internal Herfindahl index uses data on how often each type of procedure is performed.

As examples, first suppose that a facility performed three types of procedures, in relative proportions of 75%, 15%,

[§] The larger pediatric hospital has Iowa's only neonatal-perinatal medicine, pediatric cardiology, pediatric otolaryngology, and pediatric radiology residencies. A pediatric surgery residency is not available in Iowa.

and 10%. These could represent a facility's frequencies of myringotomy with insertion of tube, adenoidectomy without tonsillectomy, and tonsillectomy with adenoidectomy. The internal Herfindahl index would equal 0.60, where $0.60 = (0.75)^2 + (0.15)^2 + (0.10)^2$.

Second, suppose that a facility performed only one type of procedure among children 0–2 yr old (e.g., myringotomy with insertion of tube). Then, the internal Herfindahl index would equal 1.0, where $1.0 = (1.00)^2$. The index equals its maximum value of one when a facility “specializes” in only one type of procedure.

Third, suppose that the facility performed 100 types of procedures, each with a relative proportion of 1%. Then, the internal Herfindahl index would equal 0.01, where $0.01 = 100 \times (0.01)^2$. The minimum value of the internal Herfindahl index equals one divided by the number of different types of procedures performed at the facility.

Similarity of the Surgical Practices at the Two Pediatric Hospitals

The similarities of the relative frequencies with which different types of procedures were performed at pairs of facilities was assessed using Yue and Clayton's index.¹¹ This similarity index is a correlation coefficient between the percentages of all procedures at each facility that are accounted for by each type of procedure. Specifically, suppose that a procedure is selected at random from all of the procedures performed at each of the two facilities. The numerator gives the probability that both procedures will be of the same type of procedure (i.e., analogous to the internal Herfindahl index). The denominator normalizes the sum of the probabilities to between 0 and 1. The similarity index equals zero when there is no overlap in the types of procedures performed between two facilities. The index equals one when the relative frequency with which each type of procedure is performed is the same between facilities.

Statistical Methods

Confidence intervals for percentages were obtained using the Clopper-Pearson method.¹² Equations for the standard error of the internal Herfindahl index are given in the Appendix. Equations and algorithms to calculate the standard error of the similarity index are given in the Appendix. In the Appendix, we also describe the algorithm that we used for comparing similarity indices between two or more pairs of hospitals.

Results

Volume

During the 6-month period studied, 93 of the 119 hospitals and freestanding hospital-affiliated outpatient

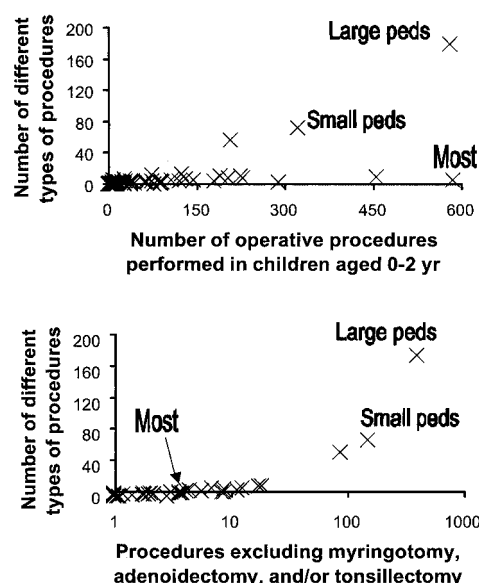


Fig. 1. Volume and diversity of the operative procedures performed in children 0 to 2 yr old. The larger pediatric hospital (*Large peds*) and smaller pediatric hospital (*Small peds*) differ from other hospitals in Iowa in that they are more comprehensive (i.e., perform many different types of procedures). Other facilities in Iowa perform a high volume of operative procedures in young children. However, those facilities perform much fewer types of procedures, mostly routine pediatric otolaryngology procedures. For example, the facility performing the most procedures (*Most*) does just seven different types of procedures. The values on the horizontal axis of the lower pane were jittered slightly so that overlapping points would be visible.

surgery centers in Iowa performed at least one procedure in children 0 to 2 yr of age (fig. 1). The 57 facilities performing between one and 25 procedures (i.e., an average of < 1 procedure per week) accounted for 7.3% of the 5,671 procedures performed statewide (95% CI, 6.6% to 8.0%).

