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ORIGINAL ARTICLE

# Ability to predict the development of surgical site infection in cardiac surgery using the Australian Clinical Risk Index versus the National Nosocomial Infections Surveillance-derived Risk Index

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**Abstract** Surgical site infection (SSI) is a major infectious complication that increases mortality, morbidity, and healthcare costs. There are scores attempting to classify patients for calculating SSI risk. Our objectives were to validate the Australian Clinical Risk Index (ACRI) in a European population after cardiac surgery, comparing it against the National Nosocomial Infections Surveillance-derived risk index (NNIS) and analyzing the predictive power of ACRI for SSI in valvular patients. All the patients that who underwent cardiac surgery in a tertiary university hospital between 2011 and 2015 were analyzed. The patients were divided into valvular and coronary groups, excluding mixed patients. The ACRI score was validated in both groups and its ability to predict SSI was compared to the NNIS risk index. We analyzed 1,657 procedures. In the valvular patient group (*n*: 1119), a correlation between the ACRI score and SSI development ($p < 0.05$) was found; there was no such correlation with the NNIS index. The area under the receiver-operating characteristic curve (AUC) was 0.64 (confidence interval [CI] 95%, 0.5–0.7) for ACRI and 0.62 (95% CI, 0.5–0.7) for NNIS. In the coronary group (*n*: 281), there was a correlation between ACRI and SSI but no between NNIS and SSI. The ACRI AUC was 0.70 (95% CI, 0.5–0.8) and the NNIS AUC was 0.60 (95% CI, 0.4–0.7). The ACRI score has insufficient predictive power, although it predicts SSI development better than the NNIS index, fundamentally in coronary artery bypass grafting (CABG). Further studies analyzing determining factors are needed.

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## Introduction

Surgical site infection (SSI) is defined as any infection related to the surgical procedure that occurs in or near the surgical incision in the first 30 days after the intervention, or within 90 days after surgery if prosthetic material has been implanted [1, 2]. In cardiac surgery, SSI is a complication associated with increased morbidity and mortality, the need for reoperations, lengthy antibiotic treatment, increase in extended hospital stays, and increased healthcare costs. This makes any improvement in monitoring and forecasting of the risk of developing an SSI extremely useful for preventing it [3, 4].

The NNIS (National Nosocomial Infections Surveillance-derived) risk index was developed in the United States in 1991 to classify patients and surgical procedures based on the risk of developing SSI and thus be able to compare SSI incidence among services, hospitals, and even countries [5, 6]. The predictive capacity of the NNIS index in SSI development in cardiac is controversial [7–12]. As cardiac surgical patients are fairly homogeneous with regard to the variables included in the NNIS index, which consequently does not correctly discriminate the risk of developing SSI.

The NNIS index combines three variables: 1) the degree of surgical contamination, 2) the American Society of Anesthesia

(ASA) pre-anesthesia score, used as the variable reflecting the patient's intrinsic risk, and 3) the length of the operation as an indication of the complexity of the surgical procedure performed [5, 6]. In cardiac surgery, most procedures are clean surgeries and the ASA pre-anesthesia score for these patients is generally ≥ III. Consequently, it is only possible to categorize the patients into two large groups according to operative time. These groups are formed, on the one hand, of patients with prolonged operative time and subsequently greater risk of developing SSI and, on the other, the group with shorter operative times, which should present lower SSI risk; the NNIS index, therefore, is not capable of discriminating well [7–16].

To improve the predictive ability of the NNIS index, Friedman reported a score to stratify SSI risk after coronary revascularization, using an Australian population, the Australian Clinical Risk Index (ACRI) [7]. This new index uses only two variables, diabetes mellitus (DM) and body mass index (BMI), so it is very simple to measure. The ACRI correlates well between the gradual increase of its score and the risk of developing SSI in patients undergoing coronary artery bypass grafting (CABG) [7]. Chen et al. validated the ACRI in an American population that had also undergone coronary revascularization (CABG) [8]. They found its SSI predictive capacity greater than that of the NNIS, just like Friedman had in the earlier study [7].

