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**A RISK INDEX FOR STERNAL SURGICAL WOUND INFECTION AFTER
CARDIOVASCULAR SURGERY**

by

Michele Kohli

**A thesis submitted in conformity with the requirements
for the degree of Masters of Science, Epidemiology
Graduate Department of Community Health
University of Toronto**

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A RISK INDEX FOR STERNAL SURGICAL WOUND INFECTION AFTER CARDIOVASCULAR SURGERY

Masters of Science, Epidemiology
Michele Kohli
Graduate Department of Community Health
University of Toronto

The purpose of this study was to look at factors that increase the risk of sternal surgical wound infection after cardiovascular surgery and to develop a clinical index to identify patients who are at high risk of infection. This study was based on data from 11,508 cardiac surgery patients at the Toronto Hospital and employed stepwise logistic regression techniques. The data were split into 3 groups so that validation could be done on new, independent data sets. The study found that reoperation due to complication, diabetes, more than 3 days in the intensive care unit and use of the internal mammary artery for revascularization were significant risk factors and these factors were included in the index. Validation using 3,836 Toronto Hospital patients showed that the index had an area under the receiver operator characteristic curve of 0.64. The risk index stratifies patients into four risk groups associated with an increasing risk of sternal surgical wound infection. The index may be used peri-operatively or as part of a wound infection surveillance system.

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Abbreviations

- 2LL	-2 log likelihood
ASA	American Society of Anaesthesiologists
BMI	Body mass index
CAB	Coronary artery bypass
CABG	Coronary artery bypass graft
COPD	Congestive obstructive pulmonary disorder
CPB	Cardiopulmonary bypass
CDC	Center for Disease Control (United States)
CVD	Cardiovascular disease
DF	Degrees of freedom
GI	Gastrointestinal tract
IABP	Intra-aortic balloon pump
IDDM	Insulin dependant diabetes mellitus
IHD	Ischaemic heart disease
LOS	Low output syndrome
MO	Microorganisms
NIDDM	Non-insulin dependant diabetes mellitus
NNIS	National Nosocomial Infection Surveillance System
NYHA	New York Heart Association
PMSG	Parisian Mediastinitis Study Group
ROC	Receiver operator characteristic
SE	Standard Error
SENIC	Study of the Efficacy of Nosocomial Infection Control
<i>S. aureus</i>	<i>Staphylococcus aureus</i>
<i>S. epidermidis</i>	<i>Staphylococcus epidermidis</i>
<i>E. coli</i>	<i>Escherichia coli</i>
SWI	Surgical wound infection
TH	Toronto Hospital
TIA	Transient ischaemic attack

1 Introduction

1.1 Overview of the Study

Major Objective:

To develop a risk index for sternal surgical wound infections after cardiovascular surgery.

Minor Objectives:

- 1) To determine risk factors of sternal surgical wound infection
- 2) To describe the morbidity, mortality and microbiology of sternal surgical wound infections at the Toronto Hospital
- 3) To compare the new risk index to existing surgical wound infection risk indexes

The purpose of this study was to develop a risk index for sternal surgical wound infections after cardiovascular surgery. This was achieved using data from cardiovascular surgery patients who received a sternotomy between April 1, 1990 and December 31, 1995 at the Toronto Hospital. The Cardiovascular Surgery Unit has maintained a database containing information on over 150 variables, including pre-operative and post-operative for all patients who underwent surgery during this period. This data was supplemented by information from the Infection Control and Prevention Unit. The data for 11,508 procedures was analysed using logistic regression analysis to determine the risk factors of sternal surgical wound infection. All significant risk factors were incorporated in the index and their weights were used to generate the instrument's scoring system. The index was designed to be simple and to be readily available for use by clinicians to calculate a patient's risk of infection. This index could serve as an integral part of a wound surveillance system to account for patient's underlying risk of infections.

1.2 Overview of the Chapter

This chapter summarizes pertinent information from the literature with the next five sections focusing on clinical information of sternal wounds. First, section 1.3 describes

the rates of cardiovascular surgery in Ontario and gives an indication of the size of the population who is at risk for sternal surgical wound infection (SWI). Next, section 1.4 reviews the definitions of sternal wound infections given in the literature.

Complementing this, Appendix A gives the definition of sternal wound infection used at the Toronto Hospital. Then, section 1.5 reviews the incidence, morbidity and mortality of sternal SWI while sections 1.6 and 1.7 describe the microbiology of sternal wound infections, detailing organisms and sources of contamination of sternal SWI.

The next 3 sections introduce risk indexes and their applications. Section 1.8 describes SWI surveillance systems and the importance of risk indexes in these systems. Section 1.8 describes risk indexes from various areas of medicine while section 1.10 introduces the risk index building strategies.

Finally, section 1.10 introduces risk factors for sternal SWI. Many risk factors have been identified in the literature, but only 11 are described in this section. For the interested reader, a description of over 20 more factors has been included in Appendix C. To minimize repetition, the methodology of previous studies on the risk factors of sternal SWI included in section 1.11 are summarized in Appendix B. In Appendix D, I have attempted to summarize the results from all studies in table format.

1.3 Cardiovascular Surgery in Ontario

In 1992, cardiovascular disease (CVD) was the leading cause of death in Canada, accounting for an estimated 38% of all mortality (Heart & Stroke Foundation, 1995). In 1994, there were 157,240 hospital separations for operations on the cardiovascular system (Statistics Canada, 1996). The most common cardiovascular surgical procedures in Ontario and the rates of these procedures, are given in Table 1.1.

Table 1.1: Age standardized rates for selected cardiovascular system surgical procedures, Ontario, April 1988 - March 1990. (Source: Gentleman et al., 1994).

<i>Surgery</i>	<i>Rate per 100,000 population</i>
Coronary bypass	47.5
Pacemaker Implantation	36.6
Valvotomy or vascularity (with or without valve replacement)	13.8
Carotid endarterectomy	6.4

The rates of cardiovascular procedures have been increasing due to greater numbers of CVD cases and improved surgical techniques that allow more severely ill patients to undergo an operation (Higginson et al., 1994; Swabey, 1996). As this trend is expected to continue, the Ontario Ministry of Health has made cardiac services one of its four priority programs (Ministry of Health, 1996). Over 2,000 open-heart surgeries per year are performed at the Toronto Hospital, making it the largest single centre in Canada for this type of procedure. Over 57% of all cardiovascular surgeries in Metro Toronto, and 25% of those in Ontario, are performed at this hospital (Cardiac Care Network, 1997).

1.4 Definition of Surgical Wound Infection

One of the possible adverse outcomes of cardiovascular surgery, and indeed all types of surgery, is infection of the surgical incision. Bacteria symbiotically colonise various parts of the human body including the skin, the respiratory tract, the gastrointestinal system and the genitourinary system. Invasive medical procedures break protective barriers, such as the epidermis, and allow bacteria to enter previously sterile tissues. After surgery, a wound infection will develop if the contaminating bacteria overwhelm the host defence systems. The infection can remain localised in the wound or can spread to other parts of the body causing complications such as bacteremia (Meakins, 1994). Many cardiovascular surgical procedures involve a sternotomy, which is a surgical incision through the sternum. In coronary artery bypass (CAB) procedures, a vein must be harvested from the patient and used to replace the damaged cardiac vessels. The internal mammary arteries and the saphenous veins are most commonly used. Harvesting of the saphenous veins necessitates a surgical incision of the leg, which may extend from the groin area to the calf.

Sternal wound infection does not usually develop until at least 4 days following cardiac surgery. Generally when a wound is infected, it is tender, pus is seen draining from the wound, erythema may develop, and leukocytosis may be present (Sarr et al., 1984; Culliford et al., 1976). Serious sternal infections can involve mediastinitis (inflammation of the cavity between the lungs, containing the heart), osteomyelitis (inflammation of the bone marrow caused by a microorganism), or both. The standard

definitions for surgical wound infection developed by the Center for Disease Control (CDC) are the most commonly used (Garner, 1986). The Infection Control Unit of the Toronto Hospital (TH) has adapted these into their working definitions of wound infection (TH Infection Control Committee, 1995), which are given in Appendix A. As discussed in Appendix A, surgical wound infections (SWI) can be further classified as deep or superficial. Deep wound infections cause greater mortality and morbidity than superficial wound infections.

1.5 Incidence, Morbidity and Mortality

The rate of sternal wound infection in cardiac surgery ranged from 0.4% to 8.2% in previous studies (Breyer et al., 1984; Culliford et al., 1976; Farrington et al., 1985; Klutymans et al., 1995; Kutsal et al., 1991; L'Ecuyer, 1995; Loop et al., 1990; Miedzinski et al., 1987; Miholic et al., 1985; Nagachinta et al., 1987; Ottino et al., 1987; Sarr et al., 1984; Shuhaiber et al., 1987). Leg wound infections have been reported in 6.8% to 14% of cardiac procedures involving leg incisions (Farrington et al., 1985; L'Ecuyer et al., 1995; Shuhaiber et al., 1987). Most, but not all infections occur before the patient is discharged from hospital. Recent surveys by Orenstein et al. (1998) and Fanning et al. (1998) found that approximately 1.5% - 4.6% of sternal wound infections developed post-discharge. Superficial sternal SWI are more common than deep ones, and usually respond to antibiotic therapy alone. For more serious infections, besides antibiotic therapy, the sternum must be reopened for debridement (the removal of infected tissues and debris in the wound). If this "conservative therapy" fails, muscle or omentum tissue are transferred to the sternum in order to provide a rich blood supply and eliminate the dead space in which bacteria quickly grow (Gellert et al., 1991; Loop et al., 1990).

Sternal wound infection increases the mortality and morbidity of patients undergoing cardiovascular surgery. The mortality rate of patients who suffer sternal wound infection has been reported as 14% to 42% with death caused by haemorrhage, septic shock and multisystem failure (Loop et al., 1990; Ottino et al., 1987). Normally, mortality in valve replacement procedures ranges from 3% to 10% (Sethi et al., 1987) and has been reported as 3.0% for coronary artery bypass (CAB) procedures (Higgins et al., 1992). Stahle et al.

(1997) found that in a series of 13,285 operations followed prospectively, there was no difference in mortality between those with sternal infections and those without within one month of the operation. However, five-year survival rates were significantly lower in the patients who had sternal SWI (Table 1.2). The authors developed a multivariate Cox model to further examine reasons for mortality and found that sternal wound infection was still a significant predictor of late survival for both valve and CABG procedures (relative hazards: 2.1 and 1.9 respectively).

Table 1.2: Percent of patients who survive five years after cardiovascular surgery (Stahle et al., 1997).

<i>Procedure</i>	<i>Patients with sternal surgical wound infection</i>	<i>Patients without surgical wound infection</i>	<i>P Value^A</i>
Coronary Artery Bypass	85%	93%	0.0061
Valve Procedure	76%	83%	0.0326

^AThe p value that results from a comparison of the survival rates using the log rank test

A sternal infection also increases the patient's length of stay in the hospital. One study matched 22 cases with sternal SWI to 132 controls and found that cases stayed in hospital a mean of 12.2 days longer (Kappstein et al., 1992). Other studies have found similar results (Haley et al., 1985a; Loop et al., 1990; Nelson & Dries, 1986; Ulicny et al., 1990). Extra time spent in hospital plus charges for extra procedures and pharmaceuticals make care of patients with sternal wound infection more expensive than those without this complication. Loop et al. (1990) calculated that it was 2.8 times more expensive to care for these patients in a hospital in Cleveland, Ohio. In summarising the findings of the Center for Disease Control's (CDC) Study on the Efficacy of Nosocomial Infection Control (SENIC), Haley commented that they found that SWI caused the longest extra hospital stay of all nosocomial infections, with an average of 7 more days spent in hospital (Condon et al., 1988).

1.6 Organisms Cultured from SWI

An important risk factor for infection is the presence of bacteria in the wound. On the basis of evidence from swabs and agar impression plates of mediastinal wounds, Davidson et al. (1971) concluded that the presence of bacteria in the wound increased risk of infection by 46.7%. The rate of wound infection has been shown to increase as the dose of bacteria in the wound increases (Meakins, 1994). In order for healthy tissue to become infected, Meakins estimated that it must be contaminated by about 1×10^6 bacteria per gram of tissue (Condon et al., 1988).

The most common bacteria genus cultured from sternal wound infections is *Staphylococcus* (Sarr et al., 1984). In six separate studies, of a total of 295 cultures from infected sternal wounds, 176 contained *Staphylococcus* species (60%). The rates of *Staphylococcus* positive culture in the individual studies varied from 29% to 85% (Klutymans et al., 1995; Kutsal et al., 1991; Loop et al., 1990; Miedzinski et al., 1987; Nagachinta et al., 1987; Ottino et al., 1987). *Staphylococcus* is a gram-positive bacteria, normally found on the skin, scalp, and sweat glands. About 30% to 40% of adults carry *S. aureus* in their nasal nares (Meakins, 1994). *S. aureus* is the most common species cultured, however *S. epidermidis* is being seen more frequently due to its increasing resistance to antibiotics used to eliminate *Staphylococcus* (Sarr et al., 1984). Other bacteria commonly isolated from sternal wounds are gram negative organisms including *Escherichia coli*, *Pseudomonas species*, *Klebsiella species*, *Proteus species*, *Enterobacter species*, and *Serratia species*. In a review of the literature, Sarr et al. (1984) found that 40% of cultures from infected sternal wounds grew both gram positive and gram negative bacteria. Sternal wound infections with fungi such as *Candida* are rare, but case reports have been published (Sarr et al., 1984).

1.7 Sources of Contamination

Contaminating bacteria can come from the hospital environment, surgical instruments, and hospital personnel (exogenous sources), or from the patient's own skin, respiratory system or gastrointestinal tract (endogenous sources) (Meakins, 1994). Kluge et al. (1974) swabbed various sites in a group of 66 patients undergoing cardiovascular surgery, 2 of whom developed infection. Positive cultures were grown from blood donor

bags (4%), the heart lung machine (3%), and the neomycin solution used to clean surgical equipment. During the operation itself, 69% of swabs from the repaired area of the heart, 52% of valve prosthesis, and 16% of surgical valve specimens grew positive cultures. In a 1984 review by Sarr et al., similar sources of contamination were identified.

Hospital personnel are another important source of contamination. One study found that 70% of nursing staff carried gram negative organisms, including *Pseudomonas*, on their hands (Rosendorf et al., 1974). Another found that the colony forming units of bacteria increased as the number of persons in the operating room increased (Blakemore et al., 1971). Air sampling has shown that organism concentration is greatest around the operating site (Kluge et al., 1974). In a study by Kluge et al. (1974), 25 of 39 cultures taken during cardiac surgery from the repaired area of the heart were positive. Of these 39 patients, all pre-operative blood and urine specimens were negative and only one developed a major wound infection (Kluge et al., 1974). Some studies have shown that rates of infection vary by operating room (Davidson et al, 1971; Ottino et al., 1987). After a review of the literature, Sarr et al. (1984) concluded that gram positive contamination most likely occurs intraoperatively, while gram negative contamination is most likely post-operative.

1.8 Surgical Wound Infection Surveillance Systems

Several hospitals have seen significant reduction in their surgical wound infection rates after implementing a surveillance system. At the Minneapolis Veterans Administration Medical Center, the rate of all surgical wound infections (SWI) declined steadily from 4.2% in 1977 to 2.5% in 1986 (Olsen & Lee, 1990). The CDC's Study of the Efficacy of Nosocomial Infection Control (SENIC) surveyed selected hospitals in the United States. They concluded that hospitals with extensive wound infection surveillance systems had the lowest rates of wound infection (Haley et al., 1985a). Haley estimated, based on SENIC data, that a surveillance system reduces the incidence of all SWI by 20%. In hospitals with both a surveillance system and an infection control physician, rates of all SWI were reduced up to 38% (Condon et al., 1988). Olsen and Lee (1990) postulated that a surveillance system reduces SWI rate by continually educating surgeons about the adverse effects of wound infections, drawing attention to situations where

infection control measures have not been strictly followed and reminding surgeons that their progress is being observed (Olsen & Lee, 1990). Haley proposed that presenting SWI data to physicians allows them to see the “aggregated view” and gives them a sense of their progress over time (Condon et al., 1988).

1.9 Risk Indexes

The development of risk indexes is relatively new and is gaining in popularity in various areas of medicine. Gross (1996) provided a summary of some of the risk indexes which have been developed in the areas of cardiac disease, infectious disease and cancer as well as ones that apply to all disease groups. He defines an index as a measure of severity of illness that is “comprised of one or more risk factors that are likely to affect the process or outcome being studied”. The index essentially divides patients into strata of increasing risk of developing the outcome (Gross, 1996). This process of stratification is sometimes called “case mix adjustment”. Greenfield (1989) defined the goal of case mix adjustment to be “to separate the effects of the care given from those of the pre-existing health status and other factors (such as age and socio-economic status) that affect outcome measures”.

A wound infection surveillance system should include a comprehensive case finding system, regular analysis of data and timely communication of the results to hospital staff (Sheretz et al., 1992; Haley et al, 1985a). In order to produce surgeon specific infection rates that reflect surgical skills rather patient referral patterns, a risk index should be used to account for the complexity of illness of the patients of each surgeon (Sheretz et al, 1992). Risk factors which potentially affect infection status are discussed in detail in future sections. Intuitively, a more severely ill person has a higher chance of developing an adverse outcome, such as infection, from an operative procedure. Surgeons may accept high risk patients differently. For example, a senior surgeon may have more severely ill patients than a junior surgeon. Therefore, without correcting for risk of infection, SWI infection rates may reflect how surgeons select their patients, rather than their skill at avoiding post-operative infections. In an investigation of a cluster of sternal wound infections, Gellert et al. (1991) found that the rate of severe infection was significantly higher for one surgical team. After correcting for severity of illness and

environmental factors, this difference remained significant. Therefore, the surgical technique of that team was implicated. A risk index must also be used to stratify patients by severity of illness before infection rates are compared between hospitals.

Risk indexes help data analysts compare outcome rates more accurately over time, by correcting for variables, independent of quality of care, which may change over the years. For example, there is evidence that cardiovascular surgeons are now accepting more severely ill patients. Jones et al. (1991) compared the characteristics of cohorts who had received isolated coronary bypass, in 1981 and 1987. In the 1987 cohort, there were more patients over the age of 70 years, more that required triple valve replacement, and more diabetics than in the 1981 cohort. These statistics indicate that the patients in 1987 were sicker than the 1981 cohort. Operative morbidity, as measured by indicators such as surgical wound infections and perioperative myocardial infarction (MI), increased between 1981 and 1987. Similarly, operative mortality also increased. However, when investigators looked at patients at low risk for complication only, they found that operative morbidity and mortality had not significantly increased within this subgroup in the six-year period.

Another potential use of a sternal SWI index would be to help physicians prepare for the operation and counsel patients. Patients who have a high risk of developing a sternal SWI could be informed of their risk and use the information when deciding whether or not to undergo surgery. Surgeons may follow infection control procedures more strictly if the patient is at high risk of developing sternal SWI. Knowing a patient's risk level may allow hospital staff to identify sternal SWI more efficiently and initiate treatment before the infection becomes serious.

Some risk indexes have been designed to correct for comorbid illness in survival studies or outcome research. For example, the Charlson comorbidity index includes 19 conditions such as AIDS, dementia and myocardial infarction which are assigned a weighted risk score (Charlson, Pompei, Ales, MacKenzie, 1987). For longitudinal survival studies, the effect of comorbid disease can be accounted for by stratifying patients by risk, using this index. The APACHE II system (acute physiology and chronic health evaluation) uses 12 physiologic measures to stratify for severity of illness (Knaus, Draper, Wagner, Zimmerman; 1985). The authors recommend using the index in non-

randomized or multi-institutional studies of the efficacy of a new treatment option. They caution that the index is less effective within specific disease groups and for predicting the outcome of individual patients. Schafer et al (1990) investigated the use of the APACHE II for predicting individual outcomes, a practise that is becoming more common. They found that the sensitivity of prediction of hospital mortality was 51.1% and the specificity was 85.4%. In overall goodness of fit testing, the predicted values were significantly different from the observed values. They concluded that although the index performs well on large groups of people, it is not accurate enough to use for prediction at the level of the individual. They found similar results for the Simplified Acute Physiology Score (SAPS) and the Mortality Prediction Model (MPM), which are also severity of illness indexes.

Some risk indexes are specifically designed to help physicians make a diagnosis. One recently developed index can be used to improve admission practises for patients with community acquired pneumonia (Fine et al., 1997). Patients at low risk of death from this condition can be treated as outpatients, although many of those admitted to hospital fall into the low risk category. The new risk index was found to decrease the rate of admission of low risk patients and thus increase the specificity of the diagnosis. Another risk index was developed to improve the specificity of admission for acute cardiac ischemia (Pozen, D'Agostino, Selker, Sytkowski, Hood, 1984). In general, only about 5% of those with true ischemic angina are not admitted to a cardiac care unit. However, approximately 50% of those admitted do not have acute cardiac ischemia and are therefore considered to be "false positives". Use of the index was found to decrease the false positive rate by 30%.

Many indexes have been developed specifically for cardiac surgery. O'Connor et al. (1992) developed an index to predict mortality after coronary artery bypass graft surgery. This index was designed to decrease bias in assessment of a patient's suitability for the procedure. For all types of open heart surgery, post-operative care in the ICU is expensive and is often the limiting resource that determines the scheduling of operations. Several indexes have been designed to predict the length of a patient's post-operative stay in the ICU. For example, Tu et al. (1994) developed an index that predicts ICU stays longer than 2, 4, 7 and 10 days. Holmes et al. (1994) validated an index developed to

determine who will die despite care in the ICU. They found that the specificity of this index was 97% for cardiac surgery, implying that only 3% will be wrongly predicted not to benefit from a stay in the ICU.

Two indexes have been proposed to stratify patients for their risk of SWI: the SENIC index and the National Nosocomial Infections Surveillance System (NNIS)-derived index (Haley et al., 1985b; Culver et al., 1991). The indicator variables for these indexes are listed in Table 1.3. The SENIC index was developed using the medical records of 58,498 randomly selected hospitalized patients in the United States (Haley et al., 1985b). Stepwise multivariate logistic regression techniques helped to produce an additive index that included four indicator variables. Included in this index is a variable that indicates the type of surgical wound. The traditional wound classification system divides incisions into clean, clean-contaminated, contaminated and dirty. (See Table 1.4). The NNIS-derived index is essentially a modified version of the SENIC index (Culver et al., 1991). Multivariate techniques were not used to develop it. As a measure of intrinsic risk, ASA score was substituted for the number of discharge diagnoses. The American Society of Anaesthesiology or ASA score is an index that stratifies patients into 5 levels of intrinsic risk. (See Table 1.5). Delgado-Rodriguez et al. (1997) tested both indexes prospectively on a cohort of 1,483 patients from a general surgery ward of a Spanish hospital. They concluded that the NNIS-index separates patients into risk groups more accurately than the SENIC-index. However, Roy et al. (1994) found that the NNIS index was not a sensitive index for predicting SWI after cardiovascular surgery. They compared the NNIS risk scores of 200 patients with SWI to 400 non-matched controls after CV surgery. The sensitivity and specificity of the index was 28% and 88% respectively while the positive and the negative predictive values were 52% and 72% respectively. Roy et al. (1997) proposed that this lack of sensitivity was due to the fact that a sternotomy is considered a clean incision and that most patients undergoing a CV procedure have an ASA score of 3 or higher.

Table 1.3: Indicators included in the SENIC and the NNIS-derived risk indexes (Haley et al., 1985b; Culver et al., 1991).

<i>SENIC Risk Index</i>	<i>NNIS derived Risk Index</i>
1) Abdominal operation	1) ASA score of 3, 4 or 5 ^A
2) Operation lasting >2 hours	2) Operation involving a contaminated or dirty-infected wound.
3) Contaminated or dirty-infected operation by the traditional wound classification system	3) Operation of long duration (This time varies depending on the procedure performed.)
4) Having 3 or more discharge diagnosis (excluding those involving sternal wound infection) as written on the discharge summary sheet	

^ASee Table 1.5

Table 1.4: The traditional wound classification system. (The Toronto Hospital Infection Control Committee, 1995).

<i>WOUND TYPE</i>	<i>CRITERIA</i>
Class I : Clean	Surgical wounds that should not ordinarily become infected, including operations where aseptic technique is maintained, no inflammation is observed and the respiratory and gastrointestinal (GI) tracts remain intact.
Class II : Clean-contaminated	Surgical wounds that should not ordinarily become infected, but contact with normal bacterial flora may occur, including operations involving the respiratory, the GI and the female reproductive tracts.
Class III : Contaminated	Surgical wounds from operations involving an acutely inflamed area or "gross spillage of the GI tract".
Class IV : Dirty	Surgical wounds from operations "in which the operative site is grossly infected or draining on admission and/ or pus is encountered during surgery e.g. incision and drainage of an abscess."

Table 1.5: Criteria used to determine a patient's ASA score (New classification of physical status, 1963).

SCORE	CRITERIA
1	A normal, healthy patient
2	A patient with a mild systemic disease
3	A patient with a severe systemic disease that limits activity, but is not incapacitating
4	A patient with an incapacitating systemic disease that is a constant threat to life
5	A moribund patient not expected to survive 24 hours with or without operation

Note: If an E proceeds the score, an emergency operation was performed.

1.10 Developing Risk Indexes

Various methods have been used to develop and validate risk indexes. Wasson et al. (1985) reviewed several indexes and concluded that a good prediction rule includes:

- 1) A clearly defined outcome that is not affected by ascertainment bias
- 2) Precise definitions of predictor variables
- 3) Predictors that are "feasible and relevant"

Validating the risk index is extremely important. In fact, Miller et al. (1993) recommended validating a risk index in each new geographical area that it is used. In some areas, the index may be less effective if the prevalence of risk factors is different from the population from which it was developed. Periodical validation helps ensure that the accuracy of the index does not decrease over time due to the changing prevalence of risk factors. As a minimum, testing the index on the data set it was developed using bootstrap or jack-knife techniques is recommended. Validating the index on a new data set from the same clinical setting will help detect overfitting of the model and provide more realistic measures of goodness of fit. Testing the index on prospectively collected data from the same clinical setting, or even better, from a new geographical location, will reduce the bias in methods of data collection (Wasson et al., 1993).