Diversity of Procedures (Comprehensiveness)

The three most common types of procedures were myringotomy tube placement, adenoidectomy, and tonsillectomy and adenoidectomy (table 1). At the facilities performing between one and 25 procedures, only 6.6% of procedures were of a type other than one of these three (95% CI, 4.4% to 9.4%).

The 11 most common types of procedures together accounted for 90% of all procedures (table 1). At the facilities performing between one and 25 procedures, only 2.7% of procedures were of a type other than one of these 11 (95% CI, 1.3% to 4.7%).

Some hospitals with high surgical volume did not perform many different types of procedures (fig. 1). For example, the facility performing the most procedures performed only seven types of procedures. The 90 hospitals performing 15 or fewer different types of procedures provided surgical care for 80% of procedures (95% CI, 79% to 81%).

Table 1. Characteristics of Operative Procedures Performed in Children 0 to 2 Yr Old in Iowa

ICD-9-CM Code	Description of Type of Procedure with Specified ICD-9-CM Code	% of Total Procedures Statewide	% of Facilities that Performed at Least One Such Type of Procedure
20.01	Myringotomy with insertion of tube	72.74	93.5
28.6	Adenoidectomy without tonsillectomy	8.45	55.9
28.3	Tonsillectomy with adenoidectomy	3.97	52.7
43.3	Pyloromyotomy	1.06	19.4
53.0	Unilateral repair of inguinal hernia	0.69	16.1
53.02	Repair of indirect inguinal hernia	0.62	17.2
2.34	Ventricular shunt to abdominal cavity	0.51	3.2
38.85	Surgical occlusion of thoracic vessel	0.48	3.2
28.2	Tonsillectomy without adenoidectomy	0.42	11.8
53.1	Bilateral repair of inguinal hernia	0.42	4.3
20.09	Other myringotomy	0.32	11.8
Overall percentage		90	99
95% lower CI		89	94
95% upper CI		90	100

The first column of values shows the percentages of all 5,671 operative procedures performed in Iowa during the 6-month period. These procedures were performed during 462 inpatient admissions and 3,143 outpatient surgery visits. The second column of values shows the percentages of the 93 facilities performing each particular type of procedure at least once.

CI = confidence interval; ICD-9-CM = International Classification of Diseases, 9th Revision, Clinical Modification.

The larger and smaller pediatric hospitals performed the most and second-most types of procedures (fig. 1). Of the 246 types of procedures performed statewide, 67% (165 types) were performed more often at the larger pediatric hospital than at any other facility statewide (table 2). That compares with 2% for the facility performing the most procedures. The smaller pediatric hospital had the highest volume for 18% of the types of procedures.

Figure 2 shows the results when analyzed using the internal Herfindahl index (see Methods). At the larger pediatric hospital, if two procedures were selected at random, there was a $7\% \pm 1\%$ (SE) chance that both procedures were of the same type. At the smaller pediatric hospital, the chance was $22\% \pm 2\%$. In comparison, at the facility performing the most procedures, the chance was $66\% \pm 2\%$.

Table 2. Percentages of Types of Procedures for which Each Facility Performed the Most in Iowa

Hospital	% of the 246 Types of Procedures for which the Facility Performed the Most Statewide	95% CI
Larger pediatric (figs. 1–3)	67	61%–73%
Smaller pediatric (figs. 1–3)	18	14%–24%
Nonpediatric performing 58 types of procedures (figs. 1,4)	13	9%–18%
Facility with fourth highest percentage in column 2	3	1%–6%
Facility performing the most procedures (figs. 1–3)	2	1%–4%

Ties were counted toward both facilities; therefore, percentages in column 2 sum to more than 100%.

CI = confidence interval.

Physiologically Complex Procedures

During the 6-month period studied, six physiologically complex procedures were performed during three hospital admissions at the 90 facilities performing 15 or fewer types of procedures (0.13% of physiologically complex procedures performed statewide; 95% CI, 0.05% to 0.3%) (table 3). A procedure was considered to be “physiologically complex” if it had more than seven ASA RVG basic units.

The percentages of procedures that were physiologically complex equaled 26% for the larger pediatric hospital and 7% for the smaller pediatric hospital. When infants and young children undergo physiologically complex surgery in Iowa, 64% of the procedures are performed at the larger

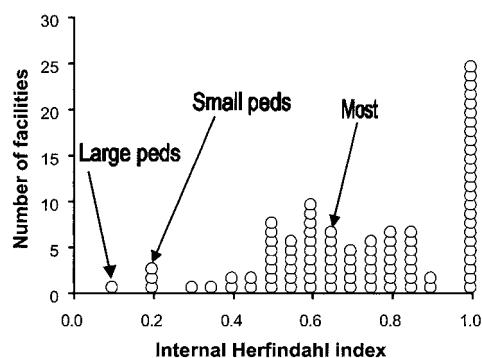


Fig. 2. Internal Herfindahl index for the types of procedure at each facility. Each circle represents one surgical facility. The internal Herfindahl index equals the probability that if two procedures from the same facility are selected at random, both will be of the same type of procedure. Examples are provided in Methods. At the larger pediatric hospital (*Large peds*), there was a $7\% \pm 1\%$ chance that any two randomly selected procedures were of the same type (i.e., internal Herfindahl index = 0.07). At the smaller pediatric hospital (*Small peds*), the chance was $22\% \pm 2\%$. At the facility performing the most (*Most*) procedures, the chance was $66\% \pm 2\%$.

Table 3. Six Physiologically Complex Procedures were Performed during Three Hospitalizations at Facilities Other than the Three Hospitals Performing the Most Types of Procedures

Hospital	Procedures Performed in Children 0–2 Yr Old at the Facility during the 6-Month Period Studied		Characteristics of the Six Physiologically Complex Procedures Performed in Three Patients	
	All Types	Myringotomy, Adenoidectomy, and/or Tonsillectomy	Age (yr)	Procedures Performed (Classified by ICD-9-CM), All Diagnoses, and Hospital Length of Stay, as Listed in Hospital Discharge Abstract
A	127	110	0	Craniotomy for removal of epidural hemorrhage (01.24) from middle meningeal artery bleeding. Other diagnoses: anemia, pneumonia, and continuous mechanical ventilation (96.71). Hospital length of stay = 4 days.
B	207	196	1	Incision of cerebral meninges (01.31) for nontraumatic subdural hemorrhage (432.1). Hospital length of stay = 2 days.
C	29	24	1	Destruction of lesion of spinal cord (03.4), repair of spinal myelomeningocele (03.52), biopsy of spinal cord or spinal meninges (03.32), and plastic operation to repair spina bifida (03.59). Diagnoses: spina bifida occulta, agenesis of spinal cord, muscle lipoma, breast lipoma, multiple subcutaneous tissue lipomas. Hospital length of stay = 3 days.

ICD-9-CM = International Classification of Diseases, 9th Revision, Clinical Modification.

pediatric hospital (95% CI, 52% to 70%). This compares with 10% for the smaller pediatric hospital.

Age of Patients

The children undergoing surgery at the pediatric hospitals were younger than at the nonpediatric hospitals. Infants (0 yr old) were 53% of the children ($n = 629$) at the two pediatric hospitals *versus* 31% of the children ($n = 2,976$) treated at the other 91 facilities ($P < 10^{-4}$). The percentages are shown in figure 3 for facilities caring for at least 25 children during the 6-month period studied.