The behavior of this index has not been assessed in a European population yet. The objective of this study was to validate the ACRI in patients operated on in an European setting for both coronary revascularization and valvular surgery. Likewise, we compared the SSI prediction performance of the ACRI with that obtained using the NNIS risk index.

## Material and methods

A prospective cohort study was carried out at the third-level La Princesa University Hospital, Madrid (Spain). All consecutive adult patients, older than 18 years old, who underwent cardiac surgery between 1 January 2011 and 31 December 2015 were included. The patients were divided in two groups: valvular surgery (CARD) and coronary revascularization (CABG). All mixed surgery cases (valvular plus coronary) were then excluded from the study. All the patients gave their express written consent for the analysis of the data in their medical records and for follow-up during the study. The study was approved by the Institutional Ethics Committee.

Epidemiological and clinical characteristics of the patients, and the variables included in calculating the ACRI score and the NNIS index, were recorded. Among these variables, the following were studied: age, sex, weight, height, diabetes mellitus, obesity, peripheral vascular disease, body mass index (BMI), chronic kidney disease, chronic obstructive pulmonary disease (COPD), elective and urgent surgery, degree of surgical contamination, ASA pre-anesthesia score, extracorporeal circulation and aortic clamp time, and total operative time. The primary outcome measure was SSI development, defined following the diagnostic criteria of the Center for Disease Control [1, 2].

Obesity was defined according to the World Heath Organization as BMI > 30. The patients were classified into three groups by their BMI (BMI <30, BMI between 30 and 34.9, and BMI ≥35). The 75th percentile was calculated for operative times, in both valvular surgery and in coronary revascularization surgery, because that is the parameter that the NNIS index uses within the operative time variable.

To calculate the risk scores, in the case of the NNIS index, 1 point was assigned for the presence of each of the following variables: ASA greater than II, classification of the wound as contaminated or dirty and operative time greater than 75th percentile, with the score being the result of the sum (range, 0–3). For the ACRI, there were two variables and the score assigned was the sum of the following: DM, 1 point; BMI from 30 to 34.9, 1 point; and BMI ≥ 35, 2 points. The score range was also 0–3 in this case.

### Statistical analysis

The data were expressed as the number of patients with the percentage in brackets, or the mean ± standard deviation. Preoperative clinical characteristics of the patients and the rate of SSI were compared using the $\chi^2$ or Fisher's exact test for dichotomous variables and the Student's *t*-test or the Mann–Whitney U-test for continuous variables, as appropriate.

All the patients were stratified by NNIS index and the ACRI. We used Chi2 for trend to analyze the correlation between the scores for each index and the SSI incidence. The goodness-of-fit was assessed with the Hosmer–Lemeshow test; the discrimination power was assessed with the receiver-operating characteristic (ROC) curve and the calculation of the area under the ROC curve (AUC). According to arbitrary guidelines, the accuracy of prediction was defined as low (AUC: 0.5–0.7), moderate (AUC: 0.7–0.9) and high (AUC: 0.9–1). The predictive scoring systems were compared using the method of DeLong. A *p*-value <0.05 was considered to be significant. Analyses were performed with IBM SPSS Statistics v.19 and EpiInfo7.

## Results

During the study period, a total of 1,657 procedures were included in the analysis. Of these, 1,119 were valvular surgery and 281 were CABG. There were 257 mixed operations (valvular plus CABG), which were excluded from analysis.

Analyzing the patients by type of procedure revealed that, in the case of valvular (CARD) patients, mean age was 69 ± 13 years, 50% were male, 24% diabetic, and 23% obese (BMI > 30). As for the operations, 92% were clean and 87% had an ASA score ≥ III, while the operative time exceeded the 75th percentile in 26% of the procedures. The SSI incidence was 3.6%. The differences between infected and non-infected patients are shown in Tables 1 and 2.