1.11 Risk Factors for Sternal SWI

Several studies have used multivariate techniques to determine the risk factors for sternal SWI. Presented below is a summary of the selected potential risk factors cited in the literature. These are all major risk factors that have frequently been identified as significant in previous studies. Also included below are the risk factors that were found significant in this study. The factors are listed alphabetically for ease of organisation, and do not reflect the relative importance of the risk factors. Appendix B gives a brief summary of selected studies mentioned in this literature review. Other potential risk factors are described in Appendix C. Appendix D gives an overview of the findings of these studies with respect to the risk factors. The conclusions of the research studies conflict for many of the factors. This may be due, in part, to power issues, as the sample size of some of the studies are quite small. Also, risk factors may vary in importance according to the location and the time (Miller et al., 1993). It is important to note that some studies classified patients with sternal SWI, other complications, or both as cases.

1.11.1 Amount of blood transfused

Blood transfusion can potentially increase the risk of SWI in several ways. Firstly, recall that Kluge et al (1974) cultured gram negative bacteria from the inside of 15 of 363 blood donor bags swabbed after cardiac surgery. Therefore, blood transfusion is a potential source of contamination. Secondly, blood transfusion reduces the immune response, an effect which appears to be related to volume transfused (Condon et al, 1988; Ulincy et al., 1990). Finally, the amount of blood transfused may be a marker for the amount of tissue traumatization (Miholic et al., 1985).

Research studies have produced conflicting results about the relationship between blood transfusion and SWI. Ottino et al. (1987) and Loop et al. (1990) both concluded that blood transfusion is a significant risk factor and included it in their multivariate models. On the other hand, Miholic et al. (1985) and Ulincy et al. (1990) found no significant relationship.

Murphy et al (1992) investigated the relationship between blood transfusion and post-operative infection after cardiovascular surgery. The amount of blood transfused, defined as the number of red cell units given, was an independent risk factor in all the

multivariate models they produced. As well, they found that total blood units, white cell units, and plasma units could be substituted for red cell units as a measure of blood transfused. Moreover, the research group determined that several factors were significantly associated with blood transfusion. Patients who were older, female, non-smoking, had greater number of grafts, had longer operations and spent more time on cardiopulmonary bypass (CPB) machines were more likely to receive more units of blood during the operation. Therefore, age, sex, smoking status, number of grafts used, duration of operation, and duration of CPB are all potential confounders of the relationship between units of blood transfused and sternal wound infection. On the basis on their multivariate models, Murphy et al. (1992) concluded that diabetes did not confound the relationship between transfusion and post-operative infection.

1.11.2 Antibiotics

There are many studies comparing the effectiveness of different antibiotics in preventing SWI. Most studies specific to SWI after cardiothoracic surgery have small sample sizes and are not powerful enough to detect significant differences between antibiotics. Kreter & Woods (1992) performed a meta-analysis of 28 prospective, randomized controlled trials comparing antibiotics used in cardiothoracic surgery. Their conclusions pertain to both leg and sternal infections. Earlier studies had suggested that antibiotics prophylaxis had no value. However, in these studies, antibiotics were only given after the operation. After examining later studies, Kreter & Woods (1992) concluded that antistaphylococcal penicillins or first-generation cephalosporins reduce wound infection rates from approximately 25% to 5%. They determined that duration of prophylaxis did not affect SWI rate. Finally, they ascertained that second-generation cephalosporins, cefamandole and cefuroxime reduced SWI rates significantly more than cefazolin. No difference in efficacy was seen between cefamandole and cefuroxime, first-generation cephalosporin or cephalothin and cefamandole or ceforanide, cefamandole and ceforanide, or cefazolin and ceftriax. There was no efficacy difference between antistaphylococcal penicillin and first or second – generation cephalosporins.

Research studies have rarely looked at how timing of the antibiotic dose affects risk of SWI. Classen et al. (1992) studied 2,847 patients who underwent clean or clean-

contaminated operations. (For more information on wound classification see section 1.8 and Table 1.4.) Patients were classified as receiving the first dose of antibiotics 2 to 24 hours before surgery (early), less than 2 hours before incision (preoperative), less than 3 hours after incision (perioperative), and greater than 3 hours after incision (postoperative). Patients receiving antibiotics less than 2 hours before incision (preoperative) had the lowest rates of SWI. This did not change after logistic regression was performed to control for confounders. The rate of SWI in the perioperative and the postoperative group was almost 3 times and 5 times that of the preoperative group respectively. Finally, relative risk of infection was also significantly higher in the early group than the preoperative one.

Information on antibiotic administration was not included in the database used for this thesis project. However, this limitation will be addressed further in the Methods section.

1.11.3 American Society of Anaesthesiology (ASA) Score

ASA scores are a measure of the general health of the patient (see criteria listed in Table 1.5). As discussed in section 1.9, ASA scores were included in the NNIS-derived SWI risk index. However, in studies focusing on sternal SWI after open-heart surgery, ASA scores were not a significant risk factor (The Parisian Mediastinitis Study Group (PMSG), 1996; Ulincy et al., 1990). In a study of inter-rater reliability of ASA scores, Owens et al. (1978) concluded that the scoring system is “useful but suffers from a lack of scientific precision”.

1.11.4 Diabetes Mellitus

Diabetes mellitus affects the immune response. People with diabetes have been found to have reduced monocyte and neutrophil chemotaxis and an abnormal ratio of helper T to suppresser T lymphocytes (Meakins, 1994). Diabetes can also damage nerves, as well as blood and lymph vessels. These tissue changes are advantageous to certain microorganisms and may predispose the person to infection (Meakins, 1994).

Diabetes has been defined in various ways and the prevalence of the disease in the population is highly dependent on that definition. Investigators may choose to include only diabetics on drug therapy. Alternatively, they may also include diabetics on diet

therapy or borderline diabetics. (Johnson et al., 1982). Despite differing definitions, numerous univariate and multivariate studies agree that diabetes increases the risk of sternal infection and wound healing problems (Casey et al., 1983; Grossi et al., 1991; Farrington et al., 1985; Johnson et al., 1982; Hazelrigg et al., 1989; Loop et al., 1990; Nagachinta et al., 1987; Schuhaiber et al., 1987). Only Ulincy et al. (1990) and Miholic et al. (1985) found that being diabetic did not increase the risk of sternal SWI or infectious complications respectively. However, these studies included only about 250 patients each. Finally, two studies concluded that diabetes was significant for one type of procedure only. The PMSG (1996) found that diabetes was not significant for CAB procedures, but was significant for other procedures. Conversely, Stahle et al. (1997), included diabetes as a significant factor in their multivariate risk model for CAB procedures, but not for valve procedures.

The presence of diabetes is linked to other risk factors for sternal infection after surgery. Increasing age, female sex, and obesity have all been identified as risk factors for non-insulin dependant diabetes (Pareschi & Tomasi, 1989). Diabetes can lead to a number of complications, including coronary heart disease, stroke and chronic renal failure (Boulton-Jones, 1981). Diabetes can cause renal failure and it has also been noted to amplify the risk of mortality from ischaemic heart disease in patients with renal failure, thus playing the role of an effect modifier (Raine, 1994).

Potentially, any relationship between the above risk factors and sternal wound infection may be due in part or in full to the presence of diabetes. Diabetes may also modify these relationships, so it should be considered in a multivariate analysis.

1.11.5 Duration of Cardiopulmonary Bypass

Cardiopulmonary bypass (CPB) or extracorporeal circulation is used in open-heart surgery so that the heart may be stopped. Blood entering the heart is rerouted to a blood-lung machine that removes carbon dioxide and re-oxygenates the blood (Britannia Online, 1998a). Cardiopulmonary bypass can lead to peri-operative complications such as hypertension, damage in the fine structure of the lung, low output syndrome, arrhythmias, peri-operative myocardial infarction and post pericardiotomy syndrome (Casthely & Bregman, 1991). Cardiopulmonary bypass can also lead to excessive

bleeding (Casthely & Bregman, 1991) and immune dysfunction (Miholic et al., 1985). During CPB, oxygen flow to the tissues is depleted (Ulincy et al., 1990). Therefore, it is plausible, that the length of CPB could affect the risk of post-operative wound infection.

Research studies that have included duration of CPB as a potential risk factor have reached varying conclusions. Miholic et al. (1985) found that it was a significant risk factor for sternal SWI after valve replacement surgery, but not aortocoronary bypass surgery. Therefore, the type of surgery may confound this relationship. Ottino et al (1987) did find the variable significant in their univariate analysis, but not the multivariate analysis. Ulincy et al. (1990) did not detect any significant relationship.

CPB time is related to several other potential risk factors. Increasing the number of grafts done during the operation will, in turn, increase CPB time and length of the operation. Length of the operation is intuitively related to CPB time. Certain surgical procedures may require more operating/ CPB time than others. The relationship between CPB and blood transfusion was discussed above. Thus all these factors are potential confounders of the relationship between CPB and sternal wound infection. As well, length of CPB may be the indirect cause of a relationship between length of operation and sternal wound infection.

1.11.6 Intensive Care Unit (ICU) Stay

A longer stay in the intensive care unit (ICU) post-operatively, increases the risk of sternal SWI contamination by microorganisms found in the unit. Microorganisms may be transferred from patient to patient via staff, clinical instruments, or the environment. Rosendorf et al. (1974) grew cultures from swabs of the nose, throat and groin preoperatively of 9% of cardiac surgery patients. Postoperatively, 91% of the same patients grew cultures, usually after staying in the ICU. Therefore, it is biologically plausible that longer stays in the ICU will increase the risk of sternal SWI. Longer stays in the ICU may also be a marker for patients with post-operative complications. Long ICU stays are necessitated by low output syndrome, respiratory insufficiency, tracheostomy, intra-aortic balloon pump (IABP), prolonged mechanical ventilation and excessive bleeding (Ottino et al., 1987). In their index to predict length of stay in the ICU after cardiovascular surgery, Tu et al (1994) included age, sex, a score of left

ventricular function (not included in this analysis), type of surgery and timing of surgery. Thus, all these factors are potential confounders.

Both Uliny et al. (1990) and Ottino et al. (1987) have failed to show that longer ICU stays increase the risk of sternal SWI. The variable was significant in the univariate analysis of the latter research group, but not the multivariate.

1.11.7 Length of Operation

There are several plausible reasons why longer surgeries might increase the risk of sternal SWI. Surgery, trauma, and anaesthesia can all depress the immune system, increasing the risk of opportunistic infection (Meakins, 1994). This effect becomes more significant in longer operations (Condon et al., 1988). Longer operations also affect the quality of wound healing since injury to tissue increases with operating time (Condon et al., 1988). Of course, the longer that tissue is exposed through a surgical incision, the greater the risk of bacterial contamination (Condon et al., 1988; Ottino et al., 1987).

As discussed previously, operating time is one of the factors included in the SENIC risk index (Haley et al., 1985b). Other researchers, including Davidson et al. (1971) and Loop et al. (1990), have included length of operation as a significant risk factor in their multivariate models. Davidson et al. (1971) defined a long operation as being greater than 60 minutes, while Loop et al. (1990) examined the incremental increase in risk per extra hour of surgery. This variable was included in the multivariate model for cardiac surgery by Simchen et al. (1981), but not colon or neurosurgery. Miholic et al. (1985) once again found that significance varied by procedure: it was significant for valve replacement surgery only for the univariate analysis, but not the multivariate analysis. PMSG (1996) determined that operating time was a significant factor in the multivariate model for procedures other than CAB only. Several research groups have concluded that length of operation does not affect the rate of sternal SWI and other complications (Breyer et al., 1984; Miedzinski et al., 1987; Nagachinta et al., 1987; Ottino et al., 1987; Sutherland et al., 1977).

1.11.8 Renal Failure

Renal failure can occur preoperatively or post-operatively. Acute renal failure can occur after haemorrhage or mismatched blood transfusions (Boulton-Jones, 1981). The lymphoid tissue of the patient with renal failure shrinks. The effectiveness of the immune system may become compromised due to lymphopenia and altered neutrophil response (Meakins, 1994). It is believed that people with renal failure are more susceptible to infection (Boulton-Jones, 1981). Diabetes and longer CPB times are risk factors for renal failure, and may therefore modify the relationship between postoperative renal failure and sternal wound infection (Boulton-Jones, 1981; Kirklin & McGiffin, 1987).

Higgins et al. (1992) found that a pre-operative serum creatinine level higher than 168 μmol was significant in a multivariate model predicting overall morbidity after cardiovascular surgery. High levels of serum creatinine, a metabolite of creatine usually cleared in urine, indicates advanced renal failure (Thomas, 1993). Stahle et al (1997) found that postoperative renal failure requiring dialysis was a significant risk factor for sternal SWI. It is a risk factor in their multivariate models for both CAB and valve procedures.

1.11.9 Re-exploration of the mediastinum due to complications

Internal bleeding, sternal dehiscence, tamponade, shock or arrest can necessitate re-exploration of the mediastinum. Reoperation increases tissue traumatization and increases total operative time, thus increasing risk of contamination (Ottino et al., 1987). Most investigators have focused on reoperation due to postoperative bleeding. Brown et al. (1969) found that reoperation for bleeding did increase the rate of mechanical sternal dehiscence, but not the rate of infectious complications. Breyer et al. (1984), Loop et al (1990), Sutherland et al. (1977) and Ulincy et al. (1990) did not find any increased risk of SWI in patients who were reoperated on due to excessive bleeding. Miholic et al. (1985), looked at the risk by procedural subgroups. They determined that reoperation by bleeding increased the risk of sternal SWI in patients undergoing CAB surgery, but not in those undergoing valve replacement procedures. Conversely, Stahle et al (1997) found that this variable was a significant risk factor for valve procedures but not CAB

procedures in their multivariate analysis. Finally, Hazelrigg et al. (1989), Ottino et al. (1987) and Farrington et al. (1980) found that reoperation for bleeding was a significant risk factor.

As discussed previously, re-exploration of the mediastinum is closely related to the amount of post-operative bleeding. Since reoperation may be required because of excessive bleeding, the procedure is often associated with increased amounts of blood transfusion. Mechanical ventilation can weaken the integrity of the sternal wound. Therefore, patients who are ventilated excessively post-operatively may require reoperation due to mechanical dehiscence of the sternum. As discussed above, tamponade can necessitate reoperation as well as also lead to low output syndrome.

1.11.10 *Type of Operative Procedure*

Generally, cardiovascular procedures are divided into three or four groups in the literature. Coronary artery bypass (CAB) grafting procedures are done when a coronary artery becomes occluded. The vessel is replaced by another vein in order to relieve angina and to prevent ischaemic damage of the heart muscle. Valve procedures include repair or replacement of a damaged cardiac valve. These procedures account for the majority of cardiovascular operations involving a sternotomy. Occasionally, patients who received both a CAB and a valve procedure were grouped separately in a combination category (Culliford et al., 1976). An “other” category, which includes congenital heart defects, may also be studied. The rates of infection do vary by procedure and it is therefore important to include this as a potential risk factor. Table 1.6 shows the rates of infection by procedure for several studies. As discussed in other sections, some studies have found that certain factors increase the risk of sternal SWI in CAB procedure and not valve procedures and vice versa (Miholic et al., 1985; PMSG, 1996). In their multivariate model for all cardiothoracic operations, the PMSG (1996) included type of procedure. However, Nagachinta et al. (1987) and Ottino et al. (1987) determined that the type of procedure was not significant in their final multivariate models and concluded it was not an independent risk factor for sternal SWI.

Table 1.6: The rate of sternal SWI and other infectious complications by procedure. See details in Appendix B for specific definition of outcome for each study.

<i>Reference</i>	<i>Coronary Artery Bypass</i>	<i>Valve Procedures</i>	<i>Combination</i>	<i>Other</i>
Culliford et al. (1976)	1.9%	2.2%	0.7%	0.4%
Farrington et al. (1985)	8.7%			1.6% ^A
Miholic et al. (1985)^B	6.8%	9.5%		
Miedzinski et al. (1987)	1%	0%	6%	8%
Shuhaiber et al. (1987)	20%			3.3% ^A

^AThese groups include all valve operations as well

^BRate includes all deep sternal SWI, pneumonia, septicaemia and prosthetic valve complications

1.11.11 Use of Internal Mammary Artery

In CAB procedures, generally either the saphenous vein of the leg or the internal mammary artery (IMA) of the chest is harvested to be used as a graft. Use of the IMA may increase the risk of sternal SWI if it reduces blood flow to the sternal wound. This question is quite controversial. Some investigators conclude that up to 90% of blood flow to the area is prevented, while others maintain that the loss of blood flow is compensated for by intercostal collateral flow through the periosteal plexus (Loop et al., 1990). Culliford et al. (1976) only performed a univariate analysis, but noted that the infection rate when one IMA is removed is double that when the saphenous vein is used. Use of bilateral IMA increases the rate eight fold, compared to saphenous vein use. Loop et al. (1990) found that use of the IMA rather than the saphenous increased the risk of sternal SWI for diabetics only. Ulincy et al. (1990), the PMSG (1996), Hazelrigg et al. (1989) and Grossi et al. (1991) found that use of IMA was an independent risk factor and included it in their multivariate models. Stahle et al. (1997) found similar results for use of the internal thoracic artery.

2 Methods

In this chapter, I delineate the methods used for this thesis starting with section 2.1, which describes the preoperative preparation of cardiovascular surgery patients at the Toronto Hospital. Next, section 2.2 introduces the reader to the Toronto Hospital data while section 2.3 details the chart review I performed. For the purpose of analysis, the data set was divided into 3 subsets and section 2.4 summarizes this process and illustrates the strength of this design. Section 2.5 illustrates how multivariate logistic regression was used to develop a basic risk model. Measures of goodness of fit and how they were used during the analysis are discussed in sections 2.6 and 2.7. Finally, the method used to determine the score associated with each factor in the index is described in section 2.8.

2.1 Cardiovascular Surgery Patients

This study is a retrospective study of a cohort of cardiac surgery patients from the Toronto Hospital. Hair removal and antibiotic policy have been shown to affect the rate of sternal SWI. (For more information see Appendix C for hair removal and section 1.9.2 for antibiotic use.) Before all operations, hair was removed from surgical incision sites using a clipper. The standard preoperative antibiotic policy is outlined in Table 2.1. Neither policy changed during the study period.

Table 2.1: Toronto Hospital cardiovascular surgery antibiotic prophylaxis policy (Antibiotic Subcommittee, 1997).

<i>Procedure</i>	<i>Antibiotic</i>	<i>Recommended dosage:</i>
Prosthetic valve surgery	Cefazolin	1g IV pre-op
Coronary bypass graft	Cefazolin	1g IV q8h for 48 hours post-op (6 doses total)
Pacemaker insertion	Cefazolin	1g IV pre-op
In Penicillin allergy	Vancomycin	1g IV pre-op (over 1 hour) 1g IV q12h x 24 hours post-op (3 doses total)

2.2 The Data

The data used for this project come from two different departments of the Toronto Hospital. The bulk of the data was supplied by the cardiac surgery division, including most of the information on risk factors. They have compiled a comprehensive database including over 150 variables on every patient that has undergone cardiovascular surgery since 1990. Appendix E contains a detailed guide of the variables in the databases, as well as a copy of the data collection forms used. Data on all pump cases from April 1, 1990 to December 31, 1995 was requested and in total, data for 11,750 patients was received. A pump case is a patient who was put on cardiopulmonary bypass during the operation. In general, pump cases require a sternotomy for surgery and are therefore at risk of sternal infection. Data from the Infection Prevention and Control unit was used to provide numerator data and additional variables such as culture information and wound class. Copies of their data collection forms are included in Appendix F. The two data sets were merged and recoded by Grant Gillis of Infection Prevention and Control and Zhao Sun of Cardiovascular Surgery. They removed all names and other identifying information from the data. The chart number was retained to provide a unique identifier for each patient. All surgeon names were recoded as surgeons A to L. The cardiac database variable for sternal infection (INFSTERN) and the infection control variable (STRSSICT) were both retained in the new data set. To the best of my knowledge, the databases were successfully merged and all records were matched correctly.

The data set was converted from Visual Fox Pro format to SAS version 6.11 format using the DBMS Copy program (DBMS Copy, 1996). A comparison of the sternal wound infection variables from each data set, using SAS version 6.12 (SAS Institute, 1996), showed that some patients were recorded under the Infection Control variable as having a sternal infection, but not under the cardiac variable and vice versa. The cardiac research nurse abstracts all information for the database from patients' charts while the infection control nurse collects information on wound infection in the cardiovascular service based on visits to the wards, and notices from the microbiology lab and ward nurses. Both nurses use the definition of wound infection discussed in the introduction and outlined in Appendix A. However, the infection control nurse may miss infections that develop on the weekend and the cardiac research nurse may miss infections that

develop after the patient is discharged. In cases where the patient is readmitted in the emergency department, the infection control nurse would be alerted. If the patient develops a sternal infection after transfer to another hospital, that hospital may call either the infection control or the cardiac surgery department to inform them of the condition. The two nurses meet periodically to ensure that their data on sternal wound infection is the same; however, there were still some cases entered into only one of the databases.

The patient information for those recorded as having sternal infection in only one database was re-examined because it was important that cases and controls were clearly identified for this study. Abstracts from infection control were examined to ensure that a data entry mistake did not occur. If a disagreement still existed, the infection control nurse re-examined the original chart and microbiology lab information to determine if an infection truly occurred using the Toronto Hospital definitions of wound infections. In this way, all cases were either confirmed or recoded as not having a sternal infection. Further details are presented in the Results section and the process is summarized in Figure 2.1.

Figure 2.1: The process of reconciling conflicting reports of sternal surgical wound infection status in the cardiovascular and infection control databases.

Detection of sternal infection occurring in the hospital was most likely complete, as two independent sources collected information on this. However sternal infection can occur after a patient is discharged. Even so, the Infection Control Unit estimates that 100% of deep sternal infections are detected, due to the fact that these infections require surgical treatment (Personal communication, Dr. Conly, 1998).

The signs of wound infection take several days to develop and patients who die shortly after surgery may not live long enough to develop an infection. Therefore, previous studies have excluded those who died within 6 to 8 days of surgery (Ottino et al., 1987). In this study, a total of 242 patients were excluded because they died less than 6 days after the surgery without signs of infection, leaving 11,508 in the study. The SAS procedure PROC COMPARE (SAS Institute, 1996) was used to compare manipulated data to original data, to ensure that data had not been changed during the manipulation process.

2.3 Chart Review

A chart review was performed, with the following objectives:

- 1) To determine the accuracy of the data extracted from patients charts and entered into the Infection Control and Cardiac databases
- 2) To extract information on selected variables that are missing because:
 - i) The field does not exist in the database
 - ii) The field exists but the data was not entered
- 3) To gain a better understanding of data which is out of the expected range for certain variables.

In order to determine the accuracy of data extraction, the information on the variables listed in Table 2.2 from 150 randomly selected charts was abstracted using the data collection form included in Appendix G. These variables were selected because they were shown to be significant risk factors in other studies of sternal wound infection using multivariate techniques (Ottino et al., 1987; Nagachinta et al., 1987). Time constraints and concerns over manageability dictated the decision to limit the chart review to 150 cases and to abstract data for selected variables only. The sample size allows estimation of up to a 50% disagreement within 0.08 absolute percentage points with 95% confidence

and a power of 0.80 (Lemeshow & Hosmer, 1990). Information on antibiotic use (type and timing) was collected since it is not recorded in either database but is an important potential risk factor for sternal infection. Because this sample of 150 charts had been randomly selected, the patterns of antibiotic use in this subgroup were used to infer those of the entire group of patients. The hospital does have an antibiotic policy for cardiovascular surgery, and the information was collected to confirm that the policy has been followed. Both the ASA score and the number of underlying diagnoses are part of previous surgical wound infection risk indexes, but are not consistently recorded in either database. These data were abstracted during the chart review so that the validity of the SENIC and NNIS risk indexes could be compared to the index derived in this thesis project.

Several variables recorded in the database are only missing 0.1% of the data and these charts were examined in order to fill this missing data. The information recorded in the database for some patients was not within the expected range for several variables and in order to get a sense of why some patients are outliers, their charts were examined. Please refer to the data collection form for missing data in Appendix G.

For the chart review, the chart number was the only identifying information that was recorded. Names or other personal information were not abstracted in order to protect confidentiality.

The information collected from this chart review was entered initially into EpiInfo 6.01. The resulting data set was converted into DBF and SAS data set formats. Both the abstracted data and the original data from Cardiac Surgery and Infection Control were cut and pasted into Microsoft Excel Version 7.0 (Microsoft, 1996) and visually compared. For most discrepancies, the charts were re-examined to determine if a mistake was made in abstracting the data. Finally the SAS procedure PROC COMPARE (SAS, 1996) was used to compare the abstracted data to the original data. Percent agreement was calculated for each variable. When agreement was less than 100%, the Kappa coefficient was calculated for binary variables while the Intra-class correlation coefficient was determined for continuous variables. Kappa corrects for the fact that some of the agreement may be due to chance. For example, a variable with a Kappa coefficient of 0.3 is 30% of the way between agreement due to chance and 100% agreement. The intra-

class correlation coefficient is equal to the Kappa coefficient for continuous variables (Kelsey et al., 1996). Several multi-level categorical variables, such as TIMING were treated as continuous variables for the purpose of the analysing results of the chart review only, so that correlation coefficients could be calculated

Table 2.2: Variables that were examined during the chart review

CODE	DEFINITION
ANTITYPE*	Type of antibiotic used before or during surgery
ANTITIME*	Time when antibiotic was administered: 1) Early: more than 2 hours before initial surgical incision 2) Preoperative: 0-2 hours before initial incision 3) Perioperative: within 3 hours of initial incision 4) Postoperative: more than 3 hours after initial incision (Categories based on study by Classen et al., 1992)
AGE	Age on date of surgery (yrs)
ASAScore*	ASA score
DIABETES	Insulin or non-insulin dependent diabetes
HT	Height (cm)
INFLEG	Leg wound infection
INSTERN	Sternal infection
NUMDIS*	Number of discharge diagnoses
ORTIME	Length of operation in minutes
PACKCELL	Number of units of blood used for transfusion
PROC	Surgical procedure 1) ACB 2) Valve surgery 3) Other
PUMP	CPB time in minutes
REOP	Reoperation: 1) Bleeding 4) Infection 7) Other 2) Tamponade 5) Dehiscence 3) Shock/arrest 6) Redo surgery
SEX	1) Male 2) Female
SURVIVAL	1) NO 2) YES (Patient left hospital and survived thirty days post DATEOR)
TIMING	1) Elective 2) Same hospitalisation: cannot go home because of urgency or anatomy (semi-urgent) 3) Urgent: < 72 hours 4) Emergent: < 12 hrs from event
WT	Weight
ACBREDO	Previous ACB
AVREDO	Previous aortic valve surgery
MVREDO	Previous mitral valve surgery
TVREDO	Previous tricuspid valve surgery
OTHREDO	Other previous cardiac surgery

Note: Code refers to the Cardiac database code for the variable. The variables marked with a * are not in either the Infection Control or Cardiac databases.