Differentiating between Hospitals

The relative percentages of each type of procedure differed significantly between the two pediatric hospitals (similarity index, 0.69 ± 0.06). For example, the larger pediatric hospital performed 138 types of procedures not performed at the smaller pediatric hospital.

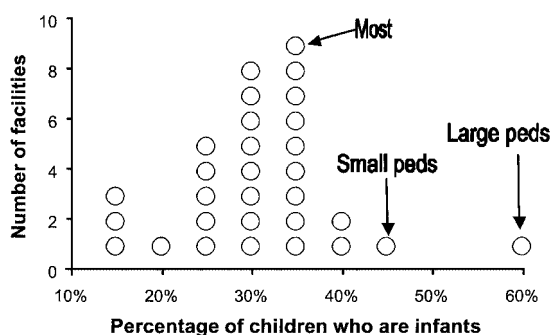


Fig. 3. Percentage of children having surgery who were infants at facilities treating at least 25 children during the 6-month period studied. Each circle represents one surgical facility. The larger pediatric hospital (*Large peds*) and smaller pediatric hospital (*Small peds*) differ from other hospitals in Iowa in caring for younger patients. The facility performing the most procedures is indicated by *Most*.

The smaller pediatric hospital performed 29 types of procedures not performed at the larger one.

The smaller pediatric hospital was no more similar to the larger pediatric hospital in its relative volumes of each type of procedure than it was to other facilities in the state (fig. 4). When the similarity between the smaller and larger pediatric hospitals (0.69 ± 0.06) was compared with the similarity between the smaller pediatric hospital and the other 91 facilities (0.74 ± 0.04), the mean difference equaled -0.06 ± 0.08 . A total of 66 facilities were located in counties with fewer than 80,000 persons and had fewer than 100 hospital beds. The difference between the similarity of the smaller pediatric hospital to the larger pediatric hospital and the

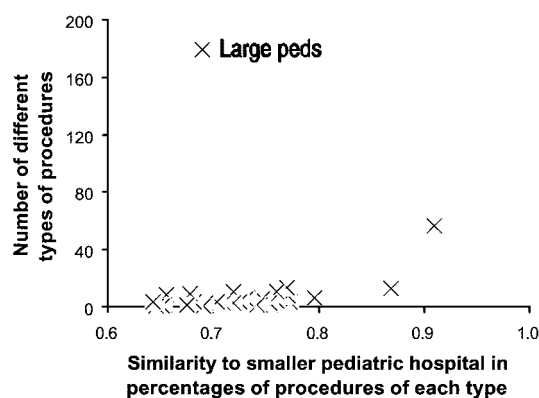


Fig. 4. Similarity in relative frequencies of different types of procedures between the smaller pediatric hospital and other hospitals in Iowa. The figure shows that the smaller pediatric hospital was no more similar to the larger pediatric hospital in its relative numbers of each type of procedure than it was to other hospitals in the state. The larger pediatric hospital (*Large peds*) (181 types of procedures) has a similarity of 0.69. The nonpediatric hospital performing 58 types of procedures (see also Fig. 1) has a similarity of 0.91. The rural hospital with 54 beds studied in the Appendix has a similarity of 0.77. To make the graph less cluttered, we included only the 36 hospitals performing at least 25 procedures during the 6-month period studied.

similarity of the smaller pediatric hospital to these small rural facilities was -0.02 ± 0.08 . The smaller pediatric hospital was significantly less similar to the larger pediatric hospital than it was to the nonpediatric hospital performing 58 types of procedures (similarity, 0.91 ± 0.03 ; difference, 0.21 ± 0.06 , $P < 0.001$) (fig. 4).

Discussion

A pediatric hospital may aim to show governmental agencies, charitable organizations, and philanthropic individuals how its clinical services differ from those of other facilities (e.g., “our patients are younger,” or “our procedures are more complicated”). We studied how each pediatric hospital can use discharge abstract data to investigate how it differs from nonpediatric hospitals. In Iowa, each pediatric hospital can show that it provides a more diverse, comprehensive, and physiologically complex selection of procedures in younger patients than 90 of 93 facilities performing pediatric surgery (figs. 1 through 3, tables 2 and 3). For example, the larger pediatric hospital can show that it performs 64% of all physiologically complex pediatric surgery statewide, and is the highest-volume facility for 67% of the different types of procedures.

A pediatric hospital may also aim to show that it differs from other pediatric hospitals in the region (*i.e.*, that the hospitals are not one collective group, interchangeable in all but location). Administrators and physicians may perceive value in showing that their hospital is not providing a commodity, “pediatric surgery,” but rather is serving a unique role in its state healthcare system. Using the methodology that we developed, we showed that the surgical practices of the pediatric hospitals were highly distinguishable (fig. 4).

Pediatric hospitals play important roles in their regions’ preparedness caring for children during disasters. Our work shows that appropriate analysis of discharge abstract databases can provide pediatric hospitals with potentially useful information as they work with governmental agencies on appropriate financial support. For example, in Iowa, many facilities statewide provide pediatric surgery (fig. 1). Thus, they have the equipment for providing anesthesia care to young children (e.g., appropriately sized endotracheal tubes). They also have frequent practical experience in performing pediatric inductions and placements of intravenous catheters. However, very few facilities provide anesthesia care for physiologically complex procedures (fig. 1, table 3). Many of the highest volume facilities perform no physiologically complex procedures. Therefore, analysis of discharge abstract databases provides an opportunity for pediatric hospitals to assist organizations in appreciating that, for purposes of disaster planning, both total pediatric surgical volume and whether a facility performs pediatric surgery are misleading.

A pediatric hospital can educate regional organizations and the public about volume guidelines for pediatric surgery. The American Academy of Pediatrics’ Guidelines for the Pediatric Perioperative Anesthesia Environment specify⁴: “There should be a . . . policy designating . . . the types of pediatric . . . procedures . . . , and indicating the minimum number of cases required in each category for the facility to maintain its clinical competence in their performance.” The Agency for Healthcare Research & Quality’s fact sheet to help prevent medical errors in children recommends that parents “choose a hospital at which many children have the procedure . . . your child needs.”¹³ However, for purposes of differentiating the services of a pediatric hospital from those of nearby nonpediatric facilities, there may be an advantage to focusing not on such volume issues but instead on the diversity of the types of procedures performed. Although a pediatric hospital is likely to be among the highest-volume facilities for pediatric surgery, it may not be the single highest-volume facility (fig. 1).

Limitations

Discharge abstract databases permit quantification of the number of procedures, outpatient visits, and hospitalizations, not the number of cases. Most surgical cases include more than one ICD-9-CM procedure.² Quantifying the diversity of the types of procedures performed at a facility using these databases is sound, because it is procedures *per se* that are relevant to that goal. These databases are weaker for making volume-based arguments, because the number of procedures is strongly correlated to but less relevant than the number of cases.

Myringotomy with insertion of tube (20.01) and total correction of transposition of great vessels (35.84) each counted as one procedure. So, “procedure” was not weighted by resource use. Hospitalizations have weights (e.g., based on hospital charges or diagnosis-related groups), but include several procedures. Thus, we suspect that it is best to use these databases to focus on issues related to the diversity of the types of procedures performed at facilities.

Sample sizes, which were sufficient to differentiate what operative procedures were performed at different facilities, are small relative to those used to compare outcomes among surgical facilities. Also, discharge abstract databases lack physiologic details needed to fully evaluate adverse events.

The State of Iowa discharge abstract database included operative procedures performed in hospitals and hospital-affiliated outpatient surgery centers, but not procedures performed at outpatient surgery centers that were not affiliated with a hospital. This limitation reduces the accuracy of quantification of how many operative procedures are performed statewide. However, the impact

is less on the quantification of the diversity of the types of procedures performed.

