ORAL HEALTH AND VENTILATOR-ASSOCIATED PNEUMONIA IN OLDER ICU PATIENTS

by

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Dedication

I dedicate this work to my beloved husband Mark Luciano and my children Mark, Nick, Cady and Dana whose unwavering love, support and encouragement have allowed me to achieve my goals. You are my inspiration. I am forever grateful.
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Dedication

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Oral Health and Ventilator-Associated Pneumonia in Older ICU Patients

Abstract

By

GINA LUCIANO

Ventilator-associated pneumonia (VAP) is the leading cause of morbidity and mortality in the ICU, particularly in older patients. Strategies to reduce or prevent the incidence of VAP are crucial. One of the less understood risk factors for VAP is poor oral health. This study provided the first evaluation of preoperative oral health status as a risk factor for ventilator-associated pneumonia in older adults. While oral health, dental plaque and oral bacteria have been suggested in the literature as linked to VAP, the association between amount of plaque before and after surgery and VAP risk has not previously been directly studied. The model used to guide this study is based on the Human Response Model (HRM) of Heitkemper and Shaver. A prospective, correlational design was used to measure the relationship between oral health and VAP. A convenience sample of 96 adults over 50 years old were recruited from patients scheduled for elective cardiac, abdominal, thoracic or vascular surgery, who required oral intubation and mechanical ventilation post-surgery. Oral health was evaluated by dental plaque accumulation using the University of Mississippi Oral Hygiene Index (UM-OHI). VAP was diagnosed using the Clinical Pulmonary Infection Score (CPIS) within 24 hours of intubation and up until postoperative day seven. Multiple and logistic regression analysis indicated that preoperative oral health significantly predicted postoperative oral health and accounted for 64% of the variability in postoperative oral health. Overall, oral health declined from preoperative to postoperative
but deteriorated less in cardiac surgery patients. Higher patient acuity, greater number of comorbidities and being female was associated with an increased likelihood of developing ventilator-associated pneumonia. Although this study did show a decline in oral health from preoperative to postoperative, it did not find a direct relationship between the quantity of dental plaque and VAP. This study did find that VAP risk is likely related to preoperative comorbidities and vulnerabilities, and to hospital acuity and course. A VAP reduction strategy which focuses on plaque quantity reduction as its target may not be effective. This study can serve as a basis for future studies investigating the impact of oral health on ventilator-associated pneumonia.
Chapter 1

Introduction

Pneumonia, the most common nosocomial infection in the intensive care unit (ICU), is the leading cause of morbidity and mortality in the ICU with mortality rates ranging from 24% to 87% (Cutler & Davis, 2005; R. Garcia, 2005). A subgroup of ICU patients, those who receive mechanical ventilation, are susceptible to developing a type of nosocomial pneumonia known as ventilator-associated pneumonia (VAP). Ventilator-associated pneumonia, defined as a parenchymal lung infection not present or incubating at the initiation of mechanical ventilation (Bonten, Kollef, & Hall, 2004; Chastre & Fagon, 2002) is the most common lethal infection in patients requiring mechanical ventilation (Bonten et al., 2004; Rello et al., 2002).

Pneumonia is the leading cause of death in hospitalized older adult patients over 60 years old (Bonten et al., 2004; Chastre & Fagon, 2002; Pesola, 2004; F. A. Scannapieco, 2006). The population of older adults in the United States is growing rapidly (Liang & Mackowiak, 2007). By 2030, 71.5 million Americans (one in every five) will be over 65 years old with the largest growth in those over 85 years old (Kinsella & He, 2009). Older adults accounted for 13.2 million hospital admissions (one of every three) and 43.6% of national cost for hospital care with pneumonia being the most frequent illness requiring hospital admission (Russo, 2006). In order to meet the healthcare needs of older patients and reduce the financial drain on the healthcare system, it is essential to identify and understand risk factors for pneumonia in older adults (File & Tan, 2005).
Poor oral health has been linked to pneumonia in hospitalized older adults (File & Tan, 2005; Pesola, 2004). While many risk factors in the ICU have been studied relatively little is known about vulnerability relating to pre-existing problems in oral health. Understanding a potential pre-existing risk such as oral health prior to hospital admission may significantly increase our ability to prevent pneumonia before it develops in the ICU. Therefore, the major focus of this study is the examination of the relationship between pre-hospital oral health status and the development of ventilator-associated pneumonia.

**Background**

Between 250,000 and 300,000 cases of ventilator-associated pneumonia (VAP) occur a year in the United States in mechanically ventilated patients (Koenig & Truwit, 2006). The risk of developing VAP increases by 1-5% for each day spent on a ventilator (F. A. Scannapieco, 2006). VAP has been reported to affect 8%-28% of mechanically ventilated patients and result in increased mortality and morbidity along with increased medical costs (Chastre & Fagon, 2002). A patient who develops VAP requires mechanically ventilation for 10 additional days, remains in the ICU for an additional 6 days and is hospitalized for 12 days longer, thereby increasing cost of hospitalization by approximately $40,000 (Craven, 2006; Rello et al., 2002; Sole et al., 2003; Tablan, Anderson, Besser, Bridges, & Hajjeh, 2004).