The distribution according the NNIS risk score of the patients that underwent valvular surgery was as follows: NNIS 0: 103 patients (9.2%), NNIS 1: 702 patients (62.7%), NNIS 2: 287 patients (25.6%) and NNIS 3: 27 patients (2.4%). Based on the ACRI score, the distribution was ACRI 0: 501 patients (57.7%), ACRI 1: 245 patients (28.2%), ACRI 2: 103 patients (11.9%) and NNIS 3: 19 patients (2.2%).

The SSI incidence for valvular patients according to NNIS and ACRI values is shown in Fig. 1. There is a statistically significant ($p < 0.05$) rising trend between the ACRI score and SSI incidence, but not for the NNIS risk index ($p > 0.05$). The AUC calculation was 0.64 (95% CI, 0.5–0.7) for ACRI and 0.62 (95% CI, 0.5–0.7) for NNIS(Fig. 2).

As for the group of patients that underwent CABG, mean age was 69 ± 9 years, 92% were male, 40% diabetic, and 22% obese (BMI > 30). All the surgeries were clean, 92% of the patients had an ASA score ≥ III, and 40% of the procedures were above the 75th percentile of operative time. The SSI incidence was 8.2%. The differences between infected and non-infected patients are also shown in Tables 1 and 2.

The distribution of these patients according to the NNIS risk index score was: NNIS 0: eight patients (2.8%), NNIS 1: 178 patients (63.3%), NNIS 2: 95 patients (33.8%) and NNIS 3: zero patients (0%). By ACRI score, the distribution was: ACRI 0: 100 patients (45.5%), ACRI 1: 85 patients (38.6%), ACRI 2: 29 patients (13.2%) and NNIS 3: six patients (2.7%).

Figure 3 presents the SSI incidence by NNIS and ACRI. There is also a statistically significant ($p < 0.05$) rising tendency between the ACRI score and SSI incidence, which does not occur with the NNIS risk index. The AUC calculated was 0.70 (95% CI, 0.5–0.8) for ACRI and 0.60 (95% CI, 0.4–0.7) for NNIS (Fig. 4).

**Table 1** Demographic and clinical information of cardiac surgery patients regarding the development of a postoperative infection: valvular surgery

| Valvular surgery | No SSI ($n$ = 1,079) | SSI ($n$ = 40) | *P*-value ($p$ < 0.05) |
|---|---|---|---|
| Age (years) | 69 ± 13 | 74 ± 10 | 0.028 |
| Sex (male) | 548 (51) | 15 (38) | 0.068 |
| Type 2 diabetes mellitus | 244 (23) | 20 (50) | 0.000 |
| Obesity (BMI >30) | 233 (22) | 20 (50) | 0.002 |
| Arteriopathy | 78 (7.2) | 8 (20) | 0.003 |
| Chronic kidney disease | 84 (7.8) | 3 (7.5) | 0.622 |
| Chronic pulmonary disease | 38 (3.5) | 1 (2.5) | 0.589 |
| Urgent surgery | 59 (5.5) | 4 (10) | 0.183 |
| Clean surgery | 989 (92) | 36 (90) | 0.437 |
| ASA score ≥III | 934 (87) | 37 (93) | 0.202 |
| Operative time (>75th percentile) | 278 (26) | 14 (35) | 0.132 |
| Total CPB time (min) | 105 ± 38 | 109 ± 37 | 0.746 |
| Aortic cross-clamp time (min) | 78 ± 32 | 78 ± 30 | 0.512 |

Values are expressed as numbers ($n$), percentages (%), and means ± standard deviation

ASA, American Society of Anesthesiology; BMI, body mass index; CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; SSI, surgery site infection; ICU, intensive care unit

**Table 2** Demographic and clinical information of cardiac surgery patients regarding the development of a postoperative infection: coronary revascularization

| Coronary revascularization | No SSI $n$ = 258 | SSI ($n$ = 23) | *P*-value ($p$ < 0.05) |
|---|---|---|---|
| Age (years) | 69 ± 9 | 67 ± 11 | 0.346 |
| Sex (male) | 212 (82) | 18 (78) | 0.408 |
| Type 2 diabetes mellitus | 95 (37) | 16 (70) | 0.002 |
| Obesity (BMI > 30) | 49 (20) | 13 (57) | 0.002 |
| Arteriopathy | 48 (19) | 4 (17) | 0.574 |
| Chronic kidney disease | 13 (5.0) | 1 (4.3) | 0.680 |
| Chronic pulmonary disease | 10 (3.9) | 2 (8.7) | 0.256 |
| Urgent surgery | 14 (5.4) | 0 (0) | 0.294 |
| Clean surgery | 258 (100) | 23 (100) | – |
| ASA score ≥III | 235 (91) | 22 (96) | 0.393 |
| Operative time (>75th percentile) | 97 (38) | 14 (61) | 0.026 |
| Total CPB time (min) | 112 ± 33 | 101 ± 36 | 0.520 |
| Aortic cross-clamp time (min) | 72 ± 25 | 62 ± 17 | 0.599 |

Values are expressed as numbers ($n$), percentages (%), and means ± standard deviation

ASA, American Society of Anesthesiology; BMI, body mass index; CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; SSI, surgery site infection; ICU, intensive care unit

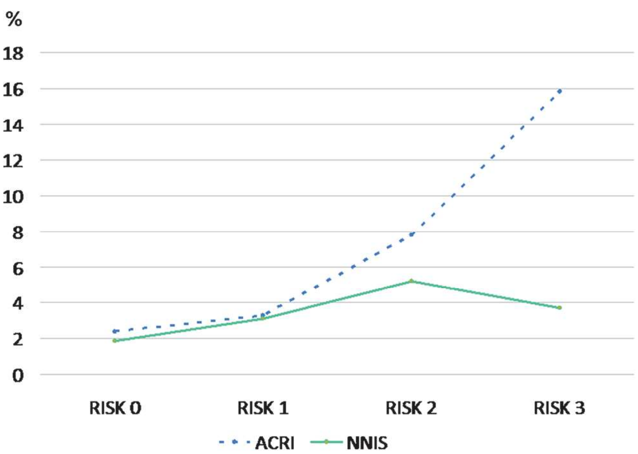
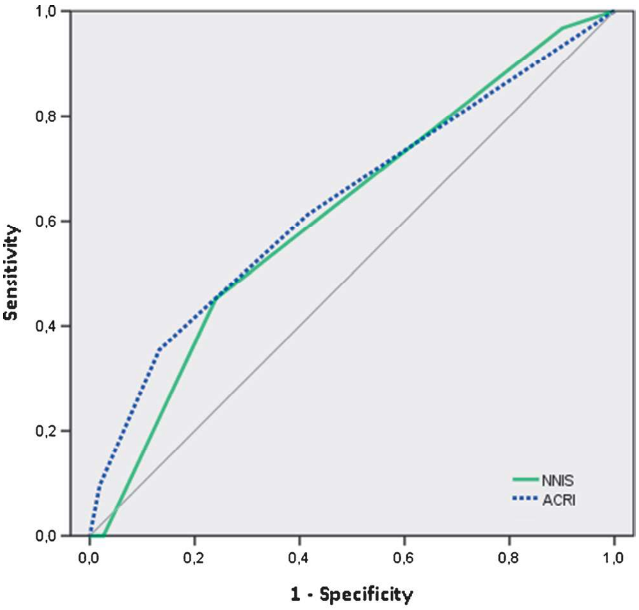
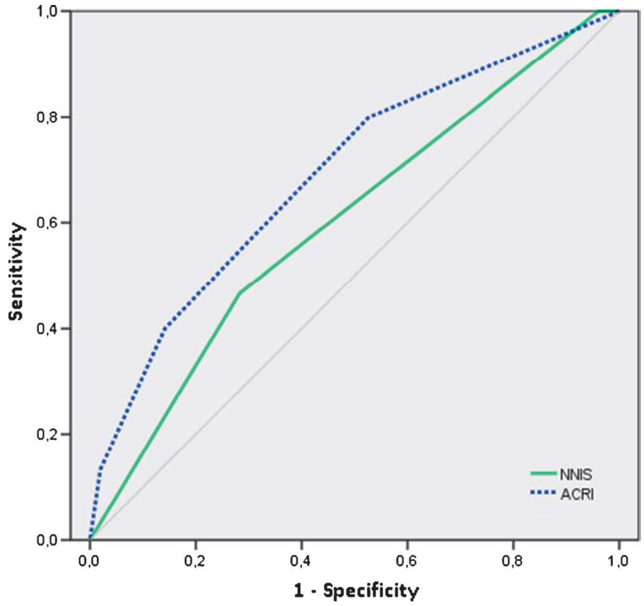



**Fig. 1** SSI incidence in valve surgery based on the NNIS and ACRI risk index




| | AUC | SE | P value | 95% CI |
|---|---|---|---|---|
| NNIS | 0.615 | 0.051 | 0.030 | 0.515 – 0.714 |
| ACRI | 0.635 | 0.056 | 0.011 | 0.525 – 0.744 |

**Fig. 2** ACRI vs NNIS in valve surgery




| | AUC | SE | P value | 95% CI |
|---|---|---|---|---|
| NNIS | 0.602 | 0.076 | 0.186 | 0.453 – 0.752 |
| ACRI | 0.691 | 0.074 | 0.014 | 0.547 – 0.835 |

**Fig. 4** Comparison of ACRI scores vs NNIS indexes in coronary revascularization

## Discussion

The main finding in our study was the verification that the ACRI presents good predictive capacity for the risk of developing SSI both in valvular and coronary patients in a European population. We also observed that the SSI predictive capacity of ACRI compared to the NNIS index is better in both groups, and highest in the group of patients that underwent CABG.

The ACRI was designed to stratify the risk of SSI after CABG. The correlation between the ACRI score and the gradual increase in SSI risk has been shown, each ACRI risk level increasing the SSI risk twice [7]. The ACRI score was validated in the USA with similar results [8], but its behavior has not been analyzed in European patients until now. Neither has its SSI predictive capacity been analyzed in valvular patients in whom the cardiovascular risk factors have lower rates of prevalence than in patients with ischemic heart disease, and that have often been associated with SSI.

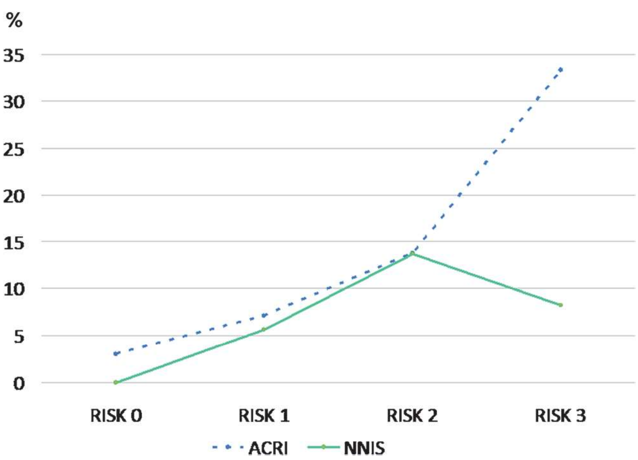



**Fig. 3** SSI incidence in coronary revascularization based on the NNIS and ACRI risk index

In our sample, the ACRI score improves the prediction of SSI after CABG, as compared to the NNIS risk index, with areas under the ROC curve (AUC 0.7 for ACRI vs AUC 0.6 for NNIS) similar to those obtained by Chen et al. in their validation using American patients that had undergone CABG [8], who found an AUC of 0.62 for ACRI against 0.57 for NNIS. We have also found that, in the group of valvular patients, the AUC with ACRI is greater than with the NNIS index. This improvement in the area is quite a bit less than in the CABG group. Based on these results, it can be said that the ACRI score might be an appropriate complement or substitute to the NNIS risk index in stratifying SSI risk in heart surgery, both for coronary and for valvular patients.

The number of CABG analyzed in our study (281) was limited in comparison to the large series used by Friedman to design the ACRI score (4,633) and the 460 patients included by Chen in its validation. However, the fact that we have obtained very similar results reinforces the idea that the ACRI could be a good score for predicting SSI in this type of surgeries.

In CABG, ACRI classified the patients into four different risk groups in which the higher the risk went, the lower the number was. However, the NNIS risk index concentrated almost all the patients (97%) in two risk groups (NNIS 1:

63.3%; NNIS 2: 33.8%). The first reason for this poor discrimination in our sample might be that all the surgical procedures analyzed were clean operations. Another reason could be that 92% of the ASA scores were ≥ III, given that the patients operated presented an elevated number of comorbidities. All of this explains why the NNIS risk index is only capable of classifying the patients that undergo CABG into two large groups. This division is based on whether the operative time is higher or lower than the 75th percentile.

The ACRI score manages to discriminate the probabilities of developing SSI; that is, it improves the predictive power for SSI after CABG with respect to the NNIS risk index. In our population, the ACRI score was correlated with a statistically significant increase in the incidence of SSI. If we take ACRI 0 as a reference, the odds ratio (OR) for each category gradually increases: 2.46 for ACRI 1, 5.17 for ACRI 2, and 16.17 for ACRI 3. These results are similar both to those observed by Freedman et al. [7] and those observed by Chen et al. [8] in the validation of ACRI in a population that had undergone CABG in the United States.

In our study, the area under the ROC curve for the ACRI score was slightly higher than that for the NNIS risk index (0.7 against 0.6). This indicates that the ACRI was a better predictor of SSI after CABG in the population studied. As for valvular surgery, ACRI also classified the patients into four risk groups, with the number of patients in each group dropping as the score increased. In contrast, the NNIS risk index again concentrated the patients into two risk groups; this was because the majority of the procedures were clean surgeries (92%) and presented ASA scores equal to or greater than III (87%). Once again, we observe the limitation of the NNIS index in stratifying patients for calculating the risk of developing SSI. The NNIS risk index only discriminated based on operative time.

The ACRI score showed a better correlation between score and SSI risk; the higher the score, the greater the risk of developing SSI. For example, taking ACRI 0 as a reference, the OR in each category progressively increased: 1.38 for ACRI 1; 3.43 for ACRI 2 and 7.64 for ACRI 3; the SSI incidences were 2.4% for ACRI 0, 3.3% for ACRI 1, 7.8% for ACRI 2 and 15.8% for ACRI 3. In valvular surgery, the AUC for ACRI is very similar to that obtained for the NNIS risk index (0.64 against 0.62) in our population; this suggests that it is necessary to continue investigating the most appropriate risk factors, or their combinations, to achieve the best SSI predictive index in this type of surgeries [17–1920].

Our greatest limitation is that the study population consists of a single Institution with a limited patient sample, in which the specific healthcare attention (low surgical volume per center compared to other countries in the European setting, the hospital flora and the control of nosocomial infection) might affect the results observed. It would be of interest to carry out this validation in other populations with patients operated on in various hospitals, not only Spanish ones. Such a validation at the European level could have differences in prevalence of risk factors analyzed and could consequently modify the results obtained.

The ACRI is a simple score for estimating the risk of SSI that uses only two variables (diabetes and obesity). In our population, the ACRI yielded good stratification of the risk of SSI in patients that had cardiac surgery. It made it possible to improve the predictive capacity obtained using the classic NNIS risk index (useful in predicting SSI risk in other surgical procedures differents to cardiac surgery) that, due to the homogeneity of the parameters it analyzes, does not correctly discriminate the patients with risk of SSI.

In spite of the improved predictive capacity that ACRI represents compared to NNIS (AUC 0.64 in valvular surgery and 0.70 in coronary revascularization), it is not a good enough model to establish good risk prediction. This means that we should continue investigating to ascertain which the main determining factors in SSI development are. Identifying these preoperative risk factors is of great interest in being able to influence them and thus reduce SSI rate.

**Compliance with ethical standards**

**Conflicts of interest** All authors report no conflicts of interest relevant to this article.

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**Ethical approval** The study was approved by the Institutional Ethics Committee.

**Informed consent** The patients gave their written consent to store their data anonymously in the hospital database.

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