Measuring the diversity of types of procedures performed using the number of different types of procedures was simple to view graphically and explain. However, this statistic is sensitive to the effects of inaccurate coding of procedures. This is a likely an advantage to using the internal Herfindahl index when quantifying the diversity of procedures performed at a facility.

Conclusions

Hospitals frequently aim to help governmental agencies, charitable organizations, and philanthropic individuals appreciate their services. In this article, we describe how inpatient and outpatient discharge abstract databases can be used to quantify pediatric operative procedures. In Iowa, each pediatric hospital can differentiate itself from other hospitals based on its providing a more diverse, comprehensive, and physiologically complex selection of procedures in younger patients. Each pediatric hospital can distinguish itself from the other based on the characteristics of their surgical practices.

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Appendix

Calculation of Point Estimate and Standard Error of Similarity Index

The analytical expression for the point estimate and standard error of the similarity index can be derived using nonparametric Maximum Likelihood Estimation and Cramér's delta method (explained in detail below). These analytical methods are accurate for "sufficiently large" values of the numbers of procedures performed at each of the facilities relative to the total number of different types of procedures. Whether our sample sizes were "sufficiently large" was unknown. Therefore, we also calculated the point estimates and standard errors using the computational method of bootstrapping. This method also has a host of potential limitations. Our strategy was to use both methods to check that the answers were nearly similar.

Let p_{jk} represent the proportion of procedures performed at the j^{th} facility that are of the k^{th} type of procedure, $k = 1, 2, \dots, S$, where S refers to the total number of different types of procedures. Then, the similarities of the relative frequencies with which different types of procedures are performed at two facilities¹¹:

$$\theta = \frac{\sum_{k=1}^S p_{1k}p_{2k}}{\sum_{k=1}^S (p_{1k} - p_{2k})^2 + \sum_{k=1}^S p_{1k}p_{2k}}. \quad (1)$$

Let n_j refer to the number of procedures performed at the j^{th} facility during the observation period. Let X_{ij} specify the type of the i^{th} procedure at the j^{th} facility, $i = 1, 2, \dots, n_j$. Let P_k refer to the k^{th} type of procedure, $k = 1, 2, \dots, S$. Finally, let $IS(\cdot)$ equal 1 if the value in the expression is true, and 0 otherwise. Then, the observed proportion of procedures at the j^{th} facility that are of the k^{th} type is:

$$\hat{p}_{jk} = \frac{1}{n_j} \sum_{i=1}^{n_j} IS(X_{ij} = P_k). \quad (2)$$

The nonparametric maximum likelihood estimator for θ is obtained by substituting the observed proportions \hat{p}_{jk} in equation 2 for the true proportions p_{jk} in equation 1:

$$\hat{\theta} = \frac{\sum_{k=1}^S \hat{p}_{1k}\hat{p}_{2k}}{\sum_{k=1}^S (\hat{p}_{1k} - \hat{p}_{2k})^2 + \sum_{k=1}^S \hat{p}_{1k}\hat{p}_{2k}}. \quad (3)$$

$\hat{\theta}$ is asymptotically normally distributed^{11,14} We used Cramér's delta method¹⁵ in the following manner^{11,14} to obtain the standard error for $\hat{\theta}$. Define:

$$\hat{a} = \sum_{k=1}^S (\hat{p}_{1k})^2, \quad (4)$$

$$\hat{b} = \sum_{k=1}^S (\hat{p}_{2k})^2, \quad (5)$$

and

$$\hat{d} = \sum_{k=1}^S \hat{p}_{1k}\hat{p}_{2k}. \quad (6)$$

Equations 4 and 5 are the nonparametric maximum likelihood estima-

tors for the internal Herfindahl index, shown in figure 2. Expanding the denominator of equation 3:

$$\hat{\theta} = \frac{\hat{d}}{\hat{a} + \hat{b} - \hat{d}}. \quad (7)$$

The square of the standard error of $\hat{\theta}$ equals:

$$\text{Var}(\hat{\theta}) \approx \frac{\hat{d}^2}{(\hat{a} + \hat{b} - \hat{d})^4} [\text{Var}(\hat{a}) + \text{Var}(\hat{b})] + \frac{(\hat{a} + \hat{b})^2}{(\hat{a} + \hat{b} - \hat{d})^4} \text{Var}(\hat{d}) - \frac{2(\hat{a} + \hat{b})\hat{d}}{(\hat{a} + \hat{b} - \hat{d})^4} [\text{Cov}(\hat{a}, \hat{d}) + \text{Cov}(\hat{b}, \hat{d})], \quad (8)$$

where

$$\text{Var}(\hat{a}) \approx \frac{4}{n_1} \left[\sum_{k=1}^s (\hat{p}_{1k})^3 - \hat{a}^2 \right], \quad (9)$$

$$\text{Var}(\hat{b}) \approx \frac{4}{n_2} \left[\sum_{k=1}^s (\hat{p}_{2k})^3 - \hat{b}^2 \right], \quad (10)$$

$$\text{Var}(\hat{d}) \approx \frac{1}{n_1} \sum_{k=1}^s \hat{p}_{1k}(\hat{p}_{2k})^2 + \frac{1}{n_2} \sum_{k=1}^s \hat{p}_{2k}(\hat{p}_{1k})^2 - \left(\frac{1}{n_1} + \frac{1}{n_2} \right) \hat{d}^2, \quad (11)$$

$$\text{Cov}(\hat{a}, \hat{d}) \approx \frac{2}{n_1} \left[\sum_{k=1}^s \hat{p}_{1k}(\hat{p}_{1k})^2 - \hat{a}\hat{d} \right], \quad (12)$$

and

$$\text{Cov}(\hat{b}, \hat{d}) \approx \frac{2}{n_2} \left[\sum_{k=1}^s \hat{p}_{2k}(\hat{p}_{2k})^2 - \hat{b}\hat{d} \right]. \quad (13)$$

Equation 9 was used to calculate the standard error of the internal Herfindahl index.

The first bootstrap estimate of Yue and Clayton's index, $\hat{\theta}^{\text{boot},1}$, was obtained in the following manner. The observed procedures performed at the first facility were of types X_{11}, X_{12}, \dots , and $X_{n_1,1}$, with notation as given in equation 2. A value $X_{n_1,1}^{\text{boot},1}$ was selected at random from the original n_1 observations. A second value $X_{21}^{\text{boot},1}$ was selected at random from the original n_1 observations. The process was continued until there were n_1 new bootstrap samples of the original observations from the first facility: $\{X_{11}^{\text{boot},1}, X_{21}^{\text{boot},1}, \dots, X_{n_1,1}^{\text{boot},1}\}$. These values were substituted into equation 2 to obtain $\{\hat{p}_{11}^{\text{boot},1}, \hat{p}_{12}^{\text{boot},1}, \dots, \hat{p}_{1s}^{\text{boot},1}\}$. A new bootstrap sample was made of the original observations from the second

facility: $\{X_{12}^{\text{boot},1}, X_{22}^{\text{boot},1}, \dots, X_{n_2,2}^{\text{boot},1}\}$. These values were likewise substituted into equation 2 to obtain $\{\hat{p}_{21}^{\text{boot},1}, \hat{p}_{22}^{\text{boot},1}, \dots, \hat{p}_{2s}^{\text{boot},1}\}$. The bootstrapped observed proportions, $\{\hat{p}_{11}^{\text{boot},1}, \hat{p}_{12}^{\text{boot},1}, \dots, \hat{p}_{1s}^{\text{boot},1}, \hat{p}_{21}^{\text{boot},1}, \hat{p}_{22}^{\text{boot},1}, \dots, \hat{p}_{2s}^{\text{boot},1}\}$, were then substituted into equation 3 to obtain $\hat{\theta}^{\text{boot},1}$.

The process described in the preceding paragraph was repeated B-1 times, providing a total of B bootstrap estimates: $\{\hat{\theta}^{\text{boot},1}, \hat{\theta}^{\text{boot},2}, \dots, \hat{\theta}^{\text{boot},B}\}$. The SD of these B values was the bootstrap estimate of the standard error of $\hat{\theta}$. We used B = 1,000 bootstrap samples.¹⁵

To compare results from Cramér's delta method and bootstrapping, we used the larger pediatric hospital, the smaller pediatric hospital, the facility performing the most procedures, the nonpediatric hospital performing 58 types of procedures (figs. 1 and 4), and a rural hospital with 54 beds in a county with fewer than 660 children 0-4 yr old. We chose the latter hospital because of its similarity to the smaller pediatric hospital ($\hat{\theta} = 0.77$). The absolute differences in the point estimates and standard errors between the analytical and bootstrap methods were small, 0.3% to 2.4% of the point estimates (table 4). The smallest differences were for the comparison of the smaller pediatric hospital and the facility performing the most procedures. The latter hospital had a ratio of the number of procedures to the number of types of procedures of 84. The largest differences were for the comparison of the smaller pediatric hospital and the small rural hospital. The latter hospital had the smallest sample size and a ratio of number to types of procedures of 8.6. In Results, we report the standard error that was the larger of the two methods.

Standard errors for the differences in similarity between many pairs of hospitals were calculated using bootstrapping. Suppose that three facilities are in the comparison. Then, the first bootstrap sampling produced $\{\hat{p}_{11}^{\text{boot},1}, \hat{p}_{12}^{\text{boot},1}, \dots, \hat{p}_{1s}^{\text{boot},1}, \hat{p}_{21}^{\text{boot},1}, \hat{p}_{22}^{\text{boot},1}, \dots, \hat{p}_{2s}^{\text{boot},1}, \hat{p}_{31}^{\text{boot},1}, \hat{p}_{32}^{\text{boot},1}, \dots, \hat{p}_{3s}^{\text{boot},1}\}$. We calculated the similarities between the first and second facilities and between the second and third facilities, calculated the difference between the similarities, repeated the process 999 times, and took the SD of the 1,000 differences. For the analysis reported in Results, the first facility corresponds to the larger pediatric hospital. The second facility corresponds to the smaller pediatric hospital. The third facility represents the pooled value for many (N-2) facilities, more than half of which performed between one and 25 procedures (*i.e.*, which had a low volume for purposes of this type of analysis). We also repeated this analysis by comparing, for each bootstrap sample, the smaller and larger pediatric hospital to the mean of the N-2 similarities between the smaller pediatric hospital and each of the other facilities. The differences in similarities and the standard errors of the differences were essentially the same (-0.06 ± 0.08 pooled *vs.* -0.04 ± 0.08 using the mean of N-2 similarities to create each bootstrap difference).

Table 4. Differences in Point Estimate and SE of the Similarity Index^{11,14} between that Calculated using Nonparametric Maximum Likelihood Estimation with Cramér's Delta Method versus Bootstrapping

Sites Compared	Relative Sample Size		Point Estimate of Similarity Index			SE of Similarity Index		
	No. of Procedures	Types of Procedures	Nonparametric Maximum Likelihood Estimate	Mean of Bootstrap Estimates	Difference	Cramér's Delta Method	SD of Bootstrap Estimates	Difference
Smaller pediatric hospital vs. larger pediatric hospital	324 vs. 582	73 vs. 182	0.691	0.676	0.015	0.055	0.052	0.003
Smaller pediatric hospital vs. facility performing the most procedures	324 vs. 588	73 vs. 7	0.734	0.731	0.002	0.040	0.041	-0.001
Smaller pediatric hospital vs. rural hospital with 54 beds	324 vs. 43	73 vs. 5	0.774	0.756	0.018	0.055	0.040	0.015
Smaller pediatric hospital vs. nonpediatric hospital performing 58 types of procedures (figs. 1 and 4)	324 vs. 210	73 vs. 58	0.911	0.903	0.008	0.027	0.018	0.009