Despite current efforts toward appropriate treatment, morbidity and mortality rates for VAP remain high (Azarpazhooh & Leake, 2006). In order to reduce the incidence of this lethal and costly nosocomial pneumonia, it is not only important to understand the pathophysiologic process of infection, but to develop a more complete
understanding of specific risk factors for ventilator-associated pneumonia in individuals and populations. A more precise risk factor analysis, prior to hospitalization, can provide information that is essential to the development of primary prevention strategies in vulnerable populations such as older adults.

Many of the risk factors for VAP have been studied and are understood. One of the less studied and understood factor is oral health status (Munro, Grap, et al., 2006; F. A. Scannapieco, Stewart, & Mylotte, 1992). While research has established a relationship between poor oral health status and the development of VAP, the focus has been on oral health status after intubation (Mori et al., 2006; Ross & Crumpler, 2007; Schleder, Stott & Lloyd, 2002). To better understand how to develop appropriate preventive interventions for VAP, research needs to focus not only on continued examination of risk factors such as oral health status after intubation, but also expand the focus of the research to include risk factors that exist earlier in the process of infection such as pre-hospital oral health status. To date, however, no one has examined the relationship between oral health prior to hospital admission and its relationship to VAP, despite the fact that epidemiologic studies have shown that 41% of older adults have poor oral health (Vargas, Kramarow, & Yellowitz, 2001). This study will be the first to examine oral health over time and the first to examine pre-intubation oral health in older adult patients who subsequently require intubation. If a relationship between pre-hospital oral health and oral health after intubation can be established, this will provide the evidence needed for earlier identification of oral health status risk for older adults.
Significance

The importance of understanding risk factors for diseases, especially in areas where there are health disparities, has been identified as a key initiative of Healthy People 2010 ("Oral health in America: a report of the Surgeon General.," 2000). More specifically, oral health disparities have been identified as a key initiative (M. Allukian, 2008; "Oral health in America: a report of the Surgeon General.," 2000). Over the past thirty years, oral health disparities for the most vulnerable populations such as older patients have been growing. The surgeon general’s report on Oral Health in America declared poor oral health to be a “silent epidemic” especially in the poor, elderly, and racial and ethnic minorities ("Oral health in America: a report of the Surgeon General.," 2000). With the well-known growth in the population of older adults (Kinsella & He, 2009) and the increase in disparities in oral health care (Vargas et al., 2001), many older adults are at risk for a lethal pneumonia acquired when they are hospitalized. Poor oral health while intubated has been linked to the development of ventilator-associated pneumonia (Munro, Grap, et al., 2006; F. A. Scannapieco, 2006). Pneumonia is the leading cause of morbidity and mortality in the ICU and has an associated high mortality risk for older ICU patients in particular (Bonten et al., 2004; Chastre & Fagon, 2002; Pesola, 2004; F. A. Scannapieco, 2006).

A gap exists in understanding the importance of pre-hospital oral health in the risk for ventilator-associated pneumonia. While a change in oral health status over time in the ICU postoperatively likely occurs, the relative role of pre-hospital oral health has not been studied. Munro et al.,(2006b) and Scannapieco (2006) have demonstrated a relationship between poor oral health and VAP. This study will contribute to the science
by being the first study to document oral health status of patients prior to admission. Further, it will evaluate the significance of pre-hospital oral health by measuring its relationship to post-intubation oral health status and to VAP.

The results of this study are important in that they may allow a shift of oral health intervention earlier in the process without depending entirely on efforts in the ICU. If, for example, it is found that pre-hospital oral health is predictive of VAP risk, then better evaluation and preparation of patients before surgery can be performed. The identification of poor oral health prior to surgery and ICU admission, will permit the development of preventive nursing interventions and may have a greater probability of implementation in the preoperative period than in the ICU where there is higher patient acuity, increased nursing workload and interventions for improving oral health prove to be timely and difficult (Furr, Binkley, McCurren, & Carrico, 2004). If, however, the findings indicate that pre-hospital oral health is not related to VAP risk, but that change in oral health over time while intubated is more strongly associated with VAP, then efforts should be focused on better delivery of oral care in the ICU.

**Purpose**

The purpose of this study was to examine the relationship between pre-hospital oral health status and ventilator-associated pneumonia in older adult ICU patients. It focused on older adult surgical patients, a vulnerable group with higher infection risk. The research questions are:

1. What is the oral health status of older adults prior to surgery?
2. What is the oral health status of older adults after intubation?
3. What is the relationship between pre-hospital oral health and oral health after intubation in older intensive care unit patients when controlling for age, gender, acuity, comorbidity, smoking history, surgery type and antibiotic use?

4. How do age, gender, acuity, comorbidity, smoking history, surgery type and antibiotic use change oral health over time from preoperative to postoperative?

5. What is the relationship between oral health (pre-hospital and post-intubation) and ventilator-associated pneumonia in older adult intensive care unit patients when controlling for gender, acuity, comorbidity, surgery type and antibiotic use?

**Theoretical Framework**

The model guiding this study is based on the Human Response Model (HRM) of Heitkemper and Shaver (1989). The model is a framework for understanding human response to health and illness or clinical therapies along multiple perspectives (Heitkemper & J. F. Shaver, 1989). The American Nurses’ Association in the *Social Policy Statement*, has established that the “phenomena of concern for nurses are human responses” (ANA, 1980, p. 9). The HRM model was chosen for this study because it provides a means for understanding the interface of person and environmental factors that may contribute to a patient’s response to a given therapy in the ICU.

The Human Response Model is based on a biopsychosocial model that has been used to study the relationship between the domains of person and environment and the impact of such relationships on individual adaptations (G. A. Kline, 2009). This model has been used to examine the impact of nursing interventions as well as examine human responses to specific clinical interventions. The HRM proposes that person factors (individual factors) and environmental factors (risk factors outside the individual) can
influence a person’s ability to adapt in response to a clinical or therapeutic intervention. Nursing interventions may be implemented which will modulate person factors or environmental risk factors to prevent or alleviate a pathophysiologic human response (Heitkemper & J. F. Shaver, 1989). The HRM has guided a number of studies on human response to interventions for diseases such as irritable bowel syndrome (M. Heitkemper, Levy, Jarrett, & Bond, 1995; Savard & Sawatzky, 2007), health conditions such as acute (Kline, 2009) and postoperative pain (Cameron & Sawatzky, 2008) and clinical therapies such as enteral feedings (Heitkemper & J. F. Shaver, 1989). Definition of the three main concepts of the model and the linkage between concepts (Figure 1) are described below.
Clinical Therapeutics are interventions to promote normal physiological responses or alleviate pathophysiologic responses (Heitkemper & J. F. Shaver, 1989). The interface between person factors and environmental risk factors influence the human response to an intervention or clinical treatment. This human response can be in the form of a pathophysiological response or human response.
physical response or behavioral response (M. Heitkemper et al., 1995; G. A. Kline, 2009). While positive human responses result in a movement towards health, negative human responses may result in illness (Mitchell, Gallucci, & Fought, 1991).

**Person Factors**

Person factors, also referred to as personal vulnerability factors, are factors that are present within a person that make them susceptible to a disease or influence their response to a therapy (M. M. Heitkemper & J. F. Shaver, 1989). Personal characteristics that may affect a response are classified as either modifiable or nonmodifiable (M. Heitkemper et al., 1995). Nonmodifiable person factors are conditions within a person that cannot be changed. Age, gender, ethnicity and prior medical history are examples of nonmodifiable person factors. In the HRM, Heitkemper and Shaver (1989) assert that nonmodifiable person factors such as age, gender and comorbid conditions could influence responses to treatment interventions such as nutritional therapy.

The second type of person factor in the HRM is modifiable person factors. These are characteristics or individual qualities within a person that can be altered. Modifiable person factors can predispose individuals to the occurrence of pathophysiologic responses to clinical treatments. Examples of modifiable risk factors include health status, knowledge about one’s health, attitudes and coping strategies (M. M. Heitkemper & J. F. Shaver, 1989). Modifiable person factors are often the aim of nursing interventions (M. Heitkemper et al., 1995) For example, by improving the health status of a person through education on managing one’s illness or lifestyle modification, behavioral human responses such as compliance with enteral feeding therapy can be influenced (Heitkemper, et al., 1995). Heitkemper et al (1995) emphasize that intervention for
diseases, such as irritable bowel syndrome, are often directed at changing modifiable person factors such as current dietary intake and psychological distress.

**Environmental Factors**

Environmental factors are defined as physical or social factors outside of the individual that could place a person at risk for negative response to interventions (M. Heitkemper et al., 1995; M. Heitkemper & J. F. Shaver, 1989; M. M. Heitkemper & Bond, 2003). Environmental factors can also be divided into nonmodifiable and modifiable categories. Nonmodifiable environmental factors are those that exist outside of the individual that cannot be changed or eliminated. Modifiable environmental factors are risks outside the individual that can be altered or removed. Both nonmodifiable and modifiable environmental factors may influence the human response to a clinical treatment. An example of a nonmodifiable environmental risk is admission to a hospital (M. Heitkemper et al., 1995; G. A. Kline, 2009). The hospital environment is disruptive to usual human function such as sleep-wake cycles, involves excessive contact with strangers, social isolation from family and has a large number and many types of microorganisms to which a person is exposed (M. Heitkemper et al., 1995). However, some conditions within the hospital environment can be modified. Examples of potentially modifiable environmental risks are exposure to microorganisms (M. M. Heitkemper & Bond, 2003), social support systems, artificial light-dark cycling, access to health care (M. Heitkemper et al., 1995; M. M. Heitkemper & J. F. Shaver, 1989) and reduction of health care disparities (M. M. Heitkemper & Bond, 2003). Kline (2009), in a study on control of acute pain, used sensory stimuli to improve the physical environment as a modifiable environmental factor to improve pain relief. Modifiable environmental
factors can be the goal of nursing interventions while nonmodifiable environmental factors would be key variables to control when feasible (M. Heitkemper et al., 1995; G. A. Kline, 2009).

**Human Responses**

The Human Response Model describes human responses as an individual’s adaptations to illness, clinical therapies, or interventions which manifest along four interrelated dimensions: physiological, pathophysiological, behavioral and experiential (M. M. Heitkemper & J. F. Shaver, 1989). The human response indicators are outcome measurements of the physiological, pathophysiological, behavioral and experiential effects of a clinical therapy or intervention (M. M. Heitkemper & J. F. Shaver, 1989).


Pathophysiologic responses are defined as “disordered biologic functioning” (Mitchell, et al., 1991, p.155). Pathophysiologic responses are the result of exhaustion or decompensation of the physiologic regulatory mechanisms’ ability to maintain
homeostasis (Mitchell et al., 1991). They are phenomena that are observable and measurable “by instruments of the biological sciences” (Mitchell, et al., 1991, p.155). Heitkemper (1989) described pathophysiologic responses to enteral feedings as the “objectively documentable signs of gastrointestinal absorption, motility or secretion dysfunction” (p. 416). Measured indicators include diarrhea, vomiting, high glucose levels and reduced lymphocyte counts (Heitkemper & Shaver, 1989). Pathophysiologic human responses will be the focus of this study.

Behavioral responses are defined as “directly observable and measurable motor and verbal behaviors” (Mitchell, et al., 1991, p.156). Heitkemper and Shaver (1989) describe behavioral responses to enteral nutrition as observable or reported behaviors such as the effect of tube feedings on activities of daily living or disruption in family meals.


**Research Concepts**

Ventilator-associated pneumonia continues to be a problem for ICU patients requiring mechanical ventilation despite a growing knowledge of many of the risk factors. These risk factors can be divided into nonmodifiable and modifiable person and
environmental risk factors. Both types of risk factors impact a patient’s ability to respond to clinical therapeutics such as oral intubation and mechanical ventilation. As a result of a clinical intervention, there may be a variety of human responses, some physiologic and some pathophysiologic (e.g. VAP).

**Clinical Therapeutics**

Conceptually, clinical therapeutics are interventions to promote normal physiological function or alleviate pathophysiologic responses. Human responses to clinical interventions are influenced by person and environmental risk factors (M. Heitkemper et al., 1995). The clinical therapy in VAP risk is oral intubation and mechanical ventilation.

**Oral intubation and mechanical ventilation.**

Oral endotracheal intubation is the insertion of a flexible plastic tube through the mouth, larynx and vocal cords, into the trachea to protect the patient's airway and provide a means of mechanical ventilation (O’Connor MF, 2005). It is the most common method for securing a patient’s airway for artificial ventilation (Soliz, Sinha, & Thakar, 2001). Indications for oral intubation include protection of the airway from obstruction or aspiration as in patients with altered mental status; facilitation of positive pressure mechanical ventilation for patients with respiratory failure; and airway control for diagnostic and therapeutic measures such as surgical procedures (Soliz et al., 2001).

Mechanical ventilation is a method to artificially assist or replace spontaneous breathing when a patient’s own ventilation is inadequate to sustain life (Manthous, Schmidt, & Hall, 2005). Patients who are orally intubated and mechanically ventilated are at risk for complications related to the presence of the endotracheal tube, namely
VAP, due to aspiration of oral bacteria that accumulate around the endotracheal tube cuff into the lower respiratory tract (Bonten et al., 2004; Furr et al., 2004).

**Nonmodifiable Person Factors**

In the HR model, nonmodifiable person factors are those conditions that are present within a person that increase vulnerability to a disease or influence response to a therapy. Nonmodifiable person factors for VAP risk include age over 60 years, male gender, comorbid conditions and higher patient acuity or severity of illness (Bonten et al., 2004; Chastre & Fagon, 2002b)

**Age.**

Age is a significant factor in VAP vulnerability. For the purposes of this study, older age will be defined as patients over 55 years of age. In the HR model, age is conceptualized as a nonmodifiable person factor that increases the risk for a pathophysiologic human response. The aging immune system in older adults plays a key role in susceptibility to infection. Despite the use of antibiotics, the morbidity and mortality from an infection in the older adult remain high. People over the age of 60 have impaired immune system function known as immune senescence which is a decline in cell mediated or adaptive immunity (Liang & Mackowiak, 2007). The depletion of T-cells with age decreases the antibody response to antigens contributing to the susceptibility of older adults to infection. Previous studies have demonstrated that the increased incidence of bacterial infections in older adults can be attributed to immune senescence (Butcher, Killampalli, Chahal, Alpar, & Lord, 2003; Miller, 1996).

Coupled with poor circulation, poor nutrition and loss of defense mechanisms such as protective cough, older adults are a population susceptible to pulmonary
infection. In addition, older adults often have an atypical presentation of infection due to the inability to develop a febrile response, one of the classic signs of infection (Liang & Mackowiak, 2007). In a study by Riquelme et al (1997) of older patients with community-acquired pneumonia, the classic symptoms for pneumonia of cough, fever and dyspnea were absent in more than two-thirds of elderly patients on admission to the hospital. A study by Trotter et al (2008), on hospital admissions for pneumonia in England demonstrated that the number of deaths from pneumonia was highest in the most elderly and those patients with more coexisting conditions. Since age is a nonmodifiable risk factor for VAP, gaining knowledge of risk prevention and interventions is crucial for this growing vulnerable population.

**Gender.**

A second nonmodifiable person factor in VAP risk is gender. Several studies have identified male gender as an independent risk factor for VAP (Cook & Kollef, 1998; Rello et al., 2002). In an epidemiological study by Rello (2002) using a large U.S. database, patients with VAP were nearly twice as likely to be male. Though the relationship between male gender and VAP is not known, it may be a marker for other potentially modifiable risk factor (Rello et al., 2002).

**Comorbid conditions.**

Comorbid conditions play a key role in vulnerability to ventilator-associated pneumonia and must be noted and controlled for in any study of VAP risk. Comorbidity is defined as diseases that coexist in the patient at the same time as the primary condition (Valderas, Starfield, Sibbald, Salisbury, & Roland, 2009). Previous studies have demonstrated that 45% of the general population and 88% of older adults have one or
more chronic conditions and 65% had multiple chronic conditions (Wolff, Starfield, & Anderson, 2002). Wolff et al., (2002) found that having multiple chronic conditions significantly increases the risk of avoidable hospitalizations and preventable complications during hospitalizations. Further, people who have more comorbidity may have more disability and rapid changes in health status (Wolf, et al., 2002).

Evidence has indicated that chronic conditions cluster so that a person with one chronic condition is more likely to have other chronic conditions (Wolff, et al., 2002). The most common cluster of comorbid conditions in older adults with pneumonia include chronic obstructive pulmonary disease, chronic heart failure, diabetes, malnutrition, swallowing disorders which increase aspiration risk (File & Tan, 2005) and poor oral health (Rello et al., 2002). In addition, patients with chronic conditions such as chronic obstructive pulmonary disease are at risk for infection with more virulent gram positive organisms such as Streptococcus pneumonia and more virulent gram negative organisms such as Haemophilus influenza and Moraxella catarrhalis (Chaste & Fagon, 2002). While comorbid conditions cannot be eliminated, understanding and controlling for their effect on VAP is important for any study on VAP risk.

**Patient Acuity.**

Patient acuity is defined as the risk of death based upon the severity of the patient’s disease. Patient acuity prognostic systems predict risk of mortality of hospitalized patients based on selected physiologic variables (Knaus et al., 1991). Higher patient acuity scores indicate higher short-term risk of death (Knaus et al., 1991; Legall, Lemeshow, & Saulnier, 1993). Several studies have demonstrated that development of ventilator-associated pneumonia is associated with severity of the underlying disease and
higher acuity scores (Apostolopoulou, Bakakos, Katostaras, & Gregorakos, 2003; Bonten et al., 2004; Chastre & Fagon, 2002).

**Modifiable Person Factor**

Modifiable person factors are those variables within a person that can be altered. A modifiable person risk factor in the pathogenesis of VAP is oral health status prior to hospitalization (Azarpazhooh & Leake, 2006; Munro, Grap, et al., 2006; Frank A. Scannapieco, Bush, & Paju, 2003).

**Oral Health.**

Conceptually, oral health is considered to be a modifiable person risk factor because previous intervention studies have demonstrated that providing oral care to orally intubated patients improves oral health status (Mori et al., 2006; Ross & Crumpler, 2007). Oral health is defined as the status of the oropharynx to include the teeth, gums, oral mucosa, and oral immunity provided by saliva and accumulation of dental plaque (Munro & Grap, 2004; Treloar & Stechmiller, 1995).

This study will examine pre-hospital oral health as a risk factor for ventilator-associated pneumonia in older surgical ICU patients, a particularly vulnerable population to infection. For the purposes of this study, pre-hospital oral health is defined as dental plaque accumulation on the teeth of patients prior to admission to the hospital. Oral health status has been linked to VAP risk (Munro, Grap, et al., 2006a; F. A. Scannapieco et al., 1992a). In patients with poor oral health, dental plaque accumulates along gingival surfaces leading to bacterial colonization, infection and inflammation of the gingiva and surrounding structures known as periodontal disease (X. Li, K. M. Kolltveit, L. Tronstad, & I. Olsen, 2000). Periodontal disease is the most common oral infection occurring in
10% to 15% of adults and has been found to be associated with systemic diseases (X. Li, Kolltveit, Tronstad, & Olsen, 2000; Perkins & Perkins, 2001; Taylor, 2001; Warren, 2001). Bacterial pneumonia in patients with periodontal disease is the result of micro-aspiration of oropharyngeal bacteria, which colonize the higher plaque content into the lower respiratory tract (Munro et al., 2006; Li et al., 2000; Taylor, 2001).

Those at highest risk for bacterial pneumonia are people with chronic diseases, smokers, those who are immunocompromised, hospitalized patients who are mechanically ventilated, those with poorer oral health, and the elderly (Munro et al., 2006; Furr et al., 2004; Li et al., 2000). Epidemiologic studies have shown the incidence of periodontal disease in those 65 years and older to be 41% (Vargas et al., 2001). In a longitudinal study of older adults by Terpenning et al., (2001), dental decay and periodontal pathogens were significant risk factors for pneumonia. In reviews by Scannapieco et al (2003) and Azarpazhooh et al (2006) an association was found between periodontal disease and pneumonia especially among the elderly. It is not known if the identification of preoperative older adult patients with poor oral health can lead to strategies of early selection or prevention which are more effective than later intervention.

**Environmental Risk Factors**

Conceptually, environmental risk factors can be divided into nonmodifiable and modifiable categories. Nonmodifiable environmental risk factors that place a patient at risk for nosocomial pneumonia in the ICU but are necessary for patient care include surgery and use of medications such as antibiotics (Bonten et al.2004; Chaste & Fagon, 2002). Modifiable environmental factors are risks outside the individual that can be
altered. A key modifiable environmental factor in VAP risk is the length of time that a patient is orally intubated and mechanically ventilated.

**Nonmodifiable Environmental Factors**

**Surgery type.**

The type of surgery that a patient will undergo is a nonmodifiable environmental factor in VAP risk given that the surgery is essential to the patient’s well-being. Patients who undergo surgery are at high risk for VAP. VAP accounts for one third of the pulmonary infiltrates in postoperative patients (Bonton et al., 2004; Chaste & Fagon, 2002). In a study by Cunnion et al., (1996), comparing adult ICU patients, postoperative patients who had thoracic or upper abdominal surgery or long surgical procedures had higher rates of VAP than medical ICU patients. In a study by the Centers for Disease Control and Prevention (1997), 75% of patients with pneumonia were infected after surgery.

While there are many factors that predispose a person for increased risk for VAP, having a surgical procedure puts patients at risk (Bonten et al., 2004; Chastre & Fagon, 2002). However, it is a risk factor that is necessary for the treatment of the patient. Therefore, the focus of this study will be on VAP risk in elective postoperative patients for two reasons; postoperative patients are at greater risk for VAP (Bonten et al., 2004; Chastre & Fagon, 2002; Cunnion et al., 1996) and they can be evaluated earlier in the process of risk during preoperative testing. If oral health status pre-surgery is found to place the patient at risk post-operatively for VAP, then this modifiable factor can be addressed in order to minimize the post-operative risk.

**Modifiable Environmental Factor**
**Antimicrobials.**

Antimicrobials are substances or compounds used to destroy or inhibit microorganisms (Taber, 1977). Antimicrobials are a potentially modifiable environmental risk factor in that they may be changed based on causative bacteria or multi-drug resistant infection. Though they are important in the prevention of postoperative surgical infection, they may increase the risk for VAP. The effect of prior antimicrobial use in the risk for VAP is mixed. In a review on antibiotic prophylaxis in the critically ill, it was found that antibiotic administration reduced VAP (D'Amico et al., 1998). However, the evidence suggests that prophylactic antibiotics only delay VAP while increasing the risk of infection with multi-drug resistant organisms (Chaste & Fagon, 2002). Previous studies have demonstrated that prophylactic use of antibiotics in the ICU increases the risk of infection from multi-drug resistant pathogens (Kollef, 1993; Rello, Ausina, Ricart, Castella, & Prats, 1993; Trouillet et al., 1998). In a study by Kollef (1993) of 320 patients, previous antibiotic use was associated with VAP. It is unclear whether antibiotics increase or decrease VAP risk.

**Length of Mechanical Ventilation.**

Length of mechanical ventilation is defined as the total number of days a patient is mechanically ventilated (IHI, 2012). The risk of developing VAP increases by 1-5% for each day spent on a ventilator (Scannapieco, 2006). A patient who develops VAP requires mechanically ventilation for an additional 10 days, increases ICU stay by 6 days and increases hospital length of stay by 12 days (Craven, 2006). Length of time spent on a mechanical ventilator is a potentially modifiable environmental risk factor.
Human Responses

In the HRM, human responses are described as an individual’s adaptation to illness, clinical therapies or interventions manifested along four interrelated dimensions: physiological, pathophysiologic, behavioral and experiential (Heitkemper & J. F. Shaver, 1989). The human response indicators are outcome measurements of the physiological, pathophysiologic, behavioral and experiential effects of a clinical therapy or intervention (Heitkemper & J. F. Shaver, 1989). However, for this study, only the pathophysiologic responses to oral intubation and mechanical ventilation will be measured because this study seeks to examine the relationship between oral health preoperatively (poor oral health being a pathophysiologic condition) with oral health post-intubation and risk for VAP (a pathophysiologic process) in the postoperative period.

Pathophysiologic.

In the HRM, pathophysiologic responses are the result of exhaustion or decompensation of the physiologic regulatory mechanisms’ ability to maintain homeostasis (Mitchell, et al., 1991). They are phenomena that are observable and measurable “by instruments of the biological sciences” (Mitchell, et al., 1991, p.155). An observable and measurable pathophysiologic response to oral intubation is accumulation of dental plaque. A measurable pathophysiologic response to mechanical ventilation is pneumonia.

Oral Health Post-Intubation

The concept of oral health post-intubation refers to the dental plaque accumulation after an oral endotracheal tube is inserted into the oropharynx. The
presence of the endotracheal tube in the oropharynx of ICU patients increases a patient's risk for pneumonia because it provides a direct route for micro-aspiration of the bacteria that colonize dental plaque into the lower respiratory tract (Bonton et al., 2004; Chastre & Fagon, 2002).

Dental plaque of ICU patients has been shown to be colonized by respiratory pathogens such as Pseudomonas aeruginosa and methicillin-resistant Staphylococcus aureus (Schleder, Stott, & Lloyd, 2002). Fourrier et al., (1998) found that approximately 40% of ICU patients had dental plaque that was colonized by respiratory pathogens and that the respiratory pathogens in the dental plaque were associated with nosocomial pneumonia. Munro et al (2006) demonstrated that microbial colonization of the oropharynx increases over time and that a correlation exists between poorer oral health and VAP. However, a gap exists in knowing which patients in the ICU have poor oral health and when it is most important to modify oral health risk. A measurable indicator of post-intubation oral health status is accumulation of dental plaque (Munro, et al., 2006).

**Ventilator-Associated Pneumonia**

In the HR model, VAP is a pathophysiologic response to oral intubation and mechanical ventilation. Two key factors, accumulation of dental plaque which acts as a reservoir for respiratory pathogens (Scannapieco et al., 1992), and micro-aspiration of bacteria into the lower respiratory tract that colonize oropharyngeal secretions accumulating around the endotracheal tube cuff, have been implicated in the pathogenesis of VAP (Binkley, Furr, Carrico, & McCurren, 2004; Bonten et al., 2004). Operationally, VAP is defined as a parenchymal lung infection not present or incubating at the initiation of mechanical ventilation (Bonten, Kollef & Hall, 2004; Chaste & Fagon, 2002). Bacteria
that normally colonize the oral cavity of healthy adults are gram positive cocci and anaerobic species (F. A. Scannapieco, 1999; Treloar & Stechmiller, 1995). Measurable indicators of pneumonia include body temperature elevation, inadequate oxygenation, elevated blood leukocyte count, presence of an infiltrate on chest radiograph and volume and purulence of tracheal secretions (Koenig & Truitt, 2006).

This study will examine pre-hospital oral health as a risk factor for ventilator-associated pneumonia in older surgical ICU patients, a particularly vulnerable population to infection. This study model proposes that a person presents with multiple vulnerabilities for VAP risk including age, gender, comorbidities and poor oral health prior to hospitalization and is exposed to risk factors in their environment such as surgery and medications while orally intubated and mechanically ventilated. Personal vulnerability and environmental risk influence their physiological response. Negative response may result in the development of ventilator-associated pneumonia. The conceptual and empirical structure of the study is presented in Figure 1.

**Summary**

With the well-known growth in the population of older adults and the increase in disparities in oral health care, many older adults are at risk for a lethal pneumonia acquired when they are hospitalized. This study will examine the oral health of older patients prior to being admitted to the hospital to help understand their risk for developing pneumonia while in an intensive care unit on a mechanical ventilator. Although risk for VAP in the ICU and VAP prevention protocols are becoming increasingly understood, early interventions (prior to ICU admission) are particularly important since additional interventions in the ICU are difficult given the high patient
acuity level and nursing workload (Aiken, Clarke, Sloane, Sochalski, & Silber, 2002; Hugonnet, Uckay, & Pittet, 2007; Tarnow-Mordi, Hau, Warden, & Shearer, 2000; Yang, 2003). The identification of an early risk factor, such as oral health prior to admission, especially for older people who may lack adequate oral health care, will permit the development of early preventative nursing interventions prior to ICU admission and may have a greater probability of implementation and a greater impact on patient outcomes.
Chapter Two

Review of the Literature

The purpose of this study is to examine the relationship between pre-hospital oral health status and the development of ventilator-associated pneumonia (VAP) in older adult ICU patients. It is posited that many older adults may have poor oral health prior to hospitalization and therefore are at greater risk for developing pneumonia when undergoing oral endotracheal intubation for mechanical ventilation. The purpose of this chapter is to review previous studies which have defined VAP as a concept, identified risk factors, suggested a link between oral health and VAP, and described the efficacy and limitations of prevention strategies. Since it is hoped that this study is a first step towards an earlier intervention strategy for VAP prevention, the literature on the potential of early prevention approaches will also be briefly discussed.

Ventilator-Associated Pneumonia

Definition and History of the VAP Concept

Pneumonia is defined as the invasion of a virulent microorganism into the normally sterile lower respiratory tract causing inflammation of the lung parenchyma (Chastre and Fagon, 2002). Microorganisms enter the lower respiratory tract through one of four routes: inhalation of contaminated air or medication aerosols; aspiration of bacterial laden secretions from the oropharynx or digestive tracts; directly from a infection in the pleural space; or by hematogenous infectivity from bacteria from an infection at a distal site such as a urinary catheter or central line related blood stream infection (Safdar, Crnich, & Maki, 2005). Pneumonia is classified as community-acquired (CAP) or nosocomial based upon when the infection occurs. Nosocomial
pneumonia is defined as pneumonia not present or incubating at the time of admission to the hospital (Horan, Andrus, & Dudeck, 2008b).

Conceptually, the definition of ventilator-associated pneumonia is “pneumonia in persons who have had a device to assist or control respiration continuously through a tracheostomy or endotracheal intubation within the 48 hour period before the onset of infection” (Horan, 2008, p. 327). VAP arising 48 to 96 hours after tracheal intubation is considered to be early-onset VAP and one that occurs after this period as late-onset VAP (Ibrahim, Ward, Sherman, & Kollef, 2000; M. H. Kollef, 1999b). Generally, early-onset VAP has a better prognosis and is more likely to be caused by aspiration of antibiotic-sensitive bacteria colonizing the oropharynx (Chastre & Fagon, 2002). Late-onset VAP may be caused by more virulent or multidrug-resistant (MDR) pathogens and is associated with greater morbidity and mortality (Chastre & Fagon, 2002).

In order for ventilator-associated pneumonia to occur, microorganisms must invade the lower respiratory tract and overwhelm the normal lung defense mechanisms. These microorganisms can come from exogenous environmental sources or endogenous patient factors. The role of respiratory equipment and mechanical ventilators as an exogenous source of nosocomial pneumonia was initially described during the 1960s in studies on respiratory infections in critically ill patients (Phillips, 1967; Reinartz, Pierce, Mays, & Sanford, 1965).

In 1981, the CDC published the first guideline for prevention of nosocomial pneumonia which addressed contaminated respiratory equipment as the main source of nosocomial pneumonia (Simmons & Wong, 1982). However, it was Johanson et al (1972a) in a prospective study on 213 patients who demonstrated the role of an
endogenous source of infection. In this study, upper airway colonization with gram negative bacilli was found in 95 (45%) of the 213 ventilated patients and nosocomial pneumonia developed in 22 (23%) of patients colonized with bacteria. In contrast, only 4 (3.4%) of 118 patients who were not colonized developed VAP. Since this time many studies have demonstrated that hospitalized patients have high rates of oropharyngeal colonization with gram negative bacilli (Bonten et al., 2004; Ewig et al., 1999; Francois Fourrier et al., 1998; A. J. H. Kerver et al., 1987; F. A. Scannapieco et al., 1992a). Micro aspiration of colonized oropharyngeal secretions accumulating around the endotracheal tube cuff is the primary route of endogenous bacterial infection (Bonten et al., 2004; Safdar et al., 2005).

From the results of the study by Johanson (1972), an operational definition based on clinical and radiographic criteria was published and used for many years to diagnose VAP. These criteria included fever, leukocytosis, purulent tracheobronchial secretions and appearance of a new or progressive pulmonary infiltrate on chest radiograph (W. G. Johanson, J. P. Sanford, G. D. Thomas, & A. K. Pierce, 1972b). The operational definition or diagnostic criteria for VAP now includes the clinical and radiographic criteria as discussed above with the addition of microbiologic examination of tracheal secretions (American Thoracic & Infectious Diseases Society of, 2005; Horan, Andrus, & Dudeck, 2008a; Koenig & Truwit, 2006b).

The National Healthcare Safety Network (NHSN) is a voluntary surveillance system established in 1970 by the Centers for Disease Control and Prevention to collect data from a sample of healthcare institutions in the United States to determine the incidence, trends, risk factors and adherence to prevention of nosocomial infections.
(Emori et al., 1991). To facilitate comparisons and determine trends, data on nosocomial pneumonia are reported as number of patients infected per 100 days in the hospital or per 1000 days of mechanical ventilation (Tablan et al., 2004).

In 2008, the Center for Disease Control and Prevention and the National Healthcare Safety Network (CDC/NHSN) redefined the term “healthcare-associated pneumonia” instead of nosocomial pneumonia (Horan, et al., 2008). Healthcare-associated pneumonia (HCAP) is defined as pneumonia in a patient who has had recent (within 90 days) contact with the healthcare system (American Thoracic Society & Infectious Disease Society of America, 2005; Kollef, et al., 2005). HCAP is further divided into hospital-acquired pneumonia (HAP) and ventilator-associated pneumonia (VAP). Hospital-acquired pneumonia was previously considered to be ventilator-associated pneumonia if the pneumonia occurs more than 48 hours after endotracheal intubation (American Thoracic Society and Infectious Disease Society of America, 2005; Bonten, et al., 2004; Chastre & Fