The RACHS-1 risk categories reflect mortality and length of stay in a Danish population of children operated for congenital heart disease

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Abstract

Objective: The Risk Adjusted classification for Congenital Heart Surgery (RACHS-1) was created in order to compare in-hospital mortality for groups of children undergoing surgery for congenital heart disease. The method was evaluated with two large multi-institutional data sets—the Paediatric Cardiac Care Consortium (PCCC) and Hospital Discharge (HD) data from three states in the USA. The RACHS-1 classification was later applied to a large German paediatric cardiac surgery population in Bad Oeynhausen (BO), where it was found that the RACHS-1 categories were also associated with length of stay. We applied the RACHS-1 classification to the 957 operations performed during January 1996 to December 2002 at Skejby Sygehus, Denmark and we examined the association between the RACHS-1 categories, in-hospital mortality and length of stay in the Intensive Care Unit. Methods: The operations were classified according to the six RACHS-1 categories by matching the procedure of each patient with a risk category. The ability of the RACHS-1 classification to predict mortality in our population was examined by estimating the area under the receiver operator characteristic (ROC) curve. Likelihood ratio χ² tests were used to compare the distribution of RACHS-1 categories and the distribution of mortality with PCCC, HD and BO. Linear regression was used to examine the correlation between the RACHS-1 categories and length of stay in the Intensive Care Unit. Results: The RACHS-1 category frequencies in our population were: category 1: 18.4%, category 2: 37.4%, category 3: 34.6%, category 4: 8.2%, category 5: 0% and category 6: 1.5%. The overall ability of the RACHS-1 classification to predict in-hospital mortality (area under the ROC curve 0.741; 95% confidence interval = 0.690; 0.791) was equal to the findings from larger populations. We also associated with length of stay. We applied the RACHS-1 classification to the 957 operations performed during January 1996 to December 2002 at Skejby Sygehus, Denmark and we examined the association between the RACHS-1 categories, in-hospital mortality and length of stay in the Intensive Care Unit. Conclusions: The RACHS-1 classification can also be used to predict in-hospital mortality and length of stay in the Intensive Care Unit in a small volume centre.

Keywords: Congenital cardiac surgery; Mortality; Length of stay; Risk adjustment; Scoring system

1. Introduction

During the latter years there has been a growing acceptance of the need of documenting and evaluating the results of congenital heart surgery [1–4]. This is crucial not only for assessment of the outcomes but also for ensuring the best possible treatment. Since each child is unique and as the specific congenital heart defects are relatively rare conditions, it is difficult to make standardised risk estimation. In recognition of this problem, the Risk Adjusted classification for Congenital Heart Surgery (RACHS-1) was published by Jenkins et al. in 2002 [5]. The classification was created with help from a panel of 11 members including both paediatric cardiologists and paediatric cardiac surgeons and was evaluated within two large multi-institutional data sets—the Paediatric Cardiac Care Consortium (PCCC) and Hospital Discharge (HD) data from three states in the USA. The result was a classification of surgical procedures into six risk categories making it possible to compare in-hospital mortality for groups of children undergoing surgery for congenital heart disease. When applied to the PCCC and HD populations the RACHS-1 classification was able to predict mortality. Boethig et al. [6] applied the RACHS-1 classification to a large German paediatric cardiac surgery population at Bad Oeynhausen (BO) and found similar results concerning distribution and prediction of mortality. Furthermore, RACHS-1 categories appeared to be associated also with length of stay in the BO population. In this study we wanted to further evaluate the generalisability of the classification and examine whether the RACHS-1 also applied to our population.
at Skejby Sygehus, Denmark a relative smaller volume institution operating approximately 145 congenital heart defects a year. Besides examining the association between the RACHS-1 categories and in-hospital mortality, we also examined if other preoperative factors including sex, weight and age could predict mortality. Furthermore, we examined the association between the RACHS-1 categories and length of stay in the Intensive Care Unit (ICU).

2. Materials and methods

2.1. Patients and variables

During January 1996 to December 2002, 1019 surgical heart operations were performed in 889 children aged 15 years or younger at Skejby Sygehus. Prospectively collected data was obtained from a database at the ICU, which contained data on sex, age, weight, procedure, in-hospital mortality and length of stay in the ICU. Data on prematurity and the presence of major noncardiac anomalies were not available. The patients were then retrospectively assigned to a RACHS-1 category by manually matching the procedure of each patient with a risk category. Operations with combined procedures performed were assigned to the procedure with the highest risk as described by Jenkins et al. [5]. Two hundred and twenty-seven of the included procedures (23.7%) were combined procedures.

We excluded pacemaker implantations (n = 1), rethoracotomies due to infection (n = 1), heart transplants (n = 10) and neonates under 30 days with patent ductus arteriosus as an isolated cardiac defect (n = 41). A number of patients (n = 109) had more than one operation during the study period and nine patients had more than one procedure during the same admission. Since we did not focus on long-term mortality, we decided to consider multiple operations during the study period as independent observations when these operations occurred during different hospital admissions. However, when more than one operation had occurred during the same admission, we categorised the patient according to the first operation and excluded the latter. This led to the exclusion of nine operations.

In total, 957 operations in 839 patients were available for further analysis.

2.2. Statistical analysis

We first tested whether in-hospital mortality changes had occurred over time at Skejby Sygehus with a $\chi^2$ test.

We then examined the ability of the RACHS-1 classification to predict in-hospital mortality by estimating the area under the receiver operator characteristic (ROC) curve. An area of 0.5 indicates a model with no predictive power while an area of 1.0 indicates that the model is right every time. Our results were then compared to the dataset of PCCC, HD and BO. For comparison of in-hospital mortality between the individual RACHS-1 groups in our population we used a $\chi^2$ test.

A likelihood ratio $\chi^2$-test was used to compare the distribution of RACHS-1 risk categories with the populations of PCCC, HD and BO. A likelihood ratio $\chi^2$-test was also used to compare the mortality in the specific RACHS-1 risk categories with the ones found in PCCC, HD and BO. Since the conditions for the test was not fulfilled in RACHS-1 category 1, a Fisher’s exact test was here used instead.

We then examined if other preoperative factors including sex, weight and age provided additional information beyond the RACHS-1 classification, when estimating the risk of in-hospital mortality. In these analyses we used multivariate logistic regression. Since the relationships between age and mortality and weight and mortality were not linear, the weight was transformed to 100/(weight in kg)$^2$ and age to square root of 365/(age in days + 1) as described in the study by Kang et al. [7].

Finally, we examined whether the RACHS-1 classification was associated with length of stay in the ICU. Since the length of stay at the ICU was not distributed normally, not even after a log transformation, a Kruskal–Wallis test was used to test for equal distribution between the RACHS-1 categories. Thereafter, a Spearman Rho Test, combined with simple summary statistics, was used to identify trends. For each RACHS-1 category a log transformation of the median value was made, and linear regression was performed under the assumption that the variation of the medians was normally distributed. To get a simple understandable graph the values were transformed back to a linear scale. For further examination of the relationship between the RACHS-1 categories and length of stay in the ICU, category-specific Kaplan–Meier curves were made for the entire group and for the survivors separately. The category specific curves were compared using pair wise log rank tests.

A $p$-value under 0.05 was considered statistically significant. Stata Statistical Software (release 8.0, Stata Corporation, College Station, TX) and SAS Version 9.1.2 (SAS Institute, Cary, NC, USA) were used for the analyses.

3. Results

Sixteen percent of the patients were under 30 days of age and 40% were between 30 days and 1 year on the day of the operation. There were no substantial changes in in-hospital mortality over time at Skejby Sygehus during the study period ($p = 0.52$).

The area under the ROC curve for our population was 0.741 (95% CI = 0.690; 0.791). We found that the in-hospital mortality differed between the RACHS-1 category groups ($p < 0.001$) and that the mortality increased according to the risk group.

The distribution of the different RACHS-1 categories is shown in Fig. 1. When comparing PCCC, HD, BO and Skejby, we found that risk category distribution was quite similar between the four populations. However, looking at the fractions of the single risk categories within the data sets, it can be seen that BO has fewer patients in RACHS-1 category 1 and more in RACHS-1 category 6. Skejby is not an outlier in any category.

3.1. Mortality

The distribution of in-hospital mortality in each RACHS-1 category (Table 1) was not different between the four populations in the categories 1, 2 and 6. Looking at RACHS-1
category 3, we found indication of variation in the mortality between the four populations \( (p = 0.003) \). However, we found no differences when Skejby was compared individually with PCCC, HD and BO. The same pattern was found for RACHS-1 category 4. There was a significant difference between the four populations \( (p = 0.006) \), but when testing PCCC, HD and BO to Skejby separately, Skejby appeared not to be an outlier.

The multivariate logistic regression model showed that RACHS-1 category and low weight were associated with increased mortality. Thus, an increase in RACHS-1 score of 1 was associated with an odds ratio of 2.45 \( (95\% \text{ CI} = 1.91—3.15) \) whereas an increase in weight of 1 unit \( \left( \frac{100}{\text{weight in kg}}^2 \right) \) was associated with an odds ratio of 1.04 \( (95\% \text{ CI} = 1.02—1.07) \). In order to compare the mortality risk according to specific weights, \( x \) and \( y \), the following equation was determined:

\[
\text{OR}_{\text{weight}} = 1.04^{\left(\frac{100}{x^2} - \frac{100}{y^2}\right)}
\]

This equation showed that a difference in weight from 2.0 kg compared to 3.5 kg was associated with an odds ratio of 1.94 while a difference of 3.5 to 5.0 kg was associated with an odds ratio of 1.18. The area under the ROC curve was 0.770 \( (95\% \text{ CI} = 0.710; 0.829) \) when the model contained both RACHS-1 and weight. In contrast, sex and age was not associated with in-hospital mortality.

### 3.2. Length of stay in the ICU

A higher RACHS-1 risk category was associated with a longer length of stay in the ICU as seen in Fig. 2. The medians followed an exponential function for both the entire group of patients \( (R^2 = 0.936) \) and for survivors \( (R^2 = 0.964) \). The high \( R^2 \) shows that the RACHS-1 classification explains much of the variation in length of stay.

The category specific Kaplan—Meier graphs confirmed the positive association between RACHS-1 category and length of stay in the ICU. This applied for both the group of survivors and the entire group. There was a significant variation in length of stay between the RACHS-1 categories \( (p < 0.001) \) for both survivors and the entire group.

### 4. Discussion

We found that it was possible to apply the RACHS-1 classification to our population covering approximately 145
operations a year. We also found that higher RACHS-1 classification was associated with longer stay in the ICU, and that higher RACHS-1 category and lower weight were associated with increased risk of in-hospital mortality, whereas sex and age were not.

There is no doubt that risk estimation in congenital heart surgery is a complicated field due to the relative few patients and the large diversity in diagnoses and procedures. Therefore, it is necessary to have a common ground in order to compare results within institutions and between institutions. RACHS-1 is one of the first methods to make a standardised risk adjustment for congenital heart surgery. We acknowledge that it has its limitations [1,6,7]; for example, it is only meant for risk adjustment for groups of children and not for individuals. The classification also lacks a few important procedures such as heart transplants and persistent ductus arteriosus in the premature, accounting for 5% of the surgical procedures in our population. Still in recognition of these limitations RACHS-1 is an easily applicable tool giving the opportunity to compare the quality of care in different institutions.

Overall the ability of the RACHS-1 classification to predict in-hospital mortality in our population resembles the findings in PCCC, HD and BO. When looking at the area under the ROC curve, we found an area of 0.741. This is very similar to the results of PCCC, HD and BO with 0.784, 0.749 and 0.755, respectively. Mortality was shown to differ significantly between all the risk categories. This also resembles the findings in the PCCC and BO populations, except that this difference was not statistically significant between categories 2 and 3 in the BO population.

The relationship between caseload and mortality has been discussed for several years and studies have suggested a negative correlation [8,9]. In Denmark, the referral system for congenital heart disease is dictated by geography. Depending on the address patients are referred to one of the two centres for congenital heart disease. Skejby Sygehus is located in Aarhus, and covers a population of approximately 3 millions resulting in a yearly caseload of approximately 145 operations in children up to the age of 15 years. This number is somewhat smaller than the 250 operations recommended for two surgeons by the EACTS Congenital Heart Disease Committee in 2003 [10]. Therefore, it is of particular importance that our results are equal to those from larger specialised institutions. In order to obtain comparable results we find that organisation and specialisation are of particular importance. Therefore, we have organised a small dedicated team with one primary surgeon.

The ability of the RACHS-1 classification and weight to predict mortality is partly in accordance with the findings of Kang et al. [7], who found that RACHS-1 category, age but not weight were significant predictors of mortality. Overall, weight did not contribute much when added to a predictive model based on RACHS-1 as indicated by the small increase in the area under the ROC curve in our analyses. However, it should be emphasised that low weight was associated with increased risk of mortality in our analyses.

The positive association between RACHS-1 score and length of stay in our study is in accordance with the findings from the BO population. The correlation between RACHS-1 category and length of stay in the ICU in our study in fact resembles the findings of Brown et al. [11] who used an earlier risk classification by Jenkins et al. and may indicate that RACHS-1 may also be useful in relation to other end points than in-hospital mortality.

The recently published Aristotle score [12] introduced a method based on the concept complexity determined by the three factors: mortality, morbidity and technical difficulty. To which extent this complexity adjusted method can prove useful for predicting individual variation and adverse outcomes of congenital heart surgery and thus be an alternative to RACHS-1 remains to be clarified.

4.1. Limitations

This follow-up study was based on the entire population in a well-defined geographic recruitment area with prospective data collection and complete follow-up on in-hospital mortality which limited the risk of selection and information biases. However, four patients in RACHS-1 categories 2—4 (one in category 2, one in category 3 and two in category 4) were referred for surgical treatment at Great Ormond Street Hospital for Children in London during the study period. This could potentially have reduced the mortality in these categories at Skejby Sygehus. Yet if we assumed that these four patients had all died at Skejby Sygehus, the mortality rate would not have changed substantially in these RACHS-1 categories and the rates would still have been lower than the mortality rates in the PCCC and HD populations.

Our study period from January 1996 to December 2002 was approximately the same period covered in the BO study, whereas the PCCC study was based on 1996 data and the HD study on data from the period 1994 to 1995. We cannot entirely exclude the possibility that these differences in the study periods combined with the general progress in cardiac surgery may have confounded the comparisons between the different populations. However, we found no changes in the in-hospital mortality rate at Skejby Sygehus during the study period.

Patients in our population were under or equal to 15 years of age compared to 18 years in PCCC, HD and BO. This difference is probably of minor importance for the interpretation of the results as age was not a predictor of mortality in our study.

No systematic validation of the database in the ICU has been made thus far. However, both collection and registration of the data was done by the same three paediatric anaesthesiologists/intensivists at the ICU throughout the entire study period.

5. Conclusion

The RACHS-1 classification can also be applied to a smaller population such as the one at Skejby Sygehus. Both the in-hospital mortality and the length of stay in ICU were associated with the RACHS-1 categories. Furthermore, we found that the mortality in each RACHS-1 category was equivalent to what has been reported in larger institutions in both America and Europe.
References