2.4 Division of the Data Set

The data set was randomly divided into 3 subsets in order to increase the validity of the final risk index. Due to the random division process, each of these subsets could be considered an independent data set and using these in the analysis had two advantages. Firstly, over 30 potential risk factors were included in the analysis because they were all biologically plausible factors that had been included in previous studies (See section 1.9 for details). The chance that variables will be falsely identified as risk factors by statistical tests increases with the number of variables tested. Developing a model on one data set and testing it on a second one allowed the chance of having false positive or “noise” variables in the final risk index to be minimized. Secondly, as noted in section 1.8, validating the model on the same data set used to develop it is inherently biased and will produce an overly optimistic measure of the predictive power of the index. Using independent data sets to determine the predictive power of the logistic regression model and the risk index produces more reliable and accurate measures.

Division of the data set does sacrifice some of the power of the study, however, only 2 of the previous studies of sternal SWI have included over 3,000 patients (Loop et al., 1990; Stahle et al., 1997). A study using a data set the size of one subset (3836) would still be one of the most powerful studies. Therefore, added validity of the index was chosen as preferable to added power of the study.

Using numbers randomly generated by CALL RANUNI of the SAS program (SAS Institute, 1996), the data set was randomly divided into 3 subsets. The 150 charts used in the chart review were included in subset 3. The first subset was used as the “training set” to develop logistic regression models while the second subset was used to choose the best model and then develop a risk index based on this model. The final set was used to validate the risk index. Figure 2.2 summarizes this entire process and more detail on the use of each data set is given in the subsequent sections. Overall, the methods used to develop the risk index are similar to those used previously to develop other risk indexes (O’Connor et al., 1992; Tu et al., 1994).

Figure 2.2: Tree diagram describing process of dividing the data set into 3 subsets

2.5 Developing a Logistic Regression Model

The majority of the variables from the cardiac database were categorical or binary. The outcome variable, sternal infection, was recoded as a binary variable represented as 0 (no infection) and 1 (superficial or deep sternal SWT). Another option would have been to look only at deep infections, which are the more serious type of infection. However, because only 133 out of the 342 sternal infections were deep, this would greatly have reduced the power of this study. The univariate analysis, discussed below, was also performed once looking at deep sternal infections only as the outcome variable and once with superficial sternal infection only. The results did not differ from coding all sternal infections as 1, except that the confidence intervals of the odds ratios were wider. Therefore, multivariate analysis was performed with the outcome variable coded as 1 for either deep or superficial infections. Only results from this outcome variable option are reported.

Logistic regression and discriminant analysis are two types of analysis that can be used for retrospective studies in which cases must be differentiated from the controls. O’Gorman and Woolson (1993) found that both methods perform equally well for samples over 100 observations when the data is normally distributed. However, logistic regression performs better if the data is not normally distributed. Logistic regression was chosen to create the model because the outcome variable for this study was binary and no assumptions about the distribution of the data had to be made. The outcome variable was either 0, which was designated as the absence of sternal SWL, or 1 which represented it’s presence. The risk associated with each variable is quantified by the parameter estimates (β_i) of the logistic regression equation. Calculating the base of the natural logarithm to the power of the parameter (e^{β_i}) gives the odds ratio associated with that variable. In a multivariate model, the resulting number is the odds ratio adjusted for all the other variables in the model.

Univariate analysis was done to choose a subset of variables to be entered into the multivariate analysis. Analysis was performed, as recommended by Hosmer & Lemeshow (1989) using the PROC FREQ, PROC GPLOT and PROC LOGISTIC procedures of the SAS program (SAS institute, 1996). They suggested that variables with p values equal to or less than 0.25 from a chi-square test, Fisher’s test (2 tailed) or univariate logistic regression analysis be considered significant in the univariate analysis. Variables were recoded where necessary, using information from graphs, univariate tests and knowledge of the biology of the variables, as recommended by Hosmer & Lemeshow (1989). Some were transformed from linear to categorical or binary variables, while some categorical variables were recoded as binary. Coding a variable as linear assumes that there is a constant increase in risk for every unit increase in the risk variables. Coding a variable as categorical or binary assumes that risk is constant within each category of the risk variable. The data was also analysed for potential clustering over time.

Multivariate analysis was performed as recommended by Hosmer & Lemeshow (1989) using the PROC LOGISTIC of the SAS program (SAS institute, 1996). Observations with missing data were dropped. Stepwise regression was performed using small groups of variables significant in the univariate analysis to try to understand how

the factors were related. Stepwise regression and best subsets regression analysis was performed on all variables significant in the univariate analysis (Hosmer & Lemeshow, 1989). Several analytical approaches were used because many of the variables were expected to be highly correlated and different methods of regression can produce different models if multicollinearity is present. Hosmer & Lemeshow (1989) cautioned that biological significance of variables should be understood because stepwise regression techniques can lead “noise variables”, which are not true independent risk factors, to become significant. The chance of this occurring increases as the number of variables tested increases.

2.6 Goodness of fit

The traditional measure of goodness of fit for the logistic model is deviance, a statistic that follows the chi square distribution and is defined as -2 times the difference in the log likelihoods of two models. The Aikake Information Criterion (AIC) is the deviance adjusted for the number of variables in the model. Hosmer & Lemeshow have developed a goodness of fit test for logistic regression that is equivalent to the chi-square test for linear regression (Hosmer & Lemeshow, 1989). All of these measures are available in the output of PROC LOGISTIC procedure of the SAS program (SAS institute, 1996).

Finally, the receiver operator characteristic (ROC) curve can be used to determine the goodness of fit of a model, as well as to compare the accuracy of two models. The ROC curve was originally developed as a method for radio signal operators to distinguish between noise and a true signal. It has been adopted by epidemiologists and is essentially a graph of the false positive fraction versus the true positive fraction. This corresponds to $(1 - \text{specificity})$ versus the sensitivity of the test. An ROC curve can be generated by choosing different cut-off points to differentiate between diseased and non-diseased people as determined by the test of interest. The area under the ROC curve is a measure of how well the test performs. The line between (0,0) and (1,1) has been referred to as the line of no information (Vida, S., 1993) because the area under it is equal to 0.5 and represents a test whose predictive power is no better than chance. For the ideal test, both sensitivity and specificity equals 1, and the area under the ROC curve is equal to 1.

Several methods of determining the area under the ROC curve have been proposed. The simplest method is the “simple trapezoidal rule” which involves calculating the area of sections of the curve between successive vertical lines that intersect the curve. This method is not optimal as it will tend to underestimate the area under the curve and there is also no way to determine the standard error of the area under the curve (Vida, 1993). Several methods of smoothing the curve and calculating its area using parametric techniques are possible but these all assume that the distribution of the underlying data is normal (Vida, 1993). Hanley and McNeil (1982) have derived non-parametric equations which show that the area under the ROC curve is equal to the Wilcoxon statistic, also known as the Mann-Whitney U statistic. Centor & Schwartz (1985) compared the parametric and non-parametric methods and determined that they produced very similar estimates of the area. However, when only a few cut-off points are used to generate a ROC curve, the non-parametric estimate is more conservative. Hanley and McNeil (1983) also developed a method to compare ROC curves generated on the same data, which, like a paired t test, corrects for data correlation.

Although ROC curves are very useful when comparing the accuracy of tests, there are limitations to this method. Aegerter et al. (1994) pointed out that results might be difficult to interpret if the curves cross over each other. Centor & Schwartz (1985) advised that the area under the clinically significant portion rather than the total curve should be compared and that comparisons of differently shaped curves are difficult to interpret. Finally, detecting a significant difference in the area for two tests is “necessary but not sufficient” to prove that one test performs better than the other (Centor & Schwartz, 1985).

2.7 Model Validation

A model should be validated on an independent data set in order to prevent overfitting (Haley et al., 1991). When a model has been overfitted, the estimated parameters and the estimated standard error may be unusually large (Hosmer & Lemeshow, 1989). Several potential models were developed on Subset 1 and then tested on Subset 2. If variables of these models became insignificant, the variables were dropped and a new version of the model was developed on Subset 1. Goodness of fit testing was performed for the final

models on both Subsets 1 and 2 using the measures described in Section 2.5. The AIC and the $-2 \log$ likelihood is part of the output from PROC LOGISTIC. The area under the ROC curve, calculated using the Mann-Whitney statistic, is output as the “C statistic” in PROC LOGISTIC (Miller et al., 1993). These statistics were produced for both data sets 1 and 2. Also, the parameter estimates were fixed based on logistic regression analysis from set 1 and the predictive power of this equation was then tested by comparing predicted and observed values on set 2. A ROC curve was generated and the trapezoidal area was calculated using on a SAS macro program developed by George Tomlinson (Personal Communication, 1998).

In order to generate accurate parameter estimates for the final model, data sets 1 and 2 were merged. Then 500 random samples were generated, with replacement, using a SAS macro program developed by Paul Corey (Personal Communication, 1998). This type of sampling is known as “Bootstrapping” and can be used to reduce bias (Wasson et al., 1983). The average logistic regression parameter estimates from these 500 samples were used in the final risk equation.

2.8 Weights of the Risk Index Variables

Statistically, the ideal risk index would use the logistic regression equation developed during the modelling process. However, clinically, the ideal index should be easy to use and understand, so that a physician can quickly determine the risk of the patient he or she is counselling. Some physicians have complained that the logistic regression equation is too cumbersome to use for a risk index (Tu & Naylor, 1997b). Several methods of translating the equation into a risk score are possible. For their risk index, Tu et al. (1994) converted the parameter estimates to odds ratios and rounded them to the nearest integer. In order to obtain the risk score, the patient’s points for each variable were added together. Harrell (1996) suggested that this was incorrect because the reference category for a categorical variable should be assigned the value of 1 and not 0 as inferred by Tu et al. (1994) because, by definition, factors that have no effect on outcome have an odds ratio of 1. He suggested multiplying the regression parameters by 10, rounding them to the nearest integer and then adding them to obtain the risk score. Tu & Naylor (1997b) countered that Harrell’s method was more complicated and did not add significantly to

the predictive power of the index. Therefore, although less statistically correct, Tu et al.'s (1994) method creates a simple index that intuitively makes sense.

Once the final model was developed, the risk associated with all possible combinations of independent factors was calculated and plotted using Microsoft Excel (Microsoft, 1996). Several ways of scoring, including those discussed above, were explored to see how predicted risk was affected. The predicted risks were divided into 4 groups of increasing risk and potential risk indexes were compared using the area under the ROC curves. Finally, the area under the ROC curve predicted by the new index was compared to the existing SENIC and NNIS-derived indexes.

The new index was used to stratify all patients included in the study into four risk groups for sternal infection. Risk group specific sternal SWI rates were calculated for each surgeon. Then direct standardisation was used to produce average surgeon specific rates of sternal SWI.

3 Results

The chapter details the results of the analysis, culminating in the development of the risk index that is described in Table 3.30, which can be found on page 65. There are three main parts. Sections 3.1 to 3.9 discuss the preliminary results of the study. Next, the index is developed in sections 3.10 to 3.14 of this chapter. The final section, 3.15, illustrates uses of the risk index.

3.1 Characteristics of the Cardiovascular Patients

Most of the cardiovascular surgery patients included in this study were male (72.6%). The age of the patients ranged from 17 to 93, with the mean age of the patients being 60. The majority of patients had serious heart problems as 80% had a New York Heart Association score of 3 or 4, although more than half of the procedures (59%) were elective. In the cohort, 88% of the operations were first time operations, while the remainder were repeat operations. Only 2% of patients had endocarditis but 21% had diabetes. More details on the cohort can be found in Tables 3.13 and 3.14, as well as section 3.6.

3.2 Rate of Sternal Infections

Originally, there were 294 sternal infections registered in the cardiac database and 300 in the infection control database. While 232 infections were registered in both databases, 62 infections were found only in the cardiac database and 71 infections were recorded only in the Infection Control database. I confirmed that 67 cases registered by Infection Control were indeed cases, by reviewing the report abstracts for wound infections. A review of selected charts revealed that many of these sternal infections were discovered because the patient had to be readmitted to the hospital. Four of the sternal SWI cases were not entered correctly into the database: 3 were leg infections and 1 was a pacemaker site infection. The Infection Control nurse reviewed the charts of the 62 potential cases in the cardiac database and concluded that 16 did not meet the definition for sternal infection. The remaining 46 (13.5% of true sternal SWI) were either not detected by Infection Control or were not entered into the computer (see Table 3.1).

Table 3.1: Results of investigation to resolve conflicting cases of sternal infection recorded in the Infection Control database and the Cardiac database.

<i>Database</i>	<i>True Cases</i>	<i>False Cases</i>	<i>Total</i>
Cardiac Only	46	16	62
Infection Control Only	67	4	71
Both Databases	232	-	232
Total	342	20	-

There were 342 sternal infections in the time period studied of which 209 were classified as superficial and 133 as deep. Using the inclusion set as the denominator (11,508 operations), the overall rate of infection is 2.97%. The rate for superficial only is 1.81% and for deep only it is 1.15%. If all operations are used as the denominator (11,750 operations) the rates are as follows: overall (2.91%), superficial (1.78%), deep (1.13%). The rate of sternal infection was examined by month and by year, but no evidence of clustering was seen (See Graph 3.1). A linear regression model of outcome across time (by month) showed that there was a linear trend to the data (p value = 0.0603) and that the rate of infection decreased approximately 0.015% per month or 0.18% per year. Data was grouped by month and logistic regression was then performed to see if the month influenced the rate of sternal infection but, the resulting model was not significant (p value=0.2922). For additional graphs illustrating the rate of infection over time, please see Appendix H.

Graph 3.1: The mean rate of sternal infection by year and month. (Rate is calculated using data from the inclusion set only.)

3.3 Organisms

In total, 382 organisms were isolated from 275 sternal wounds. For 67 wounds, either no cultures were obtained or no pathogens were isolated. A single organism infected 204 wounds, while multiple organisms were isolated from 71 (Table 3.2, 3.3). The majority of organisms were gram positive (289), mostly cocci, with the most common species being *Staphylococcus* (in 249 wounds). Gram negative bacteria, mainly from the *Enterobacteriaceae* family, were isolated 78 times. There were 3 cases of wounds infected by fungi, namely *Candida albicans* and *Candida tropicalis* while the organisms from the remaining 12 cases were classified as 'other'. The specific species isolated are listed in Table 3.4.

Table 3.2: The number of organism isolated per sternal wound, by wound type.

<i>Number of Organisms</i>	<i>All</i>	<i>Superficial SWI</i>	<i>Percent</i>	<i>Deep SWI</i>	<i>Percent</i>
1	204	126	60.3	80	60.2
2	44	26	12.4	18	13.5
3	21	11	5.3	10	7.5
4	4	2	1	2	1.5
5	1	0	0	1	0.8
6	1	0	0	1	0.8
No Cultures	67	44	21.0	21	15.7
Total	342	209	100	133	100

Table 3.3: Organisms isolated from sternal wounds by number of organisms in wound

<i>Organism</i>	<i>Single Organism in Wound</i>	<i>Multiple Organisms in Wound^A</i>	<i>Total</i>
Coagulase negative			
Staphylococcus	12	6	18
Staphylococcus aureus	57	24	81
Gram negative	16	62	78
Others	119	86	205
Total	204	178	382

^AThere are 382 organisms in 275 wounds. This column is the number of organisms, not the number of wounds with multiple organisms.

Table 3.4: The organisms isolated from all sternal wounds.

Group	Culture	TOTAL	PERCENT^A
Gram Positive	<i>Staphylococcus epidermidis</i>	150	54.5
	<i>Staphylococcus aureus</i>	81	29.5
	<i>Enterococcus</i>	25	9.1
	<i>Coagulase negative Staphylococcus</i>	18	6.5
	<i>Propionibacterium</i>	5	1.8
	<i>Diphtheroid species</i>	4	1.5
	<i>Beta Streptococcus</i>	3	1.1
	<i>Peptococcus</i>	1	0.4
	<i>Clostridium</i>	1	0.4
	<i>Alpha streptococcus</i>	1	0.4
	SUBTOTAL	289	
Gram Negative	<i>Enterobacter cloacae</i>	14	5.1
	<i>Escherichia coli</i>	12	4.4
	<i>Pseudomonas aeruginosa</i>	11	4
	<i>Proteus mirabilis</i>	9	3.3
	<i>Klebsiella pneumoniae</i>	8	2.9
	<i>Enterobacter aerogenes</i>	8	2.9
	<i>Serratia marcescens</i>	5	1.8
	<i>Klebsiella (other species)</i>	4	1.5
	<i>Morganella morganii</i>	2	0.7
	<i>Serratia liquefaciens</i>	1	0.4
	<i>Proteus vulgaris</i>	1	0.4
	<i>Haemophilus parainfluenzae</i>	1	0.4
	<i>Haemophilus influenzae</i>	1	0.4
	<i>Citrobacter freundii</i>	1	0.4
	SUBTOTAL	78	
Fungi	<i>Candida albicans</i>	2	0.7
	<i>Candida tropicalis</i>	1	0.4
	SUBTOTAL	3	
Other		12	4.4
Total		382	

^APercent is the number isolated divided by 275 (the number of wounds from which cultures were obtained).

3.4 Mortality

In the inclusion set the overall mortality rate was 1.8%. Among those who had a sternal SWI, 18 (5.3%) did not live 30 days after surgery whereas the rate for the rest of the patients was only 1.7% (185 died). A Chi-Square test showed that mortality was significantly higher in the group with sternal SWI (p value = 0.0001). For the entire

cohort, including those excluded from the study, the mortality rate was 3.8%. The mortality rate for those with sternal infections was still 5.3%, while the rate for the rest of the cohort rises to 3.74% (427 patients). The difference in rate is not statistically significant (p value of chi-square test is 0.147).

3.5 Leg Infections

According to the Infection Control database, there were 216 leg SWI, including 30 deep infections and of these, 55 also had sternal SWI. Using the inclusion set as the denominator, the rate of leg infection is 1.9% and the rate of sternal and leg co-infection is 0.5%.

3.6 Length of Post-operative Stay

Those with sternal infections spent a significantly longer time in hospital after operation than those without (T test p value < 0.0001). For those with no sternal infection, the mean post-operative stay in hospital was 10.55 days (Range: 0 to 185; Standard deviation 8.43; Median: 8). For those with sternal infection, the mean post-operative stay in hospital was 22.05 days (Range: 6 to 185; Standard deviation: 19.13; Median: 16). A post-operative stay of 0 days indicates the patient died during surgery.

3.7 Exclusion Set

All patients who died less than 6 days after surgery without signs of infection were excluded from the analysis. Table 3.5 compares selected linear variables in the inclusion set to the exclusion set. NYHA score and timing of operation were treated as linear in order to perform a t test. Essentially, operations in the exclusion set were less likely to have been elective and more likely to involve longer operating and CPB time. The exclusion group was slightly older than the inclusion. Post-operative ICU stay was shorter for the excluded patients, because they lived a maximum of only 5 days after operation. (The median survival time was 1 day while the mean was 1.68.) Table 3.6 shows that the proportion of females and “other” procedures is greater in the exclusion than the inclusion set. However, the proportion of diabetics is similar in both sets. Patients excluded from the study were expected to be different from those included,

because risk factors for early death after cardiac surgery have been identified by various studies.

Table 3.5: Comparing selected linear variables in the inclusion and exclusion sets: mean, median and t tests

<i>Variable</i>	<i>Mean Inclusion Set</i>	<i>Mean Exclusion Set</i>	<i>P Value of T Test</i>	<i>Median Inclusion Set</i>	<i>Median Exclusion Set</i>
Timing of operation	1.64	2.33	<0.0001	1	2
NYHA score	3.16	3.65	<0.0001	3	4
Operating time (minutes)	178	256	<0.0001	173	244
Time on CPB (min.)	92	149	<0.0001	88	136.5
Preoperative stay in days	3.4	5.9	<0.0001	1	1
Post-operative days in ICU	2.5	1.7	<0.0001	2	1
Age (yrs)	60.0	62.9	0.0003	62	66

Table 3.6: Frequencies of selected variables in the inclusion and exclusion sets

<i>Variable</i>	<i>Frequency in Inclusion Set (%)</i>	<i>Frequency in Exclusion Set (%)</i>	<i>P Value of Chi-square test</i>
Sex	Male: 8350 (72.6%) Female: 3158 (27.4%)	Male: 154 (63.3%) Female: 88 (36.4%)	0.0020
Diabetes	No: 9244 (80.3%) Diabetic: 2243 (19.5%) Missing: 21 (0.2%)	No: 188 (77.7%) Diabetic: 51 (21.1%) Missing: 3 (1.2%)	0.0010 (Including observations with missing information) 0.4840 (Excluding observations with missing information)
Procedure	Coronary artery bypass (CAB): 7629 (66.3%) Valve: 2336 (20.3%) Other: 1543 (13.4%)	CAB: 110 (45.5%) Valve: 56 (23.1%) Other: 76 (31.4%)	0.0010

3.8 Chart Review: Reliability of Data

Information was abstracted from 140 out of the 150 randomly selected charts (93.3%). The remaining charts were not obtained due to logistical reasons. For example, several charts could not be located while others were in deep storage at an off site location. With only 140 charts, power was reduced so that only up to a 35% disagreement within 0.08 absolute percentage points with 95% confidence and a power of 0.80. Tables 3.7 and 3.8 compare the frequencies of the variables in the subset of chart that were reviewed to all other charts from the cohort. Overall, the agreement between abstracted data and data coded in the computer was high. The variables abstracted during this chart review along with percent agreement are listed in alphabetical order in table 3.9. When agreement is less than 100%, the Kappa coefficient is given for binary variables and the intra-class correlation coefficient is given for continuous variables. Several multi-level categorical variables have been treated as continuous variables. In most cases of disagreement, the charts were re-examined to ensure that information had been abstracted correctly.

Table 3.7: Comparison of the data from the charts that were reviewed to the data from the remaining cohort: binary variables.

Variable	Frequency in reviewed charts	Frequency in remaining cohort	P Value of Chi-Square test or Fisher's Test
Previous ACB	7.0%	5.9%	0.5900
Previous aortic valve surgery	3.5%	2.9%	0.7690
Diabetes	19%	19.7%	0.3540
Leg infection	3.5%	1.7%	0.1180
Sternal infection	3.5%	2.9%	0.6760
Previous mitral valve surgery	2.1%	3.4%	0.6510
Previous other cardiac surgery	2.8%	2.2%	0.5580
Procedures	ACB: 65.5% Valve: 19.0% Other: 15.5%	ACB: 66.3% Valve: 20.3% Other: 13.3%	0.7420
Reoperation for any reason	7.0%	4.2%	0.136
Survived 30 days	98.6%	98.2%	0.7460
Timing of surgery	Elective: 50.7% Other: 49.3%	Elective: 58.8% Other: 41.2%	0.3120
Sex	Male: 77.5% Female: 22.5%	Male: 72.5% Female: 26.5%	0.1870
Previous tricuspid valve surgery	0%	0.3%	0.5550

Table 3.8: Comparison of selected data from the charts reviewed to the remaining cohort: linear variables.

Variable	Mean in subset	Mean in remaining	P value of T test
Age	60.9	60.0	0.3722
Time of Cardiopulmonary bypass	99.6	92.3	0.0166
Operating Time	185.1	178.2	0.1398

Table 3.9: Summary of results from the chart review

<i>VARIABLE</i>	<i>Number of Charts that Agree</i>	<i>% Agreement</i>	<i>Intra Class Correlation Coefficient</i>	<i>Kappa</i>
ACBREDO (Previous ACB)	140	100		
AGE	80	57.1	0.99	
AVREDO (Previous aortic valve surgery)	140	100		
DIABETES	136	97.1		0.91
HT (Height)			0.42	
INFLEG (Leg SWI)	122	87.1		0.33 ^A
INFSTERN (Sternal SWI)	140	100		
MVREDO (Previous mitral valve surgery)	140	100		
OTHREDO	138	98.6		0.8
PACKCELL (Number of blood units transfused)	66	64.7	0.53	
PROC (Surgery Category)	139	99.3		
PUMP (Time on CPB)	136	97.1	0.90	
REOP (Reoperation for complications)	137	97.9	0.93	0.89 ^A
SURVIVAL (30 days)	140	100		
TIMING (Timing of surgery)	117	83.5	0.71	
SEX	138	98.6		0.89
TVREDO (Previous tricuspid surgery)	140	100		
WT (Weight)			0.75	

^ACalculated assuming variable was binary (YES / NO)

Overall, there were only minor discrepancies in the data. For the interested reader, more detail on these discrepancies is found in Appendix I. Neither weight nor height could be used in this study, because of the amount of data missing. Unfortunately, PACKCELL, the variable for the number of units transfused was neither reliable nor very complete and therefore could not be used in this study. Based on this chart review, the definition of age as entered in the cardiac database should be age at end of year of surgery rather than age on date of surgery. This definition change would make the percent agreement almost 100% and does not affect the use of age as a potential risk factor in this study. Original database values were used for all of these variables in the analysis.

Extreme values that were found to be incorrect were changed and some missing values were abstracted from the charts and added to the database. The details of these missing and extreme values are found in Appendix G.

3.9 Chart Review: Antibiotic Use

The results of the chart review are summarised in tables 3.10 to 3.12. Cefazolin, one of the antibiotics listed in Table 3.10, is a first generation cephalosporin and is active against gram-positive cocci and selected gram-negative bacteria, such as *Escherichia coli*, *Klebsiella pneumoniae*, and *Proteus mirabilis* (Katsung, 1995). Ancef is the brand of cefazolin used by the Toronto Hospital. Vancomycin, also listed in Table 3.10, is active against gram-positive organisms, especially *Staphylococci* (Katsung, 1995). Gentamicin, an aminoglycoside complex, is active against gram-positive and gram-negative organisms while rifampin is effective against some cocci, some enteric bacteria, and mycobacteria (Katsung, 1995). Ampicillin is used to treat infections of the urinary tract or respiratory tract (Katsung, 1995). A study of the efficacy of teicoplanin took place in 1993 during which teicoplanin was used as a substitute for vancomycin, whenever a patient was allergic to penicillin (Katsung, 1995). Table 3.10 shows that the majority of patients were given cefazolin, vancomycin and teicoplanin. In the chart review, 13 out of 130 or 10% of patients were given vancomycin and teicoplanin, and this may mean that the rate of penicillin allergy was 10%.

The patient receiving ampicillin, gentamicin and rifampin had been prescribed these drugs for endocarditis. Cefazolin had been ordered before the operation, but I could not confirm whether or not it had been given. Likewise, the patients receiving ampicillin or ampicillin and gentamicin were also being treated for endocarditis. These 3 patients were the only ones to receive antibiotics more than 2 hours before their operation. From April 1990 to December 1995, 2.2% of patients operated on had endocarditis. Therefore, 2.2% of patients may have received these antibiotics instead of cephalozin before their operation. For the 15 cases classified as perioperative or postoperative in table 3.11, I could not find a note in the chart that antibiotics had been given preoperatively. Usually, I classified the timing of administration as preoperative if the chart noted that antibiotics were given “on call to the OR”. For this study, I assumed that preoperative antibiotic

administration did not vary enough to affect risk of sternal infection.

Table 3.10: Antibiotics used at the Toronto Hospital before cardiovascular surgery

<i>Type of Antibiotic</i>	<i>Frequency</i>	<i>Percent</i>	<i>Cumulative Frequency</i>	<i>Cumulative Percent</i>
Cefazolin	117	84.2	117	84.2
Vancomycin	13	9.4	130	93.6
Ampicillin	1	0.7	131	94.3
Ampicillin/ Gentamicin	1	0.7	132	95
Teicoplanin Study	6	4.3	138	99.3
Ampicillin/ Gentamicin/ Rifampin	1	0.7	139	100

*Frequency Missing = 1

Table 3.11: Timing of antibiotic administration at The Toronto Hospital before cardiovascular surgery

<i>Timing of Antibiotic Administration</i>	<i>Frequency</i>	<i>Percent</i>	<i>Cumulative Frequency</i>	<i>Cumulative Percent</i>
Early	3	2.2	3	2.2
Preoperative	116	84.7	119	86.9
Peri-operative	4	2.9	123	89.8
Postoperative	14	10.2	137	100

*Frequency Missing = 3

Table 3.12: Type of antibiotic used by timing of antibiotic administration.

	<i>Cefazolin</i>	<i>Vancomycin</i>	<i>Teicoplanin Study</i>	<i>Other</i>
Early (2-24 hours before incision)	-	-	-	3
Preoperative (>2 hours before incision)	102	10	4	-
Perioperative (0-3 hours after incision)	3	1	-	-
Postoperative (<3 hours after incision)	12	2	-	-
Missing	-	-	2	-

*Frequency Missing = 1

3.10 Random Subsets

The inclusion data set was divided randomly into 3 subsets of 3836 observations each using a SAS program. Tables 3.13 and 3.14 show selected variables from all three sets in order to demonstrate that the patients were indeed randomly assigned to the subsets. T tests were performed on selected variables and the only significant difference was in the number of preoperative days in sets 1 and 2. While the median was the same for both data subsets, the means may have differed because the values of the outliers set 1 were more extreme than the values of outliers in set 2.

Table 3.13: Comparing the values of selected linear variables from the 3 subsets of data.

<i>VARIABLE</i>	<i>SET</i>	<i>MEDIAN</i>	<i>MEAN</i>	<i>P VALUE OF T TEST</i>
AGE	1	62	60	0.468
	2	62	60	
	1			0.922
	3	62	60	
	2			0.532
	3			
Post-operative days in ICU	1	2	2.5	0.723
	2	2	2.6	
	1			0.548
	3	2	2.6	
	2			0.810
	3			
Preoperative days in hospital	1	1	3.2	0.035
	2	1	3.5	
	1			0.185
	3	1	3.4	
	2			0.495
	3			
Post-operative days in hospital	1	8	10.8	0.122
	2	8	11.1	
	1			0.707
	3	8	10.8	
	2			0.232
	3			
Length of operation (minutes)	1	171.5	178	0.536
	2	172	177	
	1			0.528
	3	175	179	
	2			0.208
	3			
Minutes on CPB	1	87	92	0.747
	2	87	92	
	1			0.429
	3	88	93	
	2			0.241
	3			
Number of cigarette packs smoked	1	0	5.2	0.385
	2	0	5.7	
	1			0.322
	3	0	5.7	
	2			0.921
	3			

Table 3.14: The frequency of selected categorical variables in the randomly divided data subsets 1, 2 and 3.

<i>VARIABLE</i>	<i>SET 1</i>	<i>SET 2</i>	<i>SET 3</i>
Sternal Infection			
None	3716	3716	3734
Superficial	79	67	63
Deep	41	53	39
Diabetes			
Non-diabetic	3054	3117	3073
Diabetic	778	710	755
Data missing	4	9	8
Reoperation due to complication			
None	3680	3671	3668
Yes	156	165	168
Number of diseased arterial systems			
0	861	916	917
1	230	227	241
2	654	651	627
3	2091	2042	2051
NYHA Score			
1	165	172	179
2	612	589	634
3	1481	1507	1449
4	1577	1568	1573
Data Missing	1	—	1

3.11 Univariate Analysis

Subset 1 was used to do the univariate analysis, which is summarised in Tables 3.16 and 3.16. All variables with a p value less than or equal to 0.25 were considered significant. The variables PACKS (number of packs smoked), SEIZURES and TIA (transient ischaemic attack) had too many missing observations and could not be included in the multivariate analysis.

Table 3.15: A summary of the univariate analysis: significant variables

Variable	Frequency	P Value	Odds Ratio
ACBNUM (Total number of distal grafts)	0: 23% 1: 4% 2: 9% 3: 25% 4: 32% 5: 7% 6: ~0% (0.4%)	0.0140	Reference Category: 1 2) 0.98 3) 2.46 4) 2.07 5) 2.90 6) 2.41
Age	Mean: 60 Minimum: 17 Maximum: 93	0.0313	1.02 (Unit change = 1 year)
Chronic obstructive pulmonary disease (COPD)	None: 83% Yes: 17%	0.0510	Odds of Yes to No= 1.56
Deep venous thrombosis (OCDVT)^A	None: 99.8% Yes: 0.2%	0.2260	Odds of yes to no= 4.43
Diabetes	None: 79% Yes: 21%	0.0010	Odds of Yes to No= 2.72
DISNUM: Total number of diseased arterial systems	0: 22% 1: 6% 2: 17% 3: 55%	0.0010	Reference category = 0 1) 0.86 2) 2.59 3) 2.56
Duration of CPB pump	Mean: 92 Minimum: 0 Maximum: 355	0.0221	1.005 (Unit= 1 minute) 1.37 (Unit = 1 hour)
ICU stay (ICU)	Mean: 2.5 Minimum: 0 Maximum: 83	0.0001	1.05 (Unit = 1 day)
Intra-aortic balloon pumping	No: 96% Yes: 4%	0.0300	Odds of yes to no: 4.31
Internal Mammary Artery Use	0: 38% 1: 61% 2: 1%	0.0430	Reference category = 0 1) 1.91 2) 5.08
Low output syndrome (LOS)	None: 92% Yes: 8%	0.0020	Odds of yes to no: 2.31
Myocardial infarction (perioperative) (MI)	None: 87% Yes: 13%	0.1340	Odds of yes to no: 2.19
Myocardial infarction (Preoperative) (PREOPMI)	No: 98% Yes: 2%	0.1090	Odds of yes to no: 1.51
Neurological deficit (Post-op) (STROKE)	No: 98% Yes: 2%	0.0260	Odds of yes to no: 3.05
New York Heart Assoc. Score (NYHA)	1: 4% 2: 16% 3: 39% 4: 41%	0.0170	Reference category= 1 2) 1.35 3) 3.20 4) 2.78
OR time	Mean: 178 Minimum: 44 Maximum: 950	0.0151	1.003 (Unit time= 1 minute) 1.21 (Unit time= 1 hr)
Peripheral vascular disease(PVD)	No: 88% Yes: 12%	0.0490	Odds of yes to no: 1.66

Variable	Frequency	P Value	Odds Ratio
Preoperative Stay (DAYSPRE)	Mean: 3.2 Minimum: 0 Maximum: 93	0.1589	0.97 (Unit = 1 day)
Procedure (PROC)	CBP: 68% Valve: 20% Other: 12%	0.0090	Reference category: valve procedures (PROC=2) CAB (PROC=1): 1.82 Other (PROC=3): 2.35
Pulmonary Complications (OCPULMC)	None: 89% Yes: 11%	0.0010	Odds of Yes to No = 2.27
Renal failure (Pre-operative) (RF)	None: 95% Yes: 5%	0.0200	Odds of yes to no: 2.23
Renal failure (perioperative) (POSTRF)	No: 99% Yes: 1%	0.00004	Odds of yes to no: 7.74
Reoperation (REOP)	No: 97% Yes: 3%	$7.4 * 10^{-10}$	Odds of yes to no: 7.37
Seizures	No: 99% Yes: 1%	0.0370	Odds of yes to no: 3.49
Shock	No: 98% Yes: 2%	0.0980	Odds of yes to no: 2.16
Smoking status (SMOKE)	No: 31% Current Smoker: 11% Previous Smoker: 58%	0.0710	Reference category= Non-smoker Current smoker: 1.90 Previous smoker: 1.51
Smoking: Number of packs smoked per day multiplied by number of years smoked (PACKS)	Mean: 5.9 Minimum: 0 Maximum: 188	0.0371	1.009 (Unit= 1 pack) 2.53 (100 Packs)
Surgeon (SURG)	A: 16% B: 14% C: 12% D: 12% E: 10% F: 7% G: 15% H: 6% I: 2% J: ~0% K: 6% L: ~0%	0.0010 ^A	Reference surgeon= A B = 5.52 C = 3.17 D = 2.39 E = 7.74 F = 0.86 G = 1.77 H = 3.81 I = 5.92 K = 1.88 Other = Undefined (no infections)
Time on Ventilator	Mean: 1.2 Minimum: 0 Maximum: 293	0.0719	1.01 (Unit=1 day)
Transient Ischaemic attack (TIA)^A	No: 99.7% Yes: 0.3%	0.1590	Odds of yes to no= 7.24
Ventricular Dysrhythmias (OCVENDYS)	No: 88% Yes: 12%	0.1320	Odds of yes to no= 1.48

AThe p value is the result of the entering the surgeons as a block variable. For multivariate analysis, surgeons were forced into the model as a block variable, regardless of the odds ratios listed in column 3.

Table 3.16: A summary of the univariate analysis: non-significant variables

Variable	Frequency	P Value	Odds Ratio
Congestive Heart Failure (CHF)	No: 78% Yes: 22%	0.6100	Odds of Yes to No = 1.12
Endocarditis (ENDOCARD)^A	No: 98% Yes: 2%	0.5180	Odds of yes to no= 0.40
Previous cardiac surgery	No: 88% Yes: 12%	0.3410	0.75
Previous stroke or TIA (THROMB)	No: 90% Yes: 10%	0.3880	0.75
Sex	Male: 74% Female: 26%	0.7730	1.06
TIMING^B	1: 59% ^C 2: 23% 3: 14% 4: 4%	0.4160	Odds of all more urgent surgeries to elective surgery: 0.87

^A These variables all had a zero count cell for exposure=1 and outcome=1. A count of one was added to this cell in order to generate statistics for these variables.

^B It is known that frequency of the timing of the operation varies by surgeon. However, in a logistic regression analysis including TIMING and SURG, timing still was not significant. Also, neither the significance nor the magnitude of the odds ratio for each category in SURG changed when TIMING was included in the model.

^CCategories for TIMING: 1) Elective 2) Same Hospitalization 3) Urgent <72 hours from event 4) Emergent <12 hours from event. For increased power, categories 2 to 4 were grouped together because they all represent more urgent types of surgery.

For the interested reader, a description of the recoding of variables is included in Appendix J. Briefly, several variables were recoded from linear into categorical or binary and from categorical into binary before the multivariate analysis was done. Graphs of the log mean rate of sternal infection versus variable categories suggested that some variables should be binary rather than linear. For example, the number of distal graphs (DISNUM), New York Heart Association score (NYHA), and post-operative days in ICU were recoded as binary variables. On the other hand, some variables, including number of distal grafts (ACBNUM), age, number of preoperative days, smoking status, operating time, and time on CPB were kept as linear variables because both the graphs and the logistic regression results indicated that linearity was a valid assumption. The

use of internal mammary arteries was coded as two separate variables: IMAC (coded as positive when either 1 or 2 arteries were used) and IMA2 (coded as positive when specifically 2 arteries were used). IMAC was used to determine if there is any risk associated with using any number of internal mammary arteries compared to not using them. IMA2 was used to look at the risk specifically associated with using 2 IMAs.

3.12 Multivariate Analysis

The significant variables from the univariate analysis were entered into a stepwise logistic regression model. Tables 3.17 to 3.20 show the variables that were significant at several different α levels, with and without the operating surgeon variables. When all of the individual surgeons were forced into the model as a block, they were significant, however, I chose not to use operating surgeon as a variable in the index. I did not see any evidence of confounding with other variables: the surgeon variables only appeared to explain an additional portion of the variability in sternal SWI status. (For the $\alpha=0.25$ model, the largest difference in the odds ratio for the model with operating surgeon and the model without was 0.17. The largest change in p value was 0.0508 for number of preoperative days, but at no point was this variable significant at the 0.05 level.) Please see section 4.1 that discusses the reasons for excluding surgeon variables from the index. The $\alpha=0.25$ level models, without surgeon variables, were entered on subset 2 and only internal mammary artery (IMA) combined, reoperation, diabetes and 4 or more days in ICU remained significant. Use of 2 IMAs was one of the variables that did not remain significant and I concluded that using 2 IMAs was not significantly riskier than using only one. Based on the various models, I noted that use of internal mammary artery was correlated to the number of distal grafts, although the first variable was much more powerful than the second. Other correlated pairs, listed with the most powerful variable first, included smoking and chronic obstructive pulmonary disease (COPD), days in ICU and pulmonary complications, days in ICU and post-operative renal failure. In order to test whether renal failure at any time during the hospital stay was a risk factor, I created RENAL, a variable that included both preoperative and postoperative renal failure. It was significant on Subset 1 at the $\alpha=0.1$ level, but not on Subset 2 and therefore renal failure was not included in the risk model (Tables 3.21 and 3.22). Several interactions,

including IMA use with reoperation and more than 3 days in ICU with reoperation, were significant on Subset 1. However, these were not significant on Subset 2 and thus I did not include any interactions in the risk model.

Table 3.17: Significant variables ($\alpha=0.05$) determined by stepwise logistic regression using subset 1.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>
Surgeon 1 ^A	0.0189	3.06
Surgeon 2	0.3079	1.71
Surgeon 3	0.6664	1.27
Surgeon 4	0.0010	3.28
Surgeon 5	0.1449	4.84
Surgeon 6	0.7108	2.21
Surgeon 7	0.1831	1.22
Surgeon 8	0.0241	5.41
Surgeon 9	0.7709	1.21
Diabetes	0.0004	2.08
Use of internal mammary artery	0.0001	2.84
More than 3 days in ICU	0.0001	5.69
Reoperation	0.0001	3.78

^A Although the p values for the individual surgeons are sometimes less than 0.05, the surgeons were significant when considered as a block variable

Table 3.18: Significant variables ($\alpha=0.05$) determined by stepwise logistic regression using subset 1 with surgeon variables removed.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>	<i>Lower</i>	<i>Upper</i>
Diabetes	0.0002	2.16	1.44	3.23
Use of internal mammary artery	0.0001	3.32	2.04	5.6
More than 3 days in ICU	0.0001	4.71	2.79	7.76
Postoperative renal failure	0.036	2.87	1.01	7.37
Reoperation	0.0001	3.84	1.99	7.04

Table 3.19: Significant variables ($\alpha=0.25$) determined by stepwise logistic regression using subset 1.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>
Surgeon 1^A	0.0416	2.67
Surgeon 2	0.3589	1.62
Surgeon 3	0.6361	1.29
Surgeon 4	0.0022	4.37
Surgeon 5	0.1384	2.24
Surgeon 6	0.8147	1.13
Surgeon 7	0.2211	2.00
Surgeon 8	0.0058	7.14
Surgeon 9	0.9640	1.03
Diabetes	0.0001	2.26
NYHA score > 2	0.1908	1.53
Smoking status	0.0386	1.41
Number of preoperative days	0.1065	0.96
Use of 1 or 2 IMAs	0.0010	2.46
Use of 2 IMAs	0.0097	4.47
> 3 days in ICU	0.0001	4.16
Pulmonary Complications	0.1663	1.47
Postoperative renal failure	0.0493	2.71
Reoperation	0.0001	4.25

^AAlthough the p values for the individual surgeons are sometimes less than 0.05, the surgeons were significant when considered as a block variable

Table 3.20: Significant variables ($\alpha=0.25$) determined by stepwise logistic regression using subset 1 with surgeon variables removed.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>	<i>Lower Limit</i>	<i>Upper Limit</i>
Diabetes	0.0001	2.30	1.53	3.43
NYHA score > 2	0.0960	1.70	0.95	3.33
Smoking status	0.0532	1.37	1.00	1.89
Preoperative renal failure	0.2323	1.51	0.74	2.85
Number of preoperative days	0.0557	0.95	0.90	1.00
Use of 1 or 2 IMAs	0.0001	2.59	1.61	4.31
Use of 2 IMAs	0.0060	4.62	1.33	12.44
> 3 days in ICU	0.0001	4.00	2.28	6.85
Pulmonary Complications	0.1946	1.42	0.82	2.38
Postoperative renal failure	0.0262	2.93	1.08	7.34
Reoperation	0.0001	4.24	2.26	7.63

Table 3.21: The significant variables ($\alpha=0.1$) of a stepwise logistic regression model derived on Subset 1 that includes the RENAL variable (pre-operative and post-operative renal failure combined).

<i>VARIABLE</i>	<i>ODDS RATIO</i>	<i>P VALUE</i>
Use of internal mammary artery	3.01	0.0001
Reoperation	4.41	0.0001
Diabetes	2.27	0.0001
4 or more days in ICU	4.48	0.0001
RENAL	1.71	0.0732

Table 3.22: The same logistic regression model as in Table 3.19, derived on Subset 2.

<i>VARIABLE</i>	<i>ODDS RATIO</i>	<i>P VALUE</i>
Use of internal mammary artery	1.67	0.0153
Reoperation	2.79	0.0022
Diabetes	2.64	0.0001
4 or more days in ICU	2.60	0.0003
RENAL	0.99	0.9808

Using the significant variables and their covariates, I developed six models and then tested their goodness of fit on data set 2 (Table 3.23). The Chi-square statistic, shown in Table 3.23, was calculated by comparing predicted and observed outcome values in 5 or more strata of the data. The areas under the ROC curve, shown in Table 3.26, were

calculated using the trapezoidal method. In the end, because the goodness of fit statistics of the models, including the AIC, the area under the ROC curve and the Chi-square statistic, were similar, the simplest model (#1) was chosen. Table 3.26 shows the parameter estimates for this model, which were determined using 500 bootstrap samples derived from subsets 1 and 2 combined. The number 500 was chosen arbitrarily.

Table 3.23: Candidate models with measures of goodness of fit on subsets 1 and 2.

<i>MODEL</i>	<i>AIC: Data Set 1^A</i>	<i>AIC: Data Set 2^B</i>	<i>χ^2^C</i>
1) IMA ^D REOP ^E DIABETES ICU ^F	953.7	1014.6	2.84 (p=0.829)
2) IMAC REOP2 DIABETES FACTOR2 ^H	961.3	1019.3	3.07 (p=0.800)
3) FACTOR1 ^G REOP DIABETES ICU	962.8	1012.4	1.77 (p=0.940)
4) FACTOR1 REOP2 DIABETES FACTOR2	968.8	1017.2	2.10 (p=0.835)
5) IMA REOP DIABETES FACTOR3 ^I	954.8	1015.1	2.76 (p=0.838)
6) FACTOR1 REOP DIABETES FACTOR3	963.7	1012.8	1.76 (p=0.940)

^A Aikake Information Criterion for model run on data subset 1

^B Aikake Information Criterion for model run on data subset 2 (without fixing parameters)

^C Chi-square goodness of fit for data subset 2

^D IMA = Use of internal mammary artery

^E REOP= Reoperation

^F ICU= 4 or more days in ICU

^G Factor1: Patient has 2 or more distal grafts and / or internal mammary artery was used as a graft

^H Factor2: Patient has postoperative or preoperative renal failure and / or has spent 4 or more days in ICU

^I Factor3: Patient has postoperative renal failure and / or has spent 4 or more days in ICU

Table 3.24: Areas under ROC curve for candidate models on subsets 1 and 2.

<i>Model</i>	<i>Area (1)</i>	<i>Rank (1)</i>	<i>Area (2)</i>	<i>Rank(2)</i>
1) IMAC REOP2 DIABETES ICUM	0.7404	3	0.6556	5
2) IMAC REOP2 DIABETES FACTOR2	0.7454	2	0.6501	6
3) FACTOR1 REOP2 DIABETES ICUM	0.7222	6	0.6740	2
4) FACTOR1 REOP2 DIABETES FACTOR2	0.7296	4	0.6662	3
5) FACTOR1 REOP2 DIABETES FACTOR3	0.7278	5	0.6744	1
6) IMAC REOP2 DIABETES FACTOR3	0.7455	1	0.6555	4

Table 3.25: Summary statistics for the areas under the ROC curve for candidate models on data subsets 1 and 2

<i>Statistic</i>	<i>Subset 1</i>	<i>Subset 2</i>
Range	0.0233	0.0243
Mean Area	0.7352	0.6626
Median Area	0.7350	0.6609

Table 3.26: Parameter and Odds Ratio estimates for the final risk model.

<i>VARIABLE</i>	<i>Parameter Estimate</i>	<i>Odds Ratio</i>
Intercept	-4.889	1.00
Use of internal mammary artery	1.117	3.23
Reoperation	1.469	4.34
Diabetes	0.877	2.40
4 or more days in the ICU	1.677	5.35

3.13 The Risk Index

This section describes the evolution of the logistic regression equation into the actual risk index. The logistic regression equation was modified in order to make calculation of patient risk less cumbersome. The chosen logistic regression equation, described in table 3.26, contained 4 binary variables. This equation essentially quantifies the risk associated with 16 possible patient types. These types are listed in Table 3.27 in order of increasing risk of sternal infection while the risk associated with each patient type is plotted in Graph 3.2.

Table 3.27: All possible combinations of risk factors using the final logistic regression equation. They are arranged according to increasing risk.

<i>PATIENT TYPE</i>	<i>RISK FACTORS</i>
1	No factors
2	Diabetes
3	Use of IMA
4	Reoperation
5	> 3 days in ICU
6	Diabetes, Use of IMA
7	Diabetes, Reoperation
8	Diabetes, >3 days in ICU
9	Use of IMA, Reoperation
10	Use of IMA, > 3 days in ICU
11	Use of IMA, Reoperation
12	Diabetes, Use of IMA, Reoperation
13	Diabetes, Use of IMA, > 3 days in ICU
14	Diabetes, Reoperation, > 3 days in ICU
15	Use of IMA, Reoperation, > 3 days in ICU
16	All factors

Several methods of grouping the 16 patient types into 4 categories were used, including visually assessing Graph 3.2. To produce the index, several ways of scoring risk using the logistic equation were determined and some examples of these are given in Table 3.27. The areas under the ROC curve for these potential indexes were calculated using the Mann-Whitney statistic on subset 3 and were compared using the method developed by Hanley and McNeil (1983). As table 3.29 shows, Grouping 1 had a significantly lower area under the ROC curve than all other groupings (1 tailed p value 0.34 to 0.064; 2 tailed p value 0.07 to 0.129) and was therefore excluded from the potential choices. Grouping 2 was then chosen to be the risk index because, of the remaining indexes, it was the simplest to use. The area under the ROC curve for Grouping 2 was not significantly different from that for the logistic regression equation with 16 possible risk categories (called Grouping 3 in table 3.28). Therefore, changing the logistic regression equation to the form of Grouping 2 did not cause a loss of predictive power. A sample form, which could be used for the new risk index, is found in Table 3.30.

Table 3.28: Selected potential indexes derived from the logistic regression equation.

<i>Number</i>	<i>Index</i>	<i>Classification of Patient Types^A</i>	<i>Scores^B</i>
1	Odds ratios rounded to nearest integer, with intercept dropped	1: 1 to 6 2: 7 to 10 3: 11 to 14 4: 14 +	1: 0 to 5 2: 6 to 8 3: 9 to 11 4: 12
2	Similar to model 1 but diabetes is given a score of 2.5 rather than 2.0.	1: 1 to 5 2: 6 to 11 3: 12 to 14 4: 15 +	1: 0 to 5 2: 5.5 to 9 3: 9.5 to 11.5 4: 12 +
3	Probability predicted by original logistic regression equation	1: 1 to 5 2: 6 to 9 3: 10 to 13 4: 14 +	1: Below 0.05 2: 0.05 to 0.09 3: 0.1 to 0.24 4: 0.25 +
4	Odds ratios (Not Rounded)	1: 1 to 4 2: 5 to 10 3: 11 to 13 4: 14 to 16	1: Below 6 2: 6 to 10 3: 10.1 to 12.9 4: 13 +

^AThe patient types correspond to those described in Table 3.27. For example, for index 1, the risk category 1 includes patient types

^BThe score of the index will determine which category the patient types 1 to 16 are classified in. Category 1=very low risk; 2=low risk; 3=medium risk; 4=high risk.

Table 3.29: Area under the ROC curve for selected potential indexes described in Table 3.28.

<i>Index</i>	<i>Area Subset 3</i>	<i>Standard Error</i>
1	0.587	0.032
2	0.636	0.031
3	0.637	0.032
4	0.633	0.031

Graph 3.2: The risk associated with each patient type as predicted by the logisitic regression equation. (Patient types are described in Table 3.27)

Table 3.30: Guide for Using Risk Index for Sternal Wound Infection

Risk Factor	Instructions	Score
Is the patient diabetic? (Non-insulin or insulin dependent)	If yes score 2.5 If no score 0	-----
Will the patient's internal mammary artery be harvested?	If yes score 3 If no score 0	-----
Did the patient require reopening because of complications within 4 days of the original surgery?	If yes score 4 If no score 0	-----
Has the patient spent 4 or more post-operative days in the ICU?	If yes score 5 If no score 0	-----
Total	Add all scores	-----

If total score is 0 to 5 then patient is in risk group 1 (Very low risk)

If total score is 5.5 to 9 then patient is in risk group 2 (Low risk)

If total score is 9.5 to 11.5 then patient is in risk group 3 (Medium risk)

If total score is 12 or above then patient is in risk group 4 (High risk)

3.14 Power Issues

Although dividing the data set into 3 subsets increased the validity of the index, it did reduce the overall power of this study. To understand how division into 3 subsets may have affected detection of risk factors of sternal SWI, stepwise logistic regression selection was performed on all subsets combined. The results are shown in Tables 3.31 and 3.32. The four factors included in the index (diabetes, reoperation, > 3 days in the ICU, use of IMA) were still significant and were the first variables chosen in the regression procedure. The odd ratios for these variables were all over 2.0. Using all data, new variables emerged as significant including chronic obstructive pulmonary disorder (COPD), operating time, post-operative pulmonary complications and preoperative

myocardial infarction. The odds ratios for these variables are all below 2.0 and the lower limit of their confidence intervals is around 1.0.

Table 3.31: Significant variables ($\alpha=0.05$) from stepwise logistic regression on all 3 subsets combined.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>
Surgeon 1 ^A	0.0406	1.65
Surgeon 2	0.6809	0.89
Surgeon 3	0.0181	0.49
Surgeon 4	0.0530	1.67
Surgeon 5	0.4400	1.26
Surgeon 6	0.4756	1.20
Surgeon 7	0.1961	1.44
Surgeon 8	0.1349	1.96
Surgeon 9	0.0612	0.46
COPD	0.0001	1.82
Diabetes	0.0001	2.46
Preoperative MI	0.0013	1.59
Use of IMA	0.0003	2.13
Operating time (minutes)	0.0001	1.004
> 3 days in ICU	0.0001	2.45
Pulmonary complications	0.0252	1.43
Reoperation	0.0001	2.63

^AAlthough the p values for the individual surgeons are sometimes less than 0.05, the surgeons were significant when considered as a block variable

Table 3.32: Significant variables ($\alpha=0.05$) from stepwise logistic regression on all 3 subsets combined, excluding the surgeon variables.

<i>Variable</i>	<i>P Value</i>	<i>Odds Ratio</i>	<i>Lower</i>	<i>Upper</i>
COPD	0.0451	1.32	1.00	1.71
Diabetes	0.0001	2.45	1.93	3.09
Preoperative MI	0.0004	1.66	1.25	2.18
Use of IMA	0.0001	2.16	1.65	2.84
Operating time (minutes)	0.0021	1.003	1.001	1.005
> 3 days in ICU	0.0001	2.71	1.95	3.72
Pulmonary complications	0.0438	1.38	1.00	1.87
Reoperation	0.0001	2.82	1.87	4.16

I developed a second index using the variables from the new index plus low output syndrome, chronic obstructive pulmonary disease, preoperative myocardial infarction and pulmonary complications. The area under the ROC curve for this second index was not

significantly different from the new index, indicating that the extra variables did not add any predictive power. (Area for subset 3 was 0.64 with SE 0.03.)

3.15 Comparison of Index to Existing Ones

Originally, I had planned to compare the SENIC index to the new risk index. Information on the number of discharge diagnosis was not available in the database, so it was abstracted from the charts of 140 patients during the chart review. However, the sample size proved too small to make a meaningful comparison of the two indexes. Infection Control recorded the ASA score for all patients in their database, while Cardiovascular Surgery collected this information sporadically. Therefore, I could compare the new index to the NNIS index using all observations with ASA scores (Table 3.33). The NNIS index had less predictive power than the new index, however, the sample used for comparison may have been biased because many of the controls were missing information on ASA score. Currently, the NNIS index is more widely accepted than the SENIC index to standardize rates (see section 1.9), so I will assume that the new index is better than the SENIC index.

Table 3.33: Comparison of the NNIS index and the new risk index using area under ROC curves. (Area is calculated using the Mann Whitney statistic as described in section 2.6.)

<i>Data Set</i>	<i>Index</i>	<i>Area Under ROC Curve</i>	<i>Standard Error of Area</i>	<i>Comparison (2 tailed P Value)</i>
Subset 3	NNIS	0.628	0.051	0.8966
	New Index	0.638	0.053	
All	NNIS	0.560	0.029	0.0024
	New Index	0.681	0.029	

3.16 Surgeon Specific Infection Rates

The crude rates of sternal SWI stratified by the operating surgeon are presented in table 3.34 along with the confidence intervals, which are provided to illustrate the accuracy of the rate estimates. None of the patients of surgeons J and L, for example, had

sternal SWI but these surgeons did very few operations. Graph 3.3 shows the relationship between number of operations performed by surgeons and their rate of sternal infections. Tables 3.35 and 3.36 show the surgeon specific rates, standardised by the new risk index and the NNIS-index respectively. The order of the surgeons varies from table 3.34 to 3.36. However, the top 3 surgeons remain the same, no matter what method is used to calculate the rates. Graph 3.4 depicts how the crude rate changes when the new index is used to standardise the surgeon specific infection rates.

Table 3.34: Crude surgeon specific rates of sternal surgical wound infections

<i>Surgeon</i>	<i>Number of Operations</i>	<i>Number of Infections</i>	<i>Rate (%)</i>	<i>Lower</i>	<i>Upper</i>
B	1549	75	4.81	3.74	5.88
E	967	42	4.29	3.01	5.57
H	786	32	4.06	2.68	5.44
I	230	9	3.86	1.37	6.35
F	848	28	3.27	2.07	4.47
C	1382	43	3.09	2.18	4
Average		342	2.97		
G	1735	47	2.67	1.91	3.43
D	1383	30	2.16	1.39	2.93
A	1833	28	1.52	0.96	2.08
K	639	8	1.24	0.38	2.1
J	54	0	0	0	0
L	8	0	0	0	0

Table 3.35: Surgeon specific rates of sternal surgical wound infections, standardized by the new index.

<i>Surgeon</i>	<i>Number of Operations</i>	<i>Rate of sternal infection (%)</i>	<i>Lower</i>	<i>Upper</i>
B	1549	4.35	3.33	5.37
E	967	4.06	2.82	5.3
H	786	3.9	2.55	5.25
C	1382	3.09	2.18	4
<i>Average</i>		2.98		
F	848	2.95	1.81	4.09
I	230	2.89	0.72	5.06
G	1735	2.7	1.94	3.46
D	1383	2.13	1.37	2.89
A	1833	2.09	1.44	2.74
K	639	1.2	0.36	2.04
J	54	0	0	0
L	8	0	0	0

Table 3.36: Surgeon specific rates of sternal surgical wound infections, standardised by the NNIS index.

<i>Surgeon</i>	<i>Number of Operations</i>	<i>Rate of Sternal Infection (%)</i>	<i>Lower</i>	<i>Upper</i>
E	444	6.27	4.02	8.52
H	110	5.6	1.3	9.9
B	546	3.66	2.08	5.24
F	141	3.49	0.46	6.52
C	480	2.79	1.32	4.26
ALL		2.76		
A	617	2.51	1.28	3.74
I	85	2.27	-0.9	5.44
K	474	1.47	0.39	2.55
G	605	1.39	0.46	2.32
D	492	1.34	0.32	2.36
J	23	0	0	0
L	0	0	0	0

Graph 3.3: The number of operations performed by each surgeon, compared to their rate of sternal surgical wound infection.

Graph 3.4: The surgeon specific sternal surgical wound infection rates standardised by the new index versus the non-standardised rates.

3.17 A Final Word on Index Validity

Specificity and sensitivity are commonly used to quantify the accuracy of a test or rule. Because the outcome of the index is not binary, I have been using the area under the ROC curve as a measure of accuracy. For readers more familiar with sensitivity and specificity, Table 3.37 shows these measures when different cut points are chosen to differentiate disease and non-diseased patients. However, the index is more effective when four risk categories are used. Overall, the specificity of the index is better than the sensitivity. As shown in Table 3.38, the rate of infection does increase as the risk level of the index increases. However, even in the highest risk category, the majority of patients do not develop wound infections. Finally, because of the low sensitivity of the index, the majority of patients who develop sternal wound infection are actually classified as low risk patients.

Table 3.37: The specificity and sensitivity of the new index when different cut points are chosen to differentiate between diseased and non-diseased patients.

<i>Cut Point</i>	<i>Sensitivity (%)</i>	<i>Specificity (%)</i>
Between risk level 1 and 2	48.4	82.0
Between risk level 2 and 3	10.9	98.5
Between risk level 3 and 4	4.4	99.6

Table 3.38: The rate of sternal surgical wound infection for each category of the wound index

<i>Risk Index Level</i>	<i>Rate of Infection (%)</i>	<i>Number of infections</i>	<i>Number of Patients</i>
1	1.9	176	9268
2	6.5	126	1946
3	15.7	23	147
4	28.3	15	53

4 Discussion

In this study, I have derived a four factor risk index for sternal surgical wound infection using multivariate techniques on a sample of over 11,500 cardiovascular patients. The new index includes diabetes, reoperation, an ICU stay of 4 or more days, and use of internal mammary artery as risk factors for sternal SWI. The index was designed to be easy to use to allow clinicians to calculate a patient's risk of infection at bedside, at different stages of hospital stay. Because previous indexes lack some of the major risk factors for sternal SWI, this index should be more effective than former ones in assessing risk. The comparison of the new index and the NNIS index in section 3.12 seems to confirm that the new index is more effective. Due to the fact that ASA score, a component of the NNIS index, was missing for many patients in this study, prospective studies should be done to corroborate this conclusion. In the discussion that follows, I will compare the new index to previous work, describe how the index may be used, outline the strengths and limitations of the index, present a proposal on how to include surgeons in the index, make recommendations for future data collection strategies and suggest future research that should be done using this index.

4.1 Comparison to Previous Work

Over 20 studies involving risk factors for sternal wound infection after cardiac surgery have been found and summarised in this thesis. Of these, only the study by Stahle et al. (1997) has sample size larger than 11,500. In fact, only one additional study, by Loop et al. (1990), uses multivariate techniques to determine risk factors and has a sample size over 3,000. These studies have already been described in section 1.11 and the Appendices. Table 4.1 recaps the significant findings of the studies.

Table 4.1: Significant risk factors from multivariate studies of sternal SWI that included over 6,000 patients ($\alpha=0.05$)

<i>Loop et al. (1990)</i>	<i>Stahle et al (1990) Valve Procedures</i>	<i>Stahle et al (1990) CAB Procedures</i>
Blood transfusions	Use of internal thoracic artery	Bilateral use of internal thoracic artery
Obesity	Postoperative renal failure requiring dialysis	Postoperative renal failure requiring dialysis
Operating time	Reoperation due to excessive bleeding	Diabetic disease
Diabetes		Year of surgery
Use of internal mammary artery in diabetics		Female sex

Both of the studies described in Table 4.1 found that diabetes was a significant risk factor for sternal infection, at least for CAB procedures. In fact, as discussed in section 1.9.4, most studies have found that diabetes is a significant risk factor for sternal surgical wound infection. In this study, diabetes was the only factor that was consistently identified using stepwise logistic regression on subsets 1, 2 and 3. Surprisingly, it was the only preoperative condition to remain significant in multivariate analysis. Previous indices such as the NNIS-derived index and the SENIC index have included more comprehensive measures of preoperative illness in the form of ASA score and number of discharge diagnoses respectively. It may be that diabetics also have other illnesses that increase the risk of sternal SWI. For example, based on the clinical impression of Dr. Conly, I had expected renal failure to be significant. Certainly, Stahle et al. found that postoperative renal failure was a significant risk factor for sternal wound infection. In fact, preoperative renal failure was significant in the univariate analysis, but not the multivariate analysis, even after merging both postoperative and preoperative renal failure, into one variable. Because diabetes can lead to renal failure, it may be that all risk associated with this condition in the univariate analysis is actually due to diabetes.

Previous studies of sternal SWI including length of stay in the ICU as a risk factor, reoperation, and use of IMA have been discussed in sections 1.11.6, 1.11.9, and 1.11.11 respectively. Briefly, longer stays in the ICU may increase the risk of colonisation by virulent organisms and may also be a marker for patients with a poor pre-operative

course. In the analysis, a stay of 4 or more days in the ICU was collinear to many variables including pulmonary complications and post-operative renal failure, two conditions which would increase the length of stay the ICU. This variable was included in two previous studies, but it did not prove significant (Miholic et al., 1985; Ottino et al., 1987). Reoperation increases tissue trauma and exposure to the outside environment. About half of the researchers that have included reoperation in their studies concluded that it was a significant risk factor (Farrington et al., 1985; Miholic et al., 1985; Ottino et al.; PMSG, 1996, Stahle et al., 1997). Removal of the internal mammary artery, or other chest artery, for use as a graft is thought to disturb blood flow to the sternal wound. All three studies which included this variable concluded that it was a significant risk factor (Loop et al., 1990; Stahle et al., 1997; Ulincy et al., 1990).

At the Toronto Hospital, certain surgeons do more elective procedures than others do and we were concerned that timing of the procedure would confound the relationship between surgeon and sternal infection. However, timing of the procedure was not even significant in the univariate analysis. Other studies have identified this variable as a risk factor for mortality (Tu, Sykora, Naylor, 1997; Higgins et al., 1992). Indeed, in the exclusion set, a high percentage of patients had non-elective procedures. The variable does not seem to affect risk of sternal infection.

Surgeons affect the risk of surgical wound infections through their surgical techniques and quality of their infection control practices. In this study, the operating surgeons were a significant risk factor for sternal SWI, however, they were not included in the index for several reasons. First of all, any surgeons who joined the hospital after 1995 would not be included in the index. Secondly, the index would not be transferable to other institutions, because these hospitals, of course, would have different surgeons. Thirdly, the odds ratios for surgeons are all relative to the person chosen as the reference surgeon and the values fluctuate when the choice of the reference surgeon changes. Finally, including surgeons in the index would fix the risk associated with that surgeon and improvements of rates due to better surgical techniques could not be accounted for unless a new index was developed. High risk surgeons would always have a "strike against them", even if they improved their infection control techniques.

As demonstrated in the section 3.13, the risk of the surgeon can be accounted for by calculating surgeon specific rates, standardised by the new index. Even after accounting for intrinsic risk, there are surgeons with high rates of sternal infections. The rank order of the surgeons changes, depending on whether crude or standardised rates are compared. However, the 3 surgeons with the highest rates remain the same, no matter which calculation method is used. Recently, the Center for Disease Control released a summary of data from the National Nosocomial Surveillance System, January 1992 – 1997 (Hospital Infections Program, 1997). The mean rate of sternal infection for CAB procedures was 3.73 percent. This is the rate standardised by the NNIS index. In section 3.13, the surgeon's rates have all been standardised by this index. Two surgeons were well above the mean rate, with sternal infections occurring in 6.3 % and 5.6 % of operations.

Factors such as quality of infection control practices and precision of surgical technique are difficult to measure directly. The Toronto Hospital does collect information on length of operating time, which could serve as a proxy measure for some of these factors. Length of operating time was not significant in the stepwise logistic regression performed on subset 1, but it was significant when all data was used. Similar results were noted for time on cardiopulmonary bypass, which is collinear to operating time.

Several other factors that were not significant on subset 1, were found to be significant in analysis using all data. These factors include low output syndrome, preoperative myocardial infarction, pulmonary complications and chronic obstructive pulmonary disease. Although it is biologically plausible that these factors could affect risk of sternal SWI, they have not been included in many previous studies. I did attempt to include these factors in several versions of the risk index. However, the area under the ROC curve did not significantly change when they were included. It may be that, regardless of whether or not these variables are risk factors, most of the predictive ability of an index is captured in the four risk factors I have included in the new index. Tu et al. (1997) found that an index with six core variables, designed to account for mortality after cardiac surgery, had an area under the ROC curve of 0.77. Adding more known risk factors to the index did not significantly change the area under the ROC curve.

Several risk factors were highly significant in the univariate analysis (p values around 0.0001), but did not remain significant in the multivariate analysis. These factors include renal failure, number of distal grafts, number of diseased arterial systems, low output syndrome, type of procedure and pulmonary complications. Many of the factors tested in this analysis were correlated, so I did not expect all factors to remain significant in the multivariate analysis. I have already discussed renal failure in paragraph 2 of this section. The number of distal grafts and number of diseased arterial systems were correlated to each other and both could be considered a marker of the complexity of the operation. I also found that number of diseased arterial systems was correlated to use of internal mammary artery. One of the risk models I contemplated included these last two factors combined into one. (A positive response for either or both would give the same risk score.) However, the predictive value of a risk model with the combined factor was no more accurate than the model with just the internal mammary artery (IMA), so, for the sake of simplicity, I chose the second model. Type of procedure is also related to use of internal mammary artery. Previous studies where coronary artery bypass procedures resulted in higher rates of sternal SWI when compared to valve procedures, did not include IMA as a factor. It may be that the increased risk associated with coronary artery bypass procedures is explained by the use of the IMA. Post-operative pulmonary complications will increase the time a patient spends in the ICU and in this analysis, pulmonary complications, which were correlated with time in ICU, lost significance when both variables were included in the model. As discussed in the previous paragraph, pulmonary complications were significant in the multivariate analysis done on all data. In this analysis, the parameter estimate of time in ICU dropped. As post-operative low output syndrome could also increase the time a patient spends in the ICU, this factor may have lost significance in the multivariate analysis for similar reasons.

4.2 Strengths of the Index

Dividing the data set into 3 subsets improved the validity of the final index. Because the data set was randomly divided, each subset could be considered an independent data set. Therefore, testing the logistic regression equations, developed on subset 1, on subset 2 helped detect overfitting of the model. Also, measures of accuracy of the logistic

regression models produced using subset 2 were less biased than measures on subset 1 would have been. The scoring system of the index was developed on subset 2 and then tested on subset 3. Therefore I was able to choose the scoring system with more accuracy than if I had tested them on subset 2.

4.3 Limitations of the Index

The data used for this study was not collected specifically to study sternal wound infection. As a result, the information on several potential risk factors was missing, including information on the amount of blood transfused and measures of height and weight to determine if the patient was obese. These factors have been discussed in section 1.11.1 and Appendix C. Stahle et al. (1997) did not include these factors in their analysis either; however, as seen in table 4.1, Loop et al. found that obesity and amount of blood transfused were significant risk factors. Potentially, reoperation, which occurs mainly when there is excessive bleeding, could account for some of the risk associated with increased amounts of blood transfusion. As these factors are easily measured, they could be consistently included in the Toronto Hospital database in the future.

The Toronto Hospital has a standard antibiotic policy for cardiovascular surgery. Based on the results of the chart review, I concluded that the timing and dose of antibiotics did not vary enough to affect the risk of sternal wound infection. Part of this conclusion was based on the assumption that an entry in the hospital charts, stating that antibiotics were given on call to the operating room, implied that the drugs were administered at most two hours prior to the operation. However, this is not always the case. In the future, accurate data on the antibiotic type and the timing of use should be collected for the cardiovascular database.

Other risk factors not measured include nutrition and immune status. These factors have not been included in many studies because they require tests not normally given before cardiovascular surgery. In fact, there is disagreement about which tests should be performed to measure these variables. These would be more difficult to incorporate in future studies.

During the five years of data collection included in the study, some variables were added or dropped and this is partly why some variables are missing large amounts of

data. Furthermore, the definition of some variables changed over the years necessitating the recoding of variables, which was done to maintain consistency in the analysis.

The Toronto Hospital, like many hospitals, does not have post-discharge surveillance for surgical wound infections. All cases of deep wound infections, which require surgical treatment, are likely to have been identified in this study. However, the hospital may not have been notified of cases of superficial sternal wound infection. The number of infections may have been underestimated because case ascertainment was incomplete. Orenstein et al. (1998) found that 1.5% of surgical patients developed a surgical wound infection post-discharge. (Patients were interviewed by telephone and then symptoms were diagnosed by a physician.) Fanning et al. (1998) found that the rate of post-discharge surgical site infections was 4.6% in their study.

4.4 Use of the Risk Index

The risk index has potential preoperative and postoperative uses. Preoperatively, the index may help surgeons gauge a patient's risk of sternal surgical wound infection. Caution must be used however, when using the index to predict an individual's risk of infection. For example, only about 28% of patients classified as risk level 4 or "high risk" in this study actually developed a sternal SWI. The presence of the risk factors can act as a flag for surgeons and supporting staff. A high-risk score may remind a surgeon to take greater care in following infection control procedures during the operation. For patients with diabetes, the surgeon may be able to choose to use the saphenous vein rather than the internal mammary artery to harvest for use as a graft. When a chest artery needs to be used, Stahle et al (1997) suggested techniques to minimise reduction of blood flow in the chest area. A discussion of surgical techniques is beyond the scope of this thesis. Patients with high risk scores can be monitored closely for sternal infection so that an infection may be detected promptly and treated early. Another note of caution: in this study, 44 (12.8%) infections occurred in patients without any of the index risk factors. Therefore, surveillance should be maintained for all patients.

The new index is more effective at predicting the risk of sternal SWI in groups than in an individual. The index can be used as part of a surveillance system, similar to how the NNIS index is currently used by the Center for Disease Control in the United States

(Hospital Infections Program, 1997). The index can be used to stratify patients into risk categories. Then direct standardisation can be used to produce the rate of sternal SWI corrected by intrinsic risk for each surgeon as demonstrated in section 3.16. A chi-square test can be used to test if rates are significantly different from each other. Potentially, this same process could be used to calculate institution-specific rates in the future, however, the index must be validated in other institutions before being used.

4.5 Including Surgeons in the Index

The Toronto Hospital may wish to include a surgeon variable in the index when attempting to assess a patient's risk of wound infection. Over a period of years a surgeon who is consistently above one standard deviation above the average rate of wound infection could be called a high risk surgeon. Conversely, a surgeon who has had rates of sternal SWI consistently lower than one standard deviation below the average could be called a low risk surgeon and those close to the average could be labelled as "average". A score for each type of surgeon could be developed and incorporated into the index. For the data used in this thesis, the odds ratios of the four other risk factors of the index did not greatly change when the surgeon variables were forced into the model. Therefore, the scores of the other factors will most likely remain the same when a surgeon variable is added to the index.

4.6 Recommendations for Future Data Collection Strategies

Future improvement of the index and surveillance of sternal surgical wound infections would be simpler if the following additional information was captured for all patients in the cardiovascular database:

- 1) **Amount of blood transfused:** Murphy et al. (1992) found that amount of blood measured as total units given or units of red cells given was a significant risk factor for sternal SWI. The cardiovascular database should include information on total units of blood given. The research unit may also wish to collect more detailed information on the type of blood units given.

- 2) **BMI:** The cardiovascular database has collected information on weight and height accurately for certain years only. These variables should be consistently collected so that calculations for BMI may be completed.
- 3) **ASA score:** Collection of ASA score would facilitate comparison of the accuracy of the risk index to that of the NNIS index.
- 4) **Preoperative antibiotic type and timing:** Collection of this information would allow verification that the antibiotic policy is followed. Also, if there is significant variation in the type or timing of preoperative antibiotic administrations, these variables may have to be added to the index.

The information for these factors could be obtained at the same time that the research nurse reviews the chart for current database information. Nutrition and immune status are other variables suggested as possible risk factors in the literature. However, collecting information on these factors would involve additional tests and expense.

4.7 Future Research

The new four factor index appears to account more accurately for sternal SWI than previous indexes such as the NNIS-derived index. I was not able to compare the index to the SENIC index. However, this comparison is less important as the NNIS index is now used by the CDC in place of the SENIC index. The area under the ROC curve for the final test set of data was only 0.64 (SE 0.03). This is comparable to another index developed to predict the number of days spent in ICU after cardiac surgery, which had an area of 0.68 (SE 0.02) (Tu et al., 1994). However, an index developed by Tu et al. (1997) to adjust mortality rates for intrinsic risk after coronary artery bypass graft surgery had an area under the ROC curve of 0.77. This suggests that the new index is not as accurate at predicting sternal SWI as Tu et al.'s index is at predicting mortality. Future work may clarify the role of factors such as COPD, operating time, time on CPB, preoperative myocardial infarction, amount of blood transfused, and obesity. Addition of new variables to the risk index may strengthen its predictive ability.

Before implementing the existing index, further validation should be done. A prospective study at The Toronto Hospital would test whether the accuracy of the index remains constant over time. Wasson et al. (1985) advocate prospective validation because it minimises bias. Finally, the index must be evaluated at other hospitals to ensure that it does not contain risk variables specific to The Toronto Hospital. A multi-institutional study would determine if the index could be generalised to other hospitals.

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APPENDIX A: Definitions of leg and sternal wound infection

APPENDIX A: Definitions

Surgical Wound Infection

Includes incisional surgical wound infection and deep surgical wound infection ie. operative site. The criteria for a wound infection may include one or more of the following:

- 1) occurs at incision site within 30 days after surgery, or within 1 year if an implant is left in place
- 2) purulent drainage from incision
- 3) organism isolated from abnormal wound drainage
- 4) an abscess or other evidence of infection is seen on direct examination during surgery or by histopathologic examination
- 5) clinical diagnosis of wound infection is made requiring either antibiotics or surgical intervention

Superficial Vs. Deep

1) Leg Wound Infections:

Superficial: Based on the presence of purulent discharge, involving skin and fat (<1cm deep)

Deep: Infection below the superficial fascia (>1 cm deep)

2) Sternal Wound Infections:

Superficial: Based on the presence of purulent discharge, involving skin and subcutaneous tissue only.

Deep: Wound that requires surgical debridement

APPENDIX B: Summary of studies referenced in the literature review

Reference	Sample Size	Methodology
Breyer et al. (1983)	877	Prospective study of open-heart surgery cases. Analysed risk factors for major sternal complications by stepwise logistic regression.
Brown et al. (1969)	748	Retrospective study of open-heart surgery patients. Univariate analysis of factors related to sternal infection and dehiscence.
Casey et al. (1982)	79	Prospective study looking for all wound complications in patients undergoing vascular operations. Univariate analysis only.
Classen et al. (1992)	2,847	Prospective, randomised controlled trial of antibiotic prophylaxis in patients undergoing clean or clean-contaminated operations.
Culliford et al. (1976)	2,594	Review of sternal SWI after open-heart surgery. Described risk factors but no comparison to control group.
Davidson et al. (1971)	1,000	Retrospective study of patients undergoing various surgeries. Stepwise multivariate analysis was used to determine risk factors of SWI.
Farrington et al. (1985)	433	Prospective study of SWI (leg and sternal) after open-heart surgery. Univariate analysis only.
Grossi et al. (1991)	2,356	Prospective study of patients undergoing CAB. Multivariate logistic regression analysis was used to determine risk factors for sternal wound infection.
Hazelrigg et al. (1989)	2579	Retrospective study of patient undergoing CAB. Multivariate logistic regression analysis was used to determine risk factors of sternal wound complications (including infection and dehiscences).
Higgins et al. (1992)	5,051	Retrospective study of patients undergoing CAB. Multivariate logistic regression analysis to determine risk factors associated with morbidity and mortality. Morbidity includes cardiac complications, prolonged ventilation, CNS complication, oliguric or anuric renal failure, serious infection, mortality.
Klutymans et al. (1994)	1,980	Case-control study of patients who developed sternal SWI due to <i>Staphylococcus aureus</i> . Univariate analysis of risk factors only.

Reference	Sample Size	Methodology
Koshal et al. (1985)	200	Prospective study of patients undergoing CAB. Univariate analysis to determine risk factors associated with infectious outcomes including wound, respiratory, urinary or generalised.
Kutsal et al. (1990)	8,803	Description of cases of sternal wound infection among patients undergoing open-heart surgery. Frequency of risk factors among cases given.
Loop et al. (1990)	6,504	Retrospective study of patients undergoing CAB procedures. Multivariate analysis of potential risk factors for sternal SWI or dehiscence.
Miedzinski et al (1987)	521	Retrospective review of patients undergoing open-heart surgery. Univariate analysis to determine risk factors associated with infectious complications including bacteremia, carditis, or deep sternal wound infection
Miholic et al. (1985)	246	Prospective analysis of patients undergoing open-heart surgery. Multivariate analysis of potential risk factors for developing infectious complications including valve endocarditis, pneumonia, and deep sternal wound infection.
Murphy et al. (1992)	238	Retrospective analysis of patients undergoing open-heart surgery for the first time. Multivariate linear and logistic regression analysis to determine if blood transfusions increase the risk of postoperative infections including sternal SWI, urinary tract infection, and septicemia.
Nagachinta et al. (1987)	1,009	Prospective study of patients undergoing elective cardiac surgery. Multivariate logistic regression analysis to determine risk factors associated with sternal SWI.
Ottino et al. (1987)	2,579	Retrospective study of patients undergoing open-heart procedures. Multivariate stepwise logistic regression to determine factors associated with sternal SWI.
Parisian Mediastinitis Study Group (1996)	1830	Prospective study of patients undergoing open-heart surgery in 10 different units in Paris, France. Multivariate stepwise logistic regression to determine factors associated with deep sternal SWI.

Reference	Sample Size	Methodology
Shuhaiber et al. (1987)	170	Review of patients undergoing open-heart surgery. Univariate analysis of suspected risk factors for sternal SWI
Simchen et al. (1981)	372	Prospective study of cardiac, colon and neurosurgery patients to identify risk factors for clean wound infection. Multivariate analysis was done for each type of surgery.
Stahle et al (1997)	13,285	Prospective study of patients receiving open-heart surgery from 1980 to 1991. Procedures were divided into CAB and valve (with or without an accompanying CAB) Risk factors for sternal SWI were determined using multivariate techniques.
Ulincoy et al. (1990)	221	Prospective study of consecutive open-heart surgery patients. Risk factors for sternal SWI were determined using multivariate analysis.

APPENDIX C: Other potential risk factors of sternal wound infection

Additional risk factors identified in the literature

Many of the potential independent risk factors that will be used to build the risk index for sternal wound infection after cardiovascular surgery are related to each other. There are three potential types of relationships. Firstly, variables could confound the relationship between a risk factor and sternal surgical wound infection (SWI). A confounder is a factor that is related to the outcome of interest as well as the independent risk factor of interest, but is not in the causal pathway between the two. Due to these associations, the confounder distorts the relationship between the risk factor and the outcome by either decreasing or magnifying its significance. Secondly, a variable could act as an effect modifier and have an antagonistic or synergistic effect on the relationship of interest. Basically, the relationship of interest will vary depending on the presence/absence (binary variable) or level (categorical or linear variable) of the effect modifier. Thirdly, when many variables are related, it is important to sort the direct causes from the indirect ones. A variable may appear to be an independent risk factor for the outcome simply because it leads to another condition which is the true independent risk factor. The variable should then be called the indirect cause, and the true risk factor called the direct cause (Kelsey et al, 1996). Some of the potential relationships between risk factors are described below.

Age

As a person ages, the immune response declines and in theory the body becomes more susceptible to infection (Condon et al., 1988). Specifically, the number of T lymphocytes circulating in the blood decreases and the B lymphocyte antibody response declines (Meakins, 1994). Therefore, age has been included in most models attempting to explain sternal SWI and other complications, as either a continuous variable, a binary or a multi-level categorical variable. In most multivariate models, age has not been a significant variable (Brown et al., 1969; Farrington et al., 1985; Miedzinski et al., 1987; Miholic et al., 1985; Nagachinta et al., 1987; Ottino et al., 1987; Simchen et al, 1981; Shuhaiber, 1987; Stahle et al., 1997). However, Davidson et al. (1971) found that age >60 years was

one of the top 5 predictors of SWI, with risk of infection increasing 0.34% per year of age. In an analysis of the all adverse events associated with CV surgery, Higgins et al. (1992) found that increasing age by decade significantly increased the risk of both peri-operative mortality and morbidity (p value < 0.0001). In the Parisian Mediastinitis Study Group (PMSG, 1996) patients were stratified into two groups: those undergoing a coronary artery bypass (CAB) procedure and those who did not. Age was included as significant in the multivariate model for the “other procedures” group but not for the CAB group.

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is a term that encompasses several disorders, sharing the common feature of chronic narrow airways of the lung (Jansen et al., 1995). These disorders include emphysema, chronic bronchitis, bronchiectasis and upper airway obstruction (Silverman & Speizer, 1996). COPD creates changes in the lungs and therefore has been suggested as a risk factor for pulmonary infection (Jansen et al., 1985). In the case of sternal SWI, a patient with COPD may be more severely ill than one without the disorder. Therefore, COPD may increase susceptibility for infection. Higgins et al. (1992), determined that those on medication for COPD had a higher risk of complications after cardiac surgery than those who did not.

Several potential risk factors for sternal infection have already been identified as risk factors for COPD. These include cigarette smoking, increasing age and male gender (Silverman & Speizer, 1996).

Cigarette Smoking

Cigarette smoking increases a person's heart rate, cardiac output, and systemic arterial blood pressure (Nagachinta et al., 1987). It significantly increases risk of heart disease and therefore risk of open-heart surgery (Heart and Stroke Foundation, 1995). Cigarette smoking can also reduce blood flow to periphery areas and may thus increase the risk of infection in these areas (Nagachinta et al., 1987). Very few studies of sternal SWI have included cigarette smoking as a potential risk factor. Shuhaiber et al. (1987) and Ulicny

et al. (1990) did not find an association between cigarette smoking and sternal SWI. Nagachinta et al. (1987) found that a cigarette smoker's risk of developing sternal SWI was two-fold higher than a non-smoker's in the univariate analysis. Cigarette smoking was highly correlated with high lymphocyte count, another factor significant in the univariate analysis. Of these two factors, cigarette smoking was included in the multivariate model since it was more biologically plausible than high lymphocyte counts. The authors stressed that the relationship between cigarette smoking and sternal SWI needs to be examined in future studies.

Deep Venous Thrombosis

Thrombosis is the formation of blood clots. Cardiopulmonary bypass can disrupt the balance of the fibrinolytic and the coagulation cascades, leading to abnormal blood clot formation. Therefore, deep venous thrombosis could be considered a crude measure of the effect of the CPB. Length of CPB may modify the relationship between deep venous thrombosis and SWI. Emboli may develop from the thrombus, and lead to myocardial infarction, pulmonary complications and neurological complications.

Excessive Bleeding

Investigators have proposed excessive operative and post-operative bleeding as a potential risk factor for SWI. This is biologically plausible since excessive bleeding can lead to the formation of blood clots, also called hematomas. Microorganisms can flourish in the rich environment of a hematoma. CPB can disrupt the balance of the fibrinolytic and the coagulation cascades, leading to excessive bleeding. Therefore, this variable may act as a crude indicator of the success of CPB. Excessive bleeding is closely related to amount of blood transfused, which may be why it loses significance in multivariate models containing both variables. Another potential risk factor closely related to both excessive bleeding and amount of blood transfused is reoperation for bleeding.

In general, excessive bleeding has not proven to be a significant risk factor for sternal SWI and other infectious complications. Ottino et al. (1987) found that excessive bleeding was significant in the univariate analysis, but not in the multivariate analysis.

Amount of blood transfused, on the other hand, was significant. Interestingly, Uliny et al. (1990) observed that excessive post-operative bleeding was significant in the multivariate model, but both amount of transfusion and reoperation for bleeding was not. Sutherland et al. (1977) found that excessive bleeding was not a significant risk factor.

Immune Status

Many of the factors discussed in this section are thought to reduce the effectiveness of the immune response and therefore increase the risk of infection in the patient. Several authors have tried to directly measure the immune response and relate it to wound infection rates. As discussed in the cigarette smoking, Nagachinta et al. (1987) found that those who developed sternal SWI actually had higher lymphocyte counts than those who did not. However, lymphocyte counts were highly correlated with cigarette smoking levels, so because the latter seemed a more plausible risk factor, lymphocyte count was excluded from the final multivariate model. On the other hand, Casey et al. (1983) did not find a correlation between lymphocyte counts and sternal SWI. Similarly, Uliny et al. (1990) determined that patients with pre-operative delayed hypersensitivity reaction did not have an increased risk of infection. Klutymans et al. (1995) concluded that use of immunosuppressive drugs pre-operatively increased the risk of infection while Uliny et al. (1990) could not attribute a significant effect to pre-operative steroids. Steroids have immunosuppressive properties. Measurements on immune status have not been included in the data used in this study and will therefore be excluded from the sternal SWI risk index.

Insertion of an Intra-Aortic Balloon Pump (IABP)

An IABP is used to increase cardiac output for some conditions before cardiac surgery and after surgery when it is difficult to wean patients from the CPB machine. It is a balloon placed in the aorta which inflates and deflates in order to moderate resistance to blood flow, thereby decreasing the work of the heart (Marks & Marks, 1993). Miholic et al. (1985) found that use of an IABP increased the risk of sternal SWI after valve replacement procedure in univariate analysis, but not the multivariate analysis. For

Hazelrigg et al. (1989) the use of IABP was a significant risk factor in their multivariate analysis. IABP may be related to reoperation: Jones et al. (1991) found that in their cohort, use of an IABP was most common in those undergoing cardiac surgery for the second time.

Insertion of Pace Maker

As noted previously, atrial fibrillation is a risk factor for stroke, because it can cause damage to cerebral blood vessels. Pace makers can be inserted to correct atrial fibrillation. Therefore insertion of pace maker is a potential confounder of the relationship of both pre-operative and post-operative stroke and sternal infection.

Low output syndrome (LOS)

LOS is directly related to dopamine and dobutamine use since these drugs are given to help treat LOS. If drugs fail to correct the problem, an intra-aortic balloon pump can be inserted to correct the circulation problem. Myocardial infarction (MI), cardiac tamponade, inadequate atrial filling and depressed myocardial contractility can lead to low output syndrome. Injury of the heart or pericarditis may lead to tamponade, which can result in LOS (Harlan et al, 1995). Because precise surgical technique may prevent LOS, this variable may prove to be a marker for the performance of the surgical team.

In their large study of mortality and morbidity, Higgins et al. (1992) determined that pre-operative low cardiac output does not affect the rate of post-operative complications. However, post-operative low cardiac output appears to increase the risk of mechanical dehiscence. With respect to sternal SWI, neither Loop et al. (1990) or Brown et al. (1969) found a significant effect of LOS on rate of infection. However, they noted that 5 of the 10 patients who developed sternal SWI had cardiac arrest or shock before their infections were diagnosed.

Mechanical Ventilation

As part of the CPB, patients are placed on mechanical ventilation. Generally, the ventilator is removed within 24 hours of the surgery (Casthely & Bregman, 1991).

Mechanical ventilation may lead to many of the same complications as CPB. Duration of mechanical ventilation can be a marker of complicated cases since patients who are difficult to wean from the ventilator are generally quite ill. Mechanical ventilation is physically harder on the lungs and the rib cage than normal breathing. Brown et al (1969) noted that longer ventilation times increased the risk of major sternal dehiscence.

In the multivariate risk model proposed by Breyer et al. (1984), mechanical ventilation was one of four independent risk factors for major sternal complications. However, the outcome of this study included both sternal dehiscence and infection. Ottino et al. (1987) and Shuhaiber et al. (1987) who focused on sternal infectious found that this variable was not significant.

Myocardial Infarction (MI)

Perioperative MI can be caused by myocardial necrosis due to graft occlusion, reperfusion injury, coronary artery spasm, and poor myocardial preservation (Casthely & Bregman, 1991). So, myocardial infarction is a crude measure of success of the CPB and may be confounded by length of CPB and other operative factors.

New York Heart Association Score

By definition, all patients in class I to IV of the New York Heart Association (NYHA) classification system have cardiac disease. Patients are grouped in class I to IV based on their tolerance to physical activity (Gross, 1996). (See Table C.1). The NYHA score is based on questions asked by the scorer, and is therefore a subjective index. Studies have estimated the inter-rater reliability of the index at 56% (Gross, 1996).

NYHA score is a potential risk factor for sternal SWI since it is a measure of the health of a patient. More severely ill patient might have a higher risk of developing sternal SWI. The PMSG (1996), the only study to include NYHA, determined that NYHA score was a not a risk factor for sternal infection. Variables such as number of grafts used during coronary artery bypass procedure and timing of procedure are potential confounders since they are also crude measures of cardiac performance.

Table C.1: Criteria for the NYHA score (Gross, 1996).

SCORE	CRITERIA
I	Patients who do not have activity limitations due to their cardiac disease.
II	Patients who have symptoms of their cardiac disease only when they exert themselves beyond ordinary, daily activity.
III	Patients who have limitations on their ordinary, daily activity due to the symptoms of cardiac disease.
IV	Patients who have symptoms of their cardiac disease even when at rest. Activity greatly limited.

Neurological Complications

Neurological complications such as stroke are usually caused by air embolisms, particle embolism or ischaemia (Kirklin & McGiffin, 1987). These complications are rare, occurring in about 1% of patients (Kirklin & McGiffin, 1987). Emboli and ischaemia can develop as a result of the CPB. Therefore, the presence of neurological complications is a measure of the success of the CPB. Jones et al. (1991) found that neurological complications were most common in those undergoing cardiac surgery for the second time.

Number of Grafts Used

A patient may require more than one coronary artery bypass (CAB) graft in order to restore adequate blood flow to the heart. Jones et al. (1991) found that the length of the operation increased as the number of grafts increased. Therefore, the number of grafts may be a measure of the complexity of the operation.

Nutrition

This section is concerned with under-nutrition. Over-nutrition as a risk factor is discussed in the section entitled 'Obesity'. Severe malnutrition has been found to increase susceptibility to infection by impairing cell-mediated and humoral immunity as well as complement and neutrophil function, in both humans and animals (Gross & Newberne, 1980; Ulincy et al., 1990). However, the question is whether or not less extreme types of malnutrition affects susceptibility to SWI. This is not easy to answer

because a reliable indicator of nutritional status has been difficult to find. Common tests include percent of body fat, serum albumin levels, serum transferrin levels, percent ideal weight, triceps skin-fold thickness, myocardial glycogen concentration, mid-arm muscle circumference, total lymphocyte count, and delayed hypersensitivity count. Abel et al. (1983) have concluded that none of these tests measure nutritional state accurately enough to determine an individual's nutritional status. However, these tests may still be useful when studying groups for statistical associations with morbidity. Also, many of these tests are not routinely done when a person is admitted to hospital for cardiovascular surgery. Therefore, studies relating malnutrition to sternal SWI must be specially designed and are often of small sample size. There are no measures of nutritional status in the data being analysed for this thesis project.

Serum albumin, a protein found in blood, has been used as a measure of protein levels. Both Nagachinta et al. (1987) and Casey et al. (1983) have found that low serum albumin levels are significantly associated with SWI in univariate analysis only. Shuhaiber et al. (1987) did not find a relationship. This indicator may not be appropriate since it has been shown that low serum albumin have not affected wound healing in rats (Ulincy et al., 1990). Casey et al (1983) also determined that low serum transferrin levels are associated with increased risk of SWI in univariate analysis. However, Ulincy et al (1990) did not find any relationship between SWI and serum transferrin, pre-albumin or retinol-binding protein. Tuten et al (1985) showed that among serum proteins, retinol binding protein had high sensitivity, transferrin had medium sensitivity and albumin had low sensitivity.

Obesity

Obese people may have a higher risk of infectious complications to surgeries than non-obese people because fatty tissue has poor blood flow. Lack of blood may suppress the immune response in this tissue. Obesity has been defined in different ways. Body mass index (BMI) is defined as weight divided by height². Nagachinta et al. (1987) found that people classified as obese according to BMI had a higher risk of sternal SWI and included the factor in their multivariate model. In a study by Koshal et al. (1985)

there was a higher rate of sternal SWI among obese people, but the difference was not significant. The PMSG (1996) determined that for all types of procedures, a BMI > 30 was a significant risk factor in the multivariate analysis. When they stratified patients by procedure however, obesity was significant only in the multivariate model for CAB procedures and not for the “other procedures” group. Casey et al. (1983) found that tricep skinfold thickness was not useful in predicting wound healing complications. Loop et al. (1990), included obesity, defined as >20% above normal body weight adjusted for height and frame, as one of four factors in their multivariate model. Breyer et al. (1984) and Ulincy et al. (1990) found that the mean weight in kilograms of those with infections was significantly higher than those without, and include the variable in their multivariate models. However, a much larger study, by Higgins et al (1992) actually found that a weight less than or equal to 65 kg increased overall morbidity after CV surgery. Note, however, that the outcome studied by this group included more than SWI. (See Appendix B.) Among studies where the definition of obesity is not described, Shuhaiber et al. (1987) and Hazelrigg et al. (1989) found that obesity was an independent risk factor while Farrington et al. (1985) did not.

Obesity, defined as a BMI greater than or equal to 27, is a risk factor for ischemic heart disease (Heart and Stroke Foundation, 1995). Among open-heart surgery patients, obesity has been associated with hypertension, hyperlipidemia, and long CPB time (Koshal et al., 1985). This last association indicates that obesity is a potential confounder or effect modifier of CPB time’s effect on sternal SWI status.

Other Previous Illnesses

Congestive heart failure (CHF) preoperative myocardial infarction (MI) and previous stroke or transient ischaemic attack (TIA) will all be considered potential risk factors in this analysis. They may all indicate the severity of illness in the patient.

CHF occurs when the output of the heart is inadequate and often results in damage to the heart muscle. CHF may lead to a myocardial infarction, so these variables may prove to be highly correlated in the analysis. In mild CHF, symptoms may only appear when the person exerts him or herself physically. In severe cases, breathing is affected and deterioration may be seen throughout the body (Brittania Online, 1998b).

The Canadian Heart and Stroke foundation identifies smoking, diabetes, and obesity as risk factors for ischaemic heart disease. As discussed previously, NYHA classification may also be related to preoperative MI (Heart and Stroke Foundation, 1995). These factors could be indirect causes of sternal infection since they are linked to preoperative MI. They are also potential confounders of the relationship between preoperative MI and sternal wound infection.

Risk factors for stroke include atrial fibrillation, diabetes, smoking, and previous transient ischaemic attack (TIA). Therefore, all of these factors may be confounders or indirect causes of sternal wound infection. As well, since heart disease predisposes to stroke, the NYHA may confound the relationship between stroke and sternal wound infection.

Pneumonia

Infection at another site of the body may predispose a patient to develop a sternal wound infection. Hazelrigg et al. (1989) found that pneumonia was a significant risk factor for sternal wound infection in their multivariate analysis. In fact, having pneumonia increased the risk of sternal infection about 22 times.

Preoperative Hospital Stay

The microorganisms (MO) found in hospitals tend to be more virulent and drug resistant than those found elsewhere (Meakins, 1994). Intuitively, longer stays in the hospital increase the chance that the patient will be colonised with hospital microorganisms through contact with the staff, other patients and the environment. More virulent bacteria have a greater chance of overwhelming host defences and causing an infection when they invade a surgical wound. Therefore, it follows that longer preoperative stays will increase the risk of SWI. As well, patients with more complications may have long preoperative stays. Therefore, length of preoperative stay may also reflect the overall preoperative health status of the patient.

Hasselgren et al. (1982), Nagachinta et al. (1987) and Ottino et al. (1987) have all concluded that longer preoperative stay increases risk of SWI and other complications.

In these studies the variable was defined as a preoperative stay greater than 1 day, greater than 5 days, and as a linear variable respectively. Note that the study by Hasselgren et al. (1982) was on a general surgery ward rather than a cardiac one. Farrington et al. (1985) did note an increased frequency of SWI among patients with long preoperative stays, but it was not statistically significant. Only Shuhaiber et al. (1987) failed to find an association.

Longer stays in the hospital may occur if a person has pre-existing conditions that require admission to hospital. Conversely, patients who need emergency cardiovascular surgery may have a short preoperative stay. Hasselgren et al. (1982) found that long preoperative stay was significantly associated with age > 60, operation > 3 hours and steroid use. Thus host factors and timing of surgery may confound the relationship between duration of preoperative stay and sternal wound infection.

Previous Cardiac Surgery

Patients who are undergoing cardiac surgery for a second time, may be at greater risk of sternal SWI than first time patients for several reasons. First of all, patients undergoing a second surgery are usually more critically ill than those undergoing their first and are therefore less able to resist invading microorganisms. Secondly, when a sternotomy heals, extra adhesions form, making separation of the sternum more difficult the second time round. Thus, second time operations require more precise dissection and extra time. Generally, more bleeding and tissue traumatization also occur (Ottino et al, 1987). During a repeat sternotomy, structures held to the sternum by the adhesions are easily damaged (Brown et al., 1969). In addition, Jones et al. (1991) found that patients having repeat operations are more susceptible to peri-operative MI and post-operative stroke. The former probably occurs because myocardial preservation becomes more difficult in succeeding operations.

Loop et al. (1990) and the PMSG (1996) failed to find that previous cardiac surgery increases the risk of sternal SWI. On the other hand, Ulincy et al. (1990) and Ottino et al. (1987) linked repeat cardiac surgery to sternal SWI, and included the variable in their multivariate models. Miholic et al. (1985) concluded that previous cardiac surgery was

only a risk factor for those undergoing repeat valve replacement surgery, but not repeat CAB.

Pulmonary Complications

Pulmonary complications include dysfunction, atelectasis, and pulmonary edema. Risk factors for these complications include long CPB time, older age and high postoperative levels of complement component C3a (Kirklin & McGiffin, 1987). The presence of pulmonary complications is another crude measure of success of the CPB since they can be caused by damage to lung tissue during the procedure. Pre-existing conditions such as COPD and smoking habits may increase the chance of pulmonary complications. Some of these variables may be indirect causes of sternal wound infection or they may be confounders. Pulmonary complications can increase the time spent on mechanical ventilation, and may therefore be confounders of the relationship between ventilation and sternal wound infection.

Sex

Sex has often been studied as a potential risk factor for SWI. Most studies have found that sex has no influence on the risk of infection (Farrington et al., 1985; Miholic et al., 1985; Nagachinta et al., 1987; Ottino et al., 1987; Simchen et al., 1981). However, Breyer et al. (1984) found that sex was one of four significant risk factors in a multivariate analysis. Stahle et al. (1997) included sex as a significant risk factor in the multivariate model for CAB procedures, but not in the one for valve procedures.

Skin Preparation

Previously, in preparation for surgery, a razor was used to shave patients in the areas where surgical incisions were planned. However, several studies then showed that the rate of SWI was higher in those patients shaved with a razor compared others who's hair was removed using depilatory cream or a hair clipper (Alexander et al., 1983; Sellick et al., 1991; Seropian & Reynolds, 1971). Now it is recommended that when hair removal is necessary, only a depilatory cream or a hair clipper be used (Meakins, 1994).

Interestingly, the PMSG (1996) found that hair removal of any type was a risk factor in the univariate analysis, but not the multivariate analysis. Throughout the study period, preoperative hair removal in the cardiovascular service of the Toronto Hospital was done using a clipper.

Timing of the Operation

Cardiovascular surgery may be performed on an elective basis, meaning that the patient is admitted to hospital for a planned surgical procedure. In some cases, events such as a myocardial infarction precipitate the need for cardiovascular surgery. Those who are operated on an emergency basis are generally in poorer health than those scheduled for elective surgery. This may effect the degree of post-operative mortality. Higgins et al. (1992) have found that having an emergency operation predicted a significant increase in postoperative mortality and morbidity in their multivariate models. In a study of all surgical wound infections, Davidson et al. (1971) found that having an emergency operation increased the risk of SWI infection in several procedures. Studies focusing on sternal SWI have not found an increase in risk (Miholic et al., 1985; Ottino et al., 1987; Sutherland et al., 1977), however, the timing of the operation is still a potential risk factor.

Use of Inotropic Agents

The PMSG (1996) found that use of inotropic agents was an independent risk factor in the multivariate analysis. When the researchers stratified the sample according to procedure, inotropic agents remained in the multivariate model for all CAB procedures but not for other types of procedures. The use of inotropic agents is closely tied to use of an intra-aortic balloon pump, long mechanical ventilation, and a long stay in the ICU (PMSG, 1996).

Ventricular Dysrhythmias

Ventricular dysrhythmias can be caused by ischaemic damage during the operation. Ischaemic damage is related to the length of operation and quality of myocardial

preservation. Myocardial infarctions can also cause ischaemic damage (Harlan et al, 1995). Therefore all of these factors are inter-related and may account for any relationship between ventricular dysrhythmias and sternal wound infection.

Other Factors

Research groups have proposed other potential risk factors for the development of sternal SWI and other infectious complications after surgery. These have not been described in detail because they were not measured in the data used for this research project and are included in a relatively small number of studies. The factors are listed, along with studies which have included them, in Table C.2.

Table C.2: Other potential risk factors included in previous research studies.

FACTOR	REFERENCES
Aortic cross clamp time	Grossi et al., 1991
Hypertension	Stahle et al., 1997
Nasal carriage of <i>Staphylococcus</i> species	Davidson et al., 1971; Klutymans et al., 1995
Operating theatre location	Davidson et al., 1971; Ottino et al., 1987; Ulincoy et al., 1990
Operative surgical glove puncture	Davidson et al., 1971
Preoperative hormone medication	Nagachinta et al., 1987
Post-operative external cardiac massage	Breyer et al., 1984; Brown et al., 1969
Race of patient	Nagachinta et al., 1987
Receiving non-cardiac operative procedures as well as a cardiovascular operation during same hospital admission.	Simchen et al., 1981
Socio-economic status of patient	Nagachinta et al., 1987; Shuhaiber et al., 1987;
Type of suture material used	Brown et al., 1969
Type of valve operated on	Stahle et al., 1997
Use of drains post-operatively	Culliford et al., 1976; Davidson et al., 1971; Simchen et al., 1981
Year of surgery	Stahle et al., 1997

A Final Note on Preoperative Factors

All post-operative factors could be related to host factors and operative factors. A patient with more comorbid diseases is more likely to have complications than a

relatively healthy patient is. A standard, well-performed operation is more likely to have fewer complications than a complex one. Complications can be prevented by good preoperative preparation, proper anaesthesia and surgical technique, careful myocardial preservation during surgery and excellent post-operative care (Harlan et al, 1995). All post-operative complications together act as a measure of the success of the operation and affect the post-operative health of the patient.

APPENDIX D: Summary of results from studies of risk factors for sternal wound infection

“YES” indicates that the factor was found to significantly affect risk of sternal SWI, “NO” indicates that it was not, “—” indicates that either the factor was not studied or the results were not reported in the journal article. For studies in which both univariate and multivariate analysis were done, only the multivariate results are presented. Only significant risk factors for increased morbidity after surgery are reported for Higgins et al. (1992). Risk factors are listed in an order similar to the text.

Research Group	Age	Blood Transfusion	Cigarette Smoking
Breyer et al. (1983)	YES	--	--
Brown et al. (1969)	NO	--	--
Casey et al. (1982)	--	--	--
Classen et al. (1992)	--	--	--
Davidson et al. (1971)	YES	--	--
Farrington et al. (1985)	NO	--	--
Grossi et al. (1989)	NO	--	--
Hasselgren et al. (1982)	--	--	--
Hazelrigg et al. (1989)	NO	--	--
Higgins et al. (1992)	YES	--	--
Johnson et al. (1982)	--	--	--
Klutymans et al. (1994)	YES	--	--
Koshal et al. (1985)	--	--	--
Loop et al. (1990)	--	YES	--
Miedzinski et al. (1987)	NO	--	--
Miholic et al. (1985)	NO	NO for CAB YES for valve	--
Nagachinta et al. (1987)	NO		YES
Ottino et al. (1987)	NO	YES	--
PMSG (1996)	NO for ACB YES for other procedures	--	
Shuhaiber et al. (1987)	NO	--	NO
Simchen et al. (1981)	NO	--	--
Stahle et al. (1997)	NO	--	--
Sutherland et al. (1977)		--	
Ulincy et al. (1990)	YES	NO	NO

Research Group	Diabetes	Duration of CPB	Duration of Surgery	Duration of ICU Stay
Breyer et al. (1983)	--	--	NO	--
Brown et al. (1969)	--	--	--	--
Casey et al. (1982)	YES	--	--	--
Classen et al. (1992)	--	--	--	--
Davidson et al. (1971)	--	--	YES	--
Farrington et al. (1985)	YES	--	--	--
Grossi et al. (1991)	YES	NO	--	--
Hasselgren et al. (1982)	--	--	--	--
Hazelrigg et al. (1989)	YES	--	--	--
Higgins et al. (1992)	YES	--	--	--
Johnson et al. (1982)	YES	--	--	--
Klutymans et al. (1994)	YES	--	--	--
Koshal et al. (1985)	--	--	--	--
Loop et al. (1990)	YES	--	YES	--
Miedzinski et al. (1987)	--	--	NO	--
Miholic et al. (1985)	NO	NO for CAB YES for valve surgeries	NO	NO
Nagachinta et al. (1987)	YES		YES	--
Ottino et al. (1987)	--	NO	NO	NO
Parisian Mediastinitis Study Group (PMSG, 1996)	NO for CAB YES for other procedures	--	NO for CAB YES for other procedures	--
Shuhaiber et al. (1987)	YES	--	YES	--
Simchen et al. (1981)	--	--	--	--
Stahle et al. (1997)	YES for CAB NO for valve	--	--	--
Sutherland et al. (1971)		--	NO	--
Uliny et al. (1990)	NO	NO	--	--

Research Group	Excessive Bleeding	Immune Status	Length of Preoperative Stay	Low Cardiac Output
Breyer et al. (1983)	--	--	--	--
Brown et al. (1969)	--	--	--	NO
Casey et al. (1982)	--	NO	--	--
Classen et al. (1992)	--	--	--	--
Davidson et al. (1971)	--	--	--	--
Farrington et al. (1985)	--	--	YES	--
Grossi et al. (1991)	--	--	--	--
Hasselgren et al. (1982)	--	--	YES	--
Hazelrigg et al. (1989)	--	--	--	--
Higgins et al. (1992)	--	--	--	NO
Johnson et al. (1982)	--	--	--	--
Klutymans et al. (1994)	--	YES	--	--
Koshal et al. (1985)	--	--	--	--
Loop et al. (1990)	--	--	--	NO
Miedzinski et al (1987)	--	--	--	--
Miholic et al. (1985)	--	--	--	--
Nagachinta et al (1987)	--	NO	YES	--
Ottino et al. (1987)	NO	--	YES	--
PMSG (1996)	--	--	--	--
Shuhaiber et al. (1987)	--	--	NO	--
Simchen et al. (1981)	--	--	--	--
Stahle et al (1997)	--	--	NO	--
Sutherland et al. (1977)	NO	--	--	--
Uliny et al. (1990)	YES	NO	NO	--

Research Group	Malnutrition	Mechanical Ventilation	Obesity
Breyer et al. (1983)	--	YES	YES
Brown et al. (1969)	--	NO	--
Casey et al. (1982)	YES	--	NO
Classen et al. (1992)	--	--	--
Davidson et al. (1971)	--	--	--
Farrington et al. (1985)	--	--	NO
Grossi et al. (1991)	--	--	--
Hasselgren et al. (1982)	--	--	--
Hazelrigg et al. (1989)	--	--	YES
Higgins et al. (1992)	--	--	YES
			Results opposite to other studies
Johnson et al. (1982)	--	--	--
Klutymans et al. (1994)	--	--	NO
Koshal et al. (1985)	--	--	NO
Loop et al. (1990)	--	--	YES
Miedzinski et al. (1987)	--	--	--
Miholic et al. (1985)	--	--	--
Nagachinta et al. (1987)	--	--	YES
Ottino et al. (1987)	NO	NO	--
Parisian Mediastinitis Study Group (PMSG) (1996)	--	--	YES
Shuhaiber et al. (1987)	NO	NO	YES
Simchen et al. (1981)	--	--	--
Stahle et al. (1997)	--	--	--
Sutherland et al. (1977)	--	--	--
Ulincy et al. (1990)	NO	--	YES

Research Group	Previous cardiac surgery	Reoperation for Bleeding	Sex
Breyer et al. (1983)	NO	NO	YES
Brown et al. (1969)		--	--
Casey et al. (1982)		--	--
Classen et al. (1992)		--	--
Davidson et al. (1971)		--	--
Farrington et al. (1985)	--	YES	NO
Grossi et al. (1991)		--	NO
Hasselgren et al. (1982)		NO	--
Hazelrigg et al. (1989)		YES	--
Higgins et al. (1992)		--	--
Johnson et al. (1982)	--	--	--
Klutymans et al. (1994)	--	--	--
Koshal et al. (1985)	--	--	--
Loop et al. (1990)	NO	NO	--
Miedzinski et al. (1987)	--	--	--
Miholic et al. (1985)	NO for CAB YES for valve procedures	YES for CAB NO for valve surgeries	NO
Nagachinta et al. (1987)	YES NO	--	NO
Ottino et al. (1987)		YES	NO
Parisian Mediastinitis Study Group (PMSG) (1996)		YES	--
Shuhaiber et al. (1987)	--	--	--
Simchen et al. (1981)	--	--	NO
Stahle et al. (1997)	--	NO for CAB YES for valve	YES for CAB No for valve
Sutherland et al. (1977)	--	NO	--
Uliny et al. (1990)	YES	NO	--

Research Group	Use of an IABP	Use of IMA	Timing of Operation
Breyer et al. (1983)	--	--	--
Brown et al. (1969)	--	--	--
Casey et al. (1982)	--	--	--
Classen et al. (1992)	--	--	--
Davidson et al. (1971)	--	--	YES
Farrington et al. (1985)	--	--	--
Grossi et al. (1991)	NO	YES	--
Hasselgren et al. (1982)	--	--	--
Hazelrigg et al. (1989)	YES	YES	--
Higgins et al. (1992)	--	--	YES
Johnson et al. (1982)	--	--	--
Klutymans et al. (1994)	--	--	--
Koshal et al. (1985)	--	--	--
Loop et al. (1990)	--	YES in diabetics only	--
Miedzinski et al (1987)	--	--	--
Miholic et al. (1985)	NO	--	NO
Nagachinta et al (1987)	--	--	--
Ottino et al. (1987)	--	--	NO
Parisian Mediastinitis Study Group (PMSG) (1996)	--	--	--
Shuhaiber et al. (1987)	--	--	--
Simchen et al. (1981)	--	--	--
Stahle et al (1997)	--	YES	--
Sutherland et al. (1977)	--	--	NO
Ulincy et al. (1990)	--	YES	--

**APPENDIX E: Data collection form and code book from the Cardiovascular
Service of the Toronto Hospital**

Cardiovascular Data Collection Form

THE TORONTO HOSPITAL - DIVISION OF CARDIOVASCULAR SURGERY

ADMISSION TO HOSPITAL: ____/____/____
 DATE OF OPERATION: ____/____/____
 DATE OF DISCHARGE: ____/____/____
 DAYS IN ICU: ____
 MINUTES ON VENT: ____
 MINUTES IN ICU: ____
 SURGEON: _____ 1ST ASSIST: _____ A
 B

Addressograph

FAMILY DR.: _____

Date Accepted for Surgery: ____/____/____

CARDIOLOGIST: _____

Triage Case Y N

Same Day Admit Y

GENERAL PATIENT DATA

TIMING:

- () 1 = Elective
 () 2 = Same Hospitalization
 () 3 = Urgent <72hrs from event
 () 4 = Emergent <12hrs from event

ANGINA PECTORIS:

- () 0 = No
 () 1 = Stable
 () 2 = Crescendo
 () 3 = A.C.I.

C.A.D. RISKS:

YES NO

- Diabetes () ()
 Hypertension () ()
 Hyperlipid () ()
 Family History () ()

NON-ELECTIVE SURGERY FROM:

- () 1 = Floor
 () 2 = CCU
 () 3 = Cath Lab
 () 5 = Other:
 (Pack/d*Yrs)

M.I. < 30 DAYS:

- () 0 = No () 0 = Never smoked
 () 1 = Non-Q Wave
 () 2 = Transmural

SMOKING:.

- () 1 = Stopped smoking
 () 2 = Still smoking
 Pack Years: ____

PREVIOUS HEART SURGERY:

Date: ____/____/____

Place: _____

of Previous Ops: ____

DATE OF M.I. ____/____/____

N.Y.H.A. C.C.S.:

- () I 1
 () II 2
 () III 3
 () IV 4 A/B/C

ASSOC. DISEASES:

YES NO

- C.O.P.D. () ()
 Stroke/ TIA () ()
 P.V.D () ()
 Renal failure () ()

PREVIOUS INTERVENTION:

- () 0 = None
 () 1 = Angioplasty Date: ____/____/____
 () 2 = Valvuloplasty Date: ____/____/____
 () Thrombolysis Date: ____/____/____

LV. EJECTION FRACTION:

- () 1 = $\geq 60\%$
 () 2 = 40-59%
 () 3 = 20-39%
 () 4 = < 20%

ELECTROCARDIOGRAM:

- () 0 = Normal Sinus Rhythm
 () 1 = A.Fib./Flutter
 () 2 = CHB / Pacer

HEART CATHETERIZATION:

- () TTH () Sunnybrook
 () Scarborough () St. Michael's
 () Centennery () Mount Sinai
 () Other _____

STRESS TEST:

- () 0 = Not done
 () 1 Negative
 () 2 = Positive

OTHER SYMPTOMS:

YES NO

- Heart Failure () ()
 Shock () ()
 Syncope () ()

Date: ____/____/____

ACB PATIENT DATA

CORONARY LESIONS > 50%

() LAD () INT () RCA
 () DIA1 () OM1 () PIV
 () DIA2 () OM2 () PL
 () FER () CX () AM

() Left Main

LIMA: () YES: _____ () NO

RIMA: () YES: _____ () NO

ARTERIES GRAFTED:

() LAD () INT () RCA
 () DIA1 () OM1 () PIV
 () DIA2 () OM2 () PL
 () FER () CX () AM

Endarterectomy: () YES: _____ () NO

Coronary Vein Patch Angioplasty:
 () YES: _____ () NO

Other conduit _____

GENERAL OPERATIVE DATA

PUMP CASE () YES () NO () STANDBY

MYOCARDIAL PROTECTION:

HYPOTHERMIA:

MINIMALLY INVASIVE SURGERY () YES () NO

Primary form of myocardial protection:

() 0 = Normothermia

() 1 = Mild (30-35°C)

ORTIME: _____ min.

() 0 = None, coronary perfusion

() 2 = Moderate (21-30°C)

() 1 = Warm blood cardioplegia (35-38°C)

() 3 = Profound (<20°C)

BYPASS TIME: _____ min.

() 2 = Tepid blood cardioplegia (2-35°C)

() 3 = Cold blood cardioplegia (<20°C)

X-CLAMP TIME: _____ min.

CIR. ARREST TIME: _____ min.

TECHNIQUE Method of Cardioplegia

OFF C.P.B.:

B.S.A.: _____ m³

() 1 = Intermittent

() 0 = Well

() 2 = Continuous

() 1 = Inotropes / Balloon

() 3 = Both

() 2 = OR Death

HEIGHT: _____ cm

WEIGHT: _____ kg

DIRECTION of Cardioplegia:

() 1 = Antegrade

() 2 = Retrograde

() 3 = Both

COMPLICATIONS

IABP:

() 0 = No
 () 1 = Preop CCU
 () 2 = Preop OR
 () 3 = OR
 () 4 = Postop ICU

REOPENING:

() 0 = No
 () 1 = Bleeding
 () 2 = Tamponade
 () 3 = Shock/arrest
 () 4 = Infection
 () 5 = Dehiscence
 () 6 = Redo Surgery
 () 7 = Other: _____

POSTOP E.C.G.:

() 0 = No change
 () 1 = New ST/T waves
 () 2 = New Q waves
 () 3 = Complete LBBB
 () 4 = Loss of R waves

Highest CK-MB: _____

Corresponding CK: _____

Perioperative MI: () YES () NO

Inotropes: () YES () NO

LOS: () YES () NO

Renal Failure: () YES () NO

Pacemaker: () YES () NO

Vent. Dysrhyth.: () YES () NO

Pulm. Complic's: () YES () NO

D.V.T.: () YES () NO

STROKE:

() 0 = No
 () 1 = Intra-operative
 () 2 = Postoperative

INFECTION:

Leg () 0 = No
 () 1 = Superficial
 () 2 = Deep

Sternum () 0 = No
 () 1 = Superficial
 () 2 = Deep

Sepsis () YES () NO

HOSPITAL SURVIVOR:
 () YES () NO

D/C TO: _____
 PROCEDURE CODE:
 () 1 () 2 () 3

VALVE PATIENT DATA

VALVULAR LESIONS

() AS () AI _____
 () MS () MI _____
 () TS () TI _____

INFECTIVE ENDOCARDITIS:

() 0 = No
 () 1 = Remote
 () 2 = Active
 () 3 = Active abscess

AORTIC VALVE SURGERY:

() 0 = None
 () 1 = Repair
 () 2 = Replacement
 () 3 = Other

AV PROSTHESIS:

TYPE: _____
 SIZE: _____ (mm)
 MODEL: _____

X PLANTED VALVE PATHOLOGY:

() 1 = Thrombosed
 () 2 = Calcified
 () 3 = Cusp Tear
 () 4 = Infected
 () 5 = Mechanical Dysfunction
 () 6 = Other _____

MITRAL VALVE SURGERY:

() 0 = None
 () 1 = Repair
 () 2 = Replacement
 () 3 = Other

MV PROSTHESIS

TYPE _____
 SIZE: _____ (mm)
 MODEL: _____

MV ANN. RECONSTRUCTION:

() 0 = No
 () 1 = Yes, autologous
 () 2 = Yes, bovine

X PLANTED VALVE PATHOLOGY:

() 1 = Thrombosed
 () 2 = Calcified
 () 3 = Cusp Tear
 () 4 = Infected
 () 5 = Mechanical Dysfunction
 () 6 = Other _____

REASON FOR URGENT SURGERY:

() 0 = Not Urgent
 () 1 = Acute Endocarditis
 () 2 = Acute pump failure
 () 3 = Acute prosthetic failure
 () 4 = Failed balloon valvuloplasty
 () 5 = Life threatening arrhythmia
 () 6 = Ischemic mitral regurgitation

AV PATHOLOGY: Check all that apply

() 1 = Rheumatic
 () 2 = Tricuspid, calcific
 () 3 = Bicuspid
 () 4 = Congenital, other
 () 5 = Aortoannular ectasia
 () 6 = Prosthetic dysfunction
 () 7 = Dissection
 () 8 = Other:

AV ANNULUS ENLARGED:

() 0 = No
 () 1 = Yes, annular
 () 2 = Yes, sinuses
 () 3 = Yes, both

X PLANTED VALVES:

TYPE: _____
 SIZE: _____ (mm)
 MODEL: _____

MV PATHOLOGY: Check all that apply

() 1 = Rheumatic
 () 2 = Ischemic
 () 3 = Myxomatous
 () 4 = Prosthetic dysfunction
 () 5 = Annular dilatation
 () 6 = Other: _____

CHORDAE PRESERVED:

() 0 = No
 () 1 = Yes, posterior only
 () 2 = Yes, posterior and anterior

Goretex sutures: () YES () NO

X PLANTED VALVES:

TYPE: _____
 SIZE: _____ (mm)
 MODEL: _____

TRICUSPID VALVE SURGERY:

- ☐ 0 = None
☐ 1 = Repair
☐ 2 = Replacement
☐ 3 = Other

TV PROSTHESIS

TYPE _____
 SIZE _____ (mm)
 MODEL _____

X PLANTED VALVE PATHOLOGY

- ☐ 1 = Thrombosed
☐ 2 = Calcified
☐ 3 = Cusp Tear
☐ 4 = Infected
☐ 5 = Mechanical Dysfunction
☐ 6 = Other

TV PATHOLOGY: Check all that apply

- ☐ 1 = Rheumatic
☐ 2 = Secondary
☐ 3 = Congenital
☐ 4 = Prosthetic dysfunction
☐ 5 = Other: _____

X PLANTED VALVES:

TYPE: _____
 SIZE: _____ (mm)
 MODEL: _____

VALVE CATHETERIZATION / ECHO DATA

C.L: _____ (L/min/M ²)	MV GRADIENT (mean)	
MPAP: _____ (mmHg)	rest: _____	ASSOCIATED PROCEDURES: (non-cardiac)
AV GRAD. (peak): _____ (mmHg)	exercise: _____	☐ 0 = No
LVEDP: _____ (mmHg)	AV AREA: _____ (cm ²)	☐ 1 = Abdominal Aortic Surgery
PVR: _____ (wood units)	MV AREA: _____ (cm ²)	☐ 2 = Carotid Endarterectomy
		☐ 3 = Other: _____

OTHER CARDIAC OPERATIONS**LEFT VENTRICULAR ANEURYSM:**

- ☐ 0 = No
☐ 1 = Anterior
☐ 2 = Posterior
☐ 3 = False Aneurysm

L.V.A. Patch: ☐ YES ☐ NO

Location: _____

Material: _____

CONGENITAL HEART DISEASE:

- ☐ 0 = No
☐ 1 = ASD
☐ 2 = VSD
☐ 3 = Both
☐ 4 = Other: (NOTES)

AORTA REPLACED:

- ☐ 0 = No
☐ 1 = Yes, separate
☐ 2 = Yes, composite

OTHER PROCEDURES:

- ☐ 0 = No
☐ 1 = Ischemic VSD - Patch
☐ 2 = Myxoma
☐ 3 = Myectomy
☐ 4 = Mapping / Arrhythmia
☐ 5 = Heart Transplant
☐ 6 = Implantable defibrillator
☐ 7 = Insertion of assist type device
☐ 8 = Other _____

NOTES

NOTE: FILL OUT FORMS ON ALL PUMP AND NON-PUMP CASES

The Toronto Hospital
DIVISION OF CARDIOVASCULAR SURGERY
CODE BOOK TTH93
Printed on: December 15, 1992

CARDEX:

NAME	Last name of patient.
PTID	Patient identification. First three letters of last name, first letter of first name, and date of birth (LLLFFMMDDYY).
CHART	Hospital chart number.
SEX	1 - male 2 - female
AGE	Age on date of surgery (yrs).

DATES & DOCTORS:

ADDATE	Admission to hospital (MM/DD/YY).
DATEOR	Date of operation (MM/DD/YY).
DISDATE	Date of discharge from hospital (MM/DD/YY).
ICU	Days in ICU (excluding OR day).
VENT	Days on ventilator (excluding OR day).
SURG	Surgeons initials.
ASSIST	First assistant (senior resident or other).
CDOC	Cardiologist following patient.
FDOC	Patient's family doctor.

GENERAL PATIENT DATA

TIMING Timing of surgery. Approximate length of time between the event resulting in hospitalization and surgery.

- 1 - Elective.
- 2 - Same hospitalization: cannot go home because of urgency or anatomy (semi-urgent).
- 3 - Urgent: < 72 hrs from event.
- 4 - Emergent: < 12 hrs from event.

FROM Where Non-Elective Surgery came from.

- 1 - Floor
- 2 - CCU
- 3 - Cath Lab
- 4 - Emergency
- 5 - Other

PREVIOUS HEART SURGERY:

ACBREDO Previous ACB (YES/NO).

AVREDO Previous aortic valve surgery.

- 1 - Repair
- 2 - Replacement

MVREDO Previous mitral valve surgery.

- 1 - Repair
- 2 - Replacement

TVREDO Previous tricuspid valve surgery.

- 1 - Repair
- 2 - Replacement

OTHREDO Any other previous cardiac surgery (YES/NO).

PREVIOUS (NON-SURGICAL) INTERVENTION:

PRECARD Previous non-surgical intervention.

- 1 - Angioplasty.
- 2 - Valvuloplasty.

PIDATE Date of previous intervention (MM/DD/YY).

PITHROMB Previous thrombolysis.

PITDATE Date of previous thrombolysis (MM/DD/YY).

HEART CATHETERIZATION:

CATH

Where patient was catheterized.

- 1 - Toronto, General Division.
- 2 - Toronto, Western Division.
- 3 - Sunnybrook Health Science Centre.
- 4 - St. Michael's Hospital
- 5 - Scarborough Centenary Hospital
- 6 - Other
- 7 - Mount Sinai Hospital

CATHDATE

Date of catheterization (MM/DD/YY).

ANGINA

Most severe angina pectoris one month prior to surgery.

- 0 - None
- 1 - Stable: predictable exertional angina
- 2 - Crescendo: increasing frequency or severity of symptoms
- 3 - Acute Coronary Insufficiency: prolonged episodes of unprovoked pain (>15 mins) despite medical therapy

PREOPMI Most recent myocardial infarction within 30 days of OR date.

- 0 - None
- 1 - Non-Q wave infarction
- 2 - Transmural infarction

MIDATE

Date of most recent MI (MM/DD/YY).

NYHA

NYHA classification (cardiac disability).

- 1 - No restrictions
- 2 - Symptoms provoked by exertion beyond daily activity
- 3 - Symptoms provoked by normal daily activity
- 4 - Unprovoked symptoms

LVGRADE LV grade based on LV ejection fraction.

- 1 - >60%
- 2 - 40-60%
- 3 - 20-40%
- 4 - <20%

STRESS Stress test.

- 0 - Not done
- 1 - Negative
- 2 - Positive

C.A.D. RISKS

DIABETES Diabetes Mellitus (insulin or non-insulin dependent) (YES/NO).

HYPER Medically treated hypertension (YES/NO).

CHLSTRL Diet or medically treated hyperlipidemia (YES/NO).

FHX Family history of heart disease including stroke, PVD, MI, angina, or heart surgery (YES/NO).

SMOKE Smoking History.
 0 - Never smoked
 1 - Stopped smoking
 2 - Still smoking

PACKS Number of packs per day multiplied by the number of years smoked.

ASSOCIATED DISEASES

COPD Chronic obstructive pulmonary disease (YES/NO).

THROMB Previous stroke or T.I.A. (YES/NO).

PVD Peripheral vascular disease (YES/NO).

RF Significant renal failure (YES/NO).

RECG Preoperative electrocardiogram (Rhythm).
 0 - Normal Sinus Rhythm
 1 - Atrial Fibrillation or Flutter
 2 - CHB/Pacemaker

OTHER SYMPTOMS

CHF Congestive Heart Failure (YES/No).

SHOCK Shock (YES/NO).

SYNCOPE Fainting spells (YES/NO).

AVDIS Aortic valve disease.
 0- None
 1 - Stenosis
 2 - Regurgitant (greater than mild: > 2+)
 3 - Mixed

MVDIS Mitral valve disease.
 (same as for AVDIS)

TVDIS Tricuspid valve disease. (same as for AVDIS)

ENDOCARD Infective endocarditis.
 0 - None
 1 - Remote
 2 - Active
 3 - Active abscess

URGENT Reason for urgent surgery.
 0 - not urgent
 1 - acute endocarditis
 2 - acute pump failure
 3 - acute prosthetic failure
 4 - failed balloon valvuloplasty
 5 - life threatening arrhythmia
 6 - ischemic mitral regurgitation
 7 - other

AORTIC VALVE SURGERY

AVSURG Aortic valve surgery.
 0 - None
 1 - Repair
 2 - Replacement

AVSIZE Size of prosthesis. (mm)

AVPATH Aortic valve pathology.
 1 - Rheumatic
 2 - Tricuspid-alcific
 3 - Bicuspid
 4 - Congenital, other
 5 - Aorto-annular ectasia
 6 - Prosthetic dysfunction
 7 - Dissection
 8 - Other

ANNULEN Aortic annular enlargement.

0 - No.

1 - Yes, annular

2 - Yes, sinuses

3 - Yes, both

AVPROS Type of prosthesis.

TISSUE

MECHANICAL

DISCONTINUED

REPAIR

HT: Hancock II
Porcine

SO: Sorin

SJ: St. Jude

AS: Angel-

Shiley

RP: Puig -

Masuga

CP: Carpentier

Mechanical

BS: Biork-

Shiley

ring (D/C)

-Edwards

HM: Hall-

CE: Carpentier

-Edwards

RD: Duran ring

Pericardial

Medtronic

Porcine

RC: Carpentier

TO: Toronto

DH: Duromedic

ring

Stentless

Hemax

DV: Devega

Porcine

ED: Edwards

repair

(*SPV™)

HOMO/AUTO

ED: Edwards

R: repair w/o

GRAFT

Duratronic

ring other

HO: Homograft

EP: Edwards

than DV.

AU: Autograft

Pericardial

PA: Pulmonary

HA: Hancock

Autograft

Pericardial

HK: Hall-Kaster

IO: Ionescu-Shiley

LK: Lillehei-Kaster

MF: Mitroflow

MI: Medtronic Intact

Porcine

MO: Hancock

Modified

Orifice

OS: Omni Science

SE: Starr-

Edwards

SP: St. Jude

Porcine

TD: Stentless

Porcine

(Medtronic)

MITRAL VALVE SURGERY

MVSURG	Mitral valve surgery. 0 - None 1 - Repair 2 - Replacement
MVPROS	Type of prosthesis. (see abbreviations above)
MVSIZE	Size of prosthesis (mm).
MVANN	Mitral valve annulus reconstruction. 0 - No 1 - Yes, autologous 2 - Yes, bovine
MVPATH	Mitral valve pathology. 1 - Rheumatic 2 - Ischemic 3 - Myxomatous 4 - Prosthetic dysfunction 5 - Annular dilatation 6 - Other
CHORD	Preservation of chordae tendineae 0 - No 1 - Yes, posterior only 2 - Yes, anterior and posterior
GORTX	Gortex sutures (YES/NO).

TRICUSPID VALVE SURGERY

TVSURG	Tricuspid valve surgery. 0 - None 1 - Repair 2 - Replacement
TVPROS	Type of prosthesis. (see abbreviations above)
TVSIZE	Size of prosthesis. (mm)
TVPATH	Tricuspid valve pathology 1 - Rheumatic 2 - Secondary 3 - Congenital, other 4 - Prosthetic dysfunction 5 - Other

VALVE CATHETERIZATION/ECHO DATA

CI	Cardiac index (l/min/m ²).
MPAP	Mean pulmonary artery pressure (mmHg).
SYSAVG	Systolic aortic valve gradient (mmHg).
LVEDP	LV end diastolic pressure (if unavailable, use mean pulmonary artery wedge pressure)
MVGRADR	Mean mitral valve gradient at rest (mmHg).
MVGRADX	Mean mitral valve gradient with exercise (mmHg).
AVAREA	Aortic valve calculated area (cm ²).
MVAREA	Mitral valve calculated area (cm ²).

XPLANTED VALVESAORTIC

AVXPLTYPE	Type of prosthesis. (see abbreviations in AVPROS)
AVXPLSIZE	Size of prosthesis. (mm)
AVXPLPATH	Xplanted valve pathology 1 - Thrombosed 2 - Calcified 3 - Cusp Tear 4 - Infected 5 - Mechanical dysfunction 6 - Other

AVXPLDATE Date of implant (MN/DD/YY)

MITRAL

MVXPLTYPE	Type of prosthesis. (see abbreviations in AVPROS)
MVXPLSIZE	Size of prosthesis (mm).
MVXPLPATH	Xplanted valve pathology. (see abbreviations above)
MVXPLDATE	Date of implant (MM/DD/YY).

TRICUSPID

TVXPLTYPE Type of prosthesis.
 (see abbreviations in AVPROS)

TVXPLSIZE Size of prosthesis (mm).

TVXPLPATH Xplanted valve pathology.
 (see abbreviations above)

TVXPLDATE Date of implant (MN/DD/YY).

OTHER NON-CARDIAC PROCEDURES:

ASSOCOP Associated operations.

- 1 - Abdominal aortic surgeries (ABF/ABI)
- 2 - Carotid endarterectomy
- 3 - Other

OTHER CARDIAC OPERATIONS:

LVA Left ventricular aneurysmectomy.
 1 - Anterior
 2 - Posterior
 3 - False aneurysm

SEPT L.V.A. patch (YES/NO).

CHD Repair of congenital defect.
 1 - ASD
 2 - VSD
 3 - ASD and VSD
 4 - Other procedures - add NOTES

AAS Ascending aorta replaced.
 0 - No
 1 - Yes, conduit separate from valve
 2 - Yes, composite

MISC Other operations.
 1 - Ischemic VSD (patch)
 2 - Myxoma
 3 - Myectomy
 4 - Mapping / Arrhythmia
 5 - Heart transplant
 6 - Implantable defibrillator
 7 - Insertion of assist device
 8 - Other

ACB PATIENT DATA

DISLAD Stenosis > 50% in the Left Anterior Descending arterial system
(YES/NO)
(LAD, DIA-1, DIA-2, PER)

DISCX Stenosis > 50% in the Circumflex arterial system (YES/NO).
(CX, INT, OM-1, OM-2)

DISRCA Stenosis > 50% in the Right Coronary Arterial system (YES/NO).
(RCA, PIV, PL, AM)

LMAIN Stenosis > 50% in the Left Main Artery (YES/NO)

ARTERIES BYPASSED:

GFTLAD Number of grafts to the Left Anterior Descending region.

GFTCX Number of grafts to the Circumflex region.

GFTRCA Number of grafts to the Right Coronary Artery region.

LIMA LIMA graft used.
 1 - LAD
 2 - CX
 3 - RCA

RIMA RIMA graft used.
 1 - LAD
 2 - CX
 3 - RCA

ENDART Endarterectomy.
 1 - LAD
 2 - CX
 3 - RCA

CVPA Coronary vein patch angioplasty.
 1 - LAD
 2 - CX
 3 - RCA

OTHGFT Other conduit used.
 1 - Gastro-epiploic artery
 2 - Artificial
 3 - Cryo-preserved

GENERAL OPERATIVE DATA

PUMPCASE	Patient went on pump (YES/NO).
ORTIME	Surgeon time in OR (minutes).
PUMP	Cardiopulmonary bypass time (minutes).
CLAMP	Cross-clamp time (minutes).
CIR ARR	Circulatory arrest (minutes).
BSA	Body Surface Area (m ²).
MYOPRO	Primary form of myocardial protection. 0 - None, coronary perfusion 1 - Warm blood cardioplegia (35-38°C) 2 - Tepid blood cardioplegia (20-35°C) 3 - Cold blood cardioplegia (<20°C)
TECHNIQUE	Method of cardioplegia. 1 - Intermittent 2 - Continuous
DIRECTION	Direction of cardioplegia. 1 - Antegrade 2 - Retrograde
HYPOTHER	Lowest level of systemic hypothermia. 0 - Normothermia 1 - Mild (30-35°C) 2 - Moderate (20-29°C) 3 - Profound (<20°C)
OFFPUMP	Patient came off pump. 0 - Well 1 - With inotropes/balloon 2 - Died

COMPLICATIONS

IABP	Insertion of intra-aortic balloon pump. 0 - None 1 - Preop in CCU 2 - Preop in OR 3 - Intra-op in OR 4 - Post-op in ICU
REOP	Reopening after surgery. 1 - Bleeding 2 - Tamponade 3 - Shock/arrest 4 - Infection 5 - Dehiscence 6 - Redo Surgery 7 - Other
IECG	Postoperative electrocardiogram - ischemic changes while in hospital. 0 - No changes 1 - New ST and T wave changes 2 - New Q waves 3 - Complete left bundle branch block 4 - Loss of R waves
CKMB	Highest postop CKMB level (units).
CK	Highest corresponding CK level (units).
MI	Perioperative myocardial infarction (YES/NO).
INO	Use of dopamine (>3 mg/kg) or dobutamine in ICU for more than 30 minutes to maintain a blood pressure greater than 90 mmHg after adequate reload and after load reduction (YES/NO).
LOS	Low output syndrome (use of inotropes or mechanical devices for more than 30 minutes to maintain a blood pressure <u>greater than 90 mmRQ with a CI. (2.2 l/m/mz 1200)</u> (YES/NO). NOTE: This includes all patients with IABP inserted in OR or postop in ICU.
POSTRF	Renal failure requiring dialysis. (YES/NO)
PACE	Insertion of permanent pacemaker. (YES/NO)
OCVENDYS	Medically treated ventricular dysrhythmias. (YES/NO)
OCDVT	D.V.T. (YES/NO)
OCPULMC	Pulmonary complications. (YES/NO)

STROKE	Evidence of a persistent neurological deficit. 1 - Intraoperative (did not awaken from operation). 2 - postoperative.
INFSTERN	Sternal infection. 0 - None 1 - Superficial (based on the presence of purulent discharge, involving skin & subcutaneous tissue only) 2 - Deep (requiring surgical debridement)
INFLEG	Leg infection. 0 - None 1 - Superficial (based on the presence of purulent discharge, involving skin & fat - <1 cm deep) 2 - Deep (below the superficial fascia - >1 cm deep)
INFSEP	Sepsis - based on positive blood culture. (YES/NO)
SURVIVAL	Patient left hospital and survived thirty days post DATEOR. (YES/NO)
PROC	Surgery category: to be completed after review of surgical procedure. 1 - ACB: isolated bypass surgery (without VALVE or OTHER procedures). 2 - VALVE: any valve replacement or repair (with VALVE procedure as a primary procedure. 3 - OTHER: other cardiac surgery including CHD, LVA, MISC, and AAS (with VALVE procedure as a secondary procedure).
NOTES	Fifty character space for extra notes.

CONVENTIONS:

0 - Negative entry (NO)
1 - Positive entry (YES)

MM/DD/YY Date format.

MISSING DATA

For TEXT (character field): BLANK
For Numbers (numeric field): 9 or -9
For Dates (date field): (09/09/09) or midpoint if partially complete:
eg.: Jan. 1989 = {15/1/89}
1978 = (06/30/78)

If a category requires an entry other than the listed choices, use a number one greater than the last numbered category and inform the database coordinator.

**APPENDIX F: Data collection form from the Toronto Hospital Infection
Control and Prevention Unit**

Infection Control Data Form

SSI Surveillance Form

Service _____

Quarter _____ Year _____

Sex _____ Birthdate _____

Name: _____

Specimen #	Last Name	Date	First Name	Type	Organism(s) Isolated
_____	_____	dd/mm/yy	_____	_____	_____
_____	_____	dd/mm/yy	_____	_____	_____
_____	_____	dd/mm/yy	_____	_____	_____
_____	_____	dd/mm/yy	_____	_____	_____
_____	_____	dd/mm/yy	_____	_____	_____

Admission: _____ Discharge: _____

dd mm yy dd mm yy

Onset: _____ Current Admission: Yes/ No

dd mm yy Previous Admission: Yes/ No

SSI Site: _____ SSI Category: Superficial _____ Deep _____ Organ/Space _____ 2^o Sepsis _____

Surgery: _____ Classification 1 Clean _____ 2 Clean Contaminated _____

Surgeon _____	Surgical Directorate _____	Business Unit _____
Surgery _____	Medical Directorate _____	Business Unit _____
dd mm yy	Cardiovascular _____	
	Neurosciences _____	
	Transplant _____	
	Oncology _____	

Service _____

Prophylaxis: Pre-Op Yes _____	Intra-Op Yes _____	Post-Op _____
No _____	No _____	N/A _____
		<24H _____
		24-48 H _____
		>48 H _____

Risk Factors:

- ☐ Diabetes
- ☐ Transplant (Solid)
- ☐ Transplant (Bone Marrow)
- ☐ Renal Failure
- ☐ ICU Stay >48 Hours
- ☐ Remote Site Infection
- ☐ HIV Infection
- ☐ Implant/Prosthesis/Graft/Appliance
- ☐ Neutropenia
- ☐ Malnutrition
- ☐ Alcoholism
- ☐ Cancer/Radiotherapy/Chemotherapy
- ☐ Other _____

Infection Criteria:

- ☐ Purulent Drainage
- ☐ Positive Culture
- ☐ Pain/Tenderness
- ☐ Inflammation/Swelling/Heat
- ☐ Incision Opened by Surgeon
- ☐ Spontaneous Dehiscence of Incision
- ☐ Fever >38°C
- ☐ Physician Diagnosis
- ☐ Radiology Results
- ☐ Antibiotic Regimen
- ☐ Increasing WBC

Notes:

APPENDIX G: Data collection forms from the chart review

Data Collection Form For Chart Review

CHART NUMBER _____

ANTITYPE _____

PUMP _____ minutes

ANTITIME

- 1 Early > 2 hrs before incision
- 2 Preoperative 0-2 hrs before incision
- 3 Perioperative 0-3 hrs after incision
- 4 Postoperative > 3 hrs after incision

 SEX 1 Male
 2 Female

SURVIVAL 0 No 1 Yes

 TIMING 1 Elective
 2 Same
 hospitalization
 3 Urgent < 72 hrs from event
 4 Emergent < 12 hrs from event

AGE _____ (yrs)

ASAScore _____

DIABETES 0 No 1 Yes

HT _____ cm

 INFLEG 0 None
 1 Superficial
 2 Deep

 INFSTERN 0 None
 1 Superficial
 2 Deep

NUMDIS _____

 REOP 0 None
 1 Bleeding
 2 Tamponade
 3 Shock/ arrest
 4 Infection
 5 Dehiscence
 6 Redo Surgery
 7 Other

WT _____ kg

ACBREDO 0 No 1 Yes

 AVREDO 0 No
 1 Repair
 2 Replacement
 3 Repair of an in-situ prosthetic valve

MVREDO 0 1 2 3

TVREDO 0 1 2 3

OTHREDO 0 No 1 Yes

ORTIME _____ minutes

 PACKCELL _____ units (total)
 _____ units (during OR)

 PROC 1 ACB
 2 VALVE
 3 Other

 DATEOR _____
 month/ day/ year

VARIABLES THAT NEED TO BE VERIFIED

CHART	DATE	OR	VARIABLE				
6180131	08/06/92		AVREDO	0	1	2	3
22276930	06/10/94		AVREDO	0	1	2	3
22317164	03/20/95		AVREDO	0	1	2	3
21284441	05/06/95		AVREDO	0	1	2	3
2350421	07/05/95		AVREDO	0	1	2	3
2295491	11/10/95		AVREDO	0	1	2	3
655842	10/17/95	IABP	0	1	2	3	4
833396	11/05/91	INFLEG	0	1	2		
833396	11/05/91	INFSEP	0		1		
833396	11/05/91	INFSTERN	0		1	2	
1030444	11/09/95	LIMA	0	1	2	3	
1286670	02/07/91	MVREDO	0	1	2	3	
1304034	02/26/91	POSTRF	0	1	2		
957135	09/10/91	POSTRF	0	1	2		
833396	11/05/91	POSTRF	0	1	2		
2095892	04/29/92	POSTRF	0	1	2		
2062392	10/06/92	POSTRF	0	1	2		
2154964	12/03/92	POSTRF	0	1	2		
2173435	12/09/94	POSTRF	0	1	2		
2073766	01/20/95	POSTRF	0	1	2		
504823	05/24/95	POSTRF	0	1	2		
833396	11/05/91	STROKE	0		1	2	
1286670	02/07/91	TVREDO	0	1	2	3	
6124409	05/26/92	OTHREDO	0		1		
09/10/91	957135	PACE	0	1			
11/05/91	833396	PACE	0	1			

CHART DATEOR VARIABLE OLD VALUE

1280264	12/18/90	PACKS	150	<u>150</u>
6025361	09/05/91	PACKS	185	<u>185</u>
975177	06/21/93	PACKS	156	<u>156</u>
1304702	09/12/94	PACKS	150	<u>150</u>
2031309	05/26/92	PUMP	380	<u>380</u>
224726	11/18/92	PUMP	372	<u>372</u>
774053	04/14/95	PUMP	379	<u>259</u>
2086164	05/24/95	PUMP	820	<u>82</u>
2047204	10/05/95	PUMP	870	<u>87</u>
1268368	06/25/90	ORTIME	750	<u>75</u>
466207	02/01/93	ORTIME	950	<u>195</u>
2295801	01/30/95	ORTIME	700	<u>?</u>
1123089	02/10/95	ORTIME	801	<u>?</u>
2086164	05/24/95	ORTIME	950	<u>?</u>
2005874	04/13/91	DAYSPOST	185	<u>OK</u>
910124	12/31/91	DAYSPOST	345	<u>10</u>
2081547	01/27/92	DAYSPOST	285	<u>11</u>
224413	11/30/92	DAYSPOST	185	<u>OK</u>
2296396	09/09/94	DAYSPOST	164	<u>OK</u>
6325459	07/08/91	PREODAY	371	<u>OK</u>
140249	10/23/91	PREOPDAY	286	<u>OK</u>
2157086	01/13/93	PREOPDAY	367	<u>1</u>
2269966	11/14/94	PACKCELL	48	<u>25</u>
561883	07/07/95	PACKCELL	61	<u>61*Includes this</u>
				and next operation on 07/08/95
561883	07/08/95	PACKCELL	61	<u> </u>
1108880	10/11/95	PACKCELL	64	<u>69</u>

APPENDIX H: Graphs

Rate of sternal infection over time, by year

Rate of sternal infection over time, by month

Rate of sternal infection associated with number of distal graphs (ACBNUM)

Rate of sternal infection associated with total number of diseased arterial systems

Rate of sternal infections associated with NYHA score

Rate of sternal infection associated with amount of cigarettes smoked

Rate of sternal infection associated with operating time **Rate of sternal infection associated with time on CPB**

APPENDIX I: Details from chart review

CHART REVIEW

AGE: Age on date of surgery (yrs)

The majority of disagreements were only by one year, which is why the intra class correlation coefficient is high for this variable. It seems that this variable should be redefined as age by end of year of surgery. In 59 cases, the patient's date of birth was after the surgery. For example, while age on date of surgery was 52, the patient had a birthday that year after the surgery date, so age was recorded as 53. Only 1 case was a true disagreement. Unfortunately, I was unable to return to the chart to confirm the age of the patient.

DIABETES: Diabetes mellitus (insulin or non-insulin dependent) (Yes/ No)

One case of diabetes noted in the chart was not recorded in the database. For another case of diabetes in the database, I found no evidence of diabetes in the chart. In the chart there were two sources of information on diabetes: the admission record (under previous illnesses) and the Cardiovascular service's coronary artery disease risk sheet. Two patients were recorded as having diabetes in only one of these sources and were not included in the database as having diabetes. I recorded them as having diabetes.

HT: Height of patient in cm.

* Frequency missing in database (Coded as 0 or . in database) = 72 (51.4%)

* All observations with a 0 or . for HT in the database have been dropped from this comparison.

The reliability of this variable is quite good. The coefficient is deceptive: the means of the heights in the database and chart review are 170.7 and 169.2 respectively. Most errors are simply differences in significant digits. There was only one observation with a difference greater than one cm for the two height measurements. For this individual, a height of 61 cm was recorded in the chart, which was most likely an error. The height in the database is more likely.

INFLEG: Leg wound infection

*Kappa coefficient calculated assuming INFLEG was a binary variable (YES / NO)

I found 18 cases of leg wound infection that were not in the database. However, my case definition may not have been specific enough. Culture results were generally not included in the chart. Therefore, I considered a leg wound infected if serosanguinous drainage was noted from the leg wound for at least 2 days. Similarly, I had found 3 potential cases of sternal wound infection that were not found in either database. Ms. Garcia examined these charts and concluded that they did not meet the definition of a sternal SWI.

ORTIME: Surgeon time in OR (minutes):

The accuracy of this variable is difficult to ascertain based on available information in the chart. A copy of the OR record was included in the chart only in earlier years. For other years, the Anaesthesiology record was the only source of OR time, but this is a

much less accurate source. For all of these years, the database OR time was abstracted directly from the OR record.

OTHREDO: Previous other cardiac surgery

One patient coded as OTHREDO = 0 in the database had had a previous carotid endarterectomy and an aorta bifemoral bypass. One patient that I coded as OTHREDO = 0 but was coded as 1 in the database had had a patent ductus. I may have classified these patients incorrectly.

PACKCELLS: Number of units of packed cells transfused

* Number of observations with PACKCELLS coded as . in database: 38 (27.1%)

* Number of observations with PACKCELLS coded as 0 in database: 73 (52.1%)

There are 31 observations coded as 0 for PACKCELLS who actually received some units of blood. For 5 observations, the number of PACKCELLS in the database and from the chart review differed. I counted the total number of units transfused including packed cells, red cells, platelets, albumin, etc. I assumed that if a transfusion record was missing from the chart, no blood was transfused.

PROC: Surgery category

I coded patients with VALVE and ACB as 2. I coded patients with ACB and an endarterectomy as 1. The only disagreement was with a patient who had had a Bentall procedure which I entered as 3, but it was coded as 2 in the database.

REOP: Reopening after surgery

Frequency of Responses:

Database	Chart Review
0: 130	0: 130
1: 6	0: 7
3: 1	3: —
5: 3	5: 2
7: —	7: 1

* Kappa coefficient was calculated by merging all types of reopenings (1 – 7) into one category to create a binary variable

I found one case of reopening not noted in the database. I did not find evidence of reopening for one case noted in the database. For one case, the reasons noted for reopening differed.

TIMING: Timing of surgery.

- 1 Elective
- 2 Same hospitalization: cannot go home because of urgency or anatomy (semi-urgent)
- 3 Urgent: < 72 hrs from event
- 4 Emergent: < 12 hrs from event

Frequency of responses:

Database	Chart Review
1: 71	1: 76
2: 43	2: 57
3: 21	3: 6
4: 5	4: 1

Disagreements for TIMING Variable :

<i>Database Code</i>	<i>Chart Review Code</i>	<i>Number</i>
2	1	3
2	3	2
3	1	3
3	2	11
4	2	3
4	3	1

When I abstracted data from the chart, I considered the time between date of admission and date of surgery.

SEX: 1- Male
2- Female

Unfortunately, I was not able to return to the chart to check if data was abstracted incorrectly.

WT: Weight of patient in KG

* Frequency missing in database (Coded as 0 or . in database) = 72 (51.4%)

* All observations with a 0 or * for WT in the database have been dropped from this comparison.

The reliability of this variable is quite good. The means of the weights in the database and chart review are 78.2 and 79.2 respectively. Most errors are simply differences in significant digits and rounding. Only 6 observations differed 1 kg or more for weight.

APPENDIX J: Recoded variables

Appendix J: Variables Created by Merging Database Codes

DISNUM Merge 0 and 1
 2 and 3

(Creates a binary variable)

IABP: Merge options 1, 2, 3, 4 which describe timing of use of IABP
(Creates a binary variable)

ICU (Length of post-operative stay in ICU in days): If ICU is greater than or equal to 4, code ICUM as 1, else code as 0.
(Creates a binary variable)

NYHA (New York Heart Association Score of cardiac function)
Merge Options 1 and 2
 3 and 4

(Creates a binary variable)

POSTRF: Merge options 1 and 2: 1 Dialysis required
 2 No dialysis required but patient died in renal failure

(Creates a binary variable)

PREOPMI: Merge options 1, 2 and 3: 1 Non Q wave infarction
 2 Transmural infarction
 3 Not defined in code book

(Creates a binary variable)

Previous Cardiac Surgery (REDO):
AVREDO: Merge options 1, 2, 3 1 Repair
(previous aortic valve surgery) 2 Replacement
 3 Repair of an in-situ prosthetic valve

The same procedure is used for MVREDO (previous mitral valve surgery) and TVREDO (tricuspid valve surgery). If any of these variables then equals 1, REDO equals 1.

Otherwise, REDO equals 0.

(Creates a binary variable)

REOP: Merge options 1, 2, 3, 5, 6, 7, Exclude option 4 (recode these as 0)
(Reopening after surgery) 1 Bleeding

- 2 Tamponade
- 3 Shock/ arrest
- 4 Infection
- 5 Dehiscence
- 6 Redo surgery
- 7 Other

(Creates a binary variable)

STROKE: Merge options 1 and 2: 1 Intraoperative
 2 Postoperative

(Creates a binary variable)

Use of internal mammary artery (IMAC)

LIMA and RIMA: Merge options 1, 2 and 3: 1 LAD
 2 CX
 3 RCA

Then, if IMAC=1 when LIMA and/ or RIMA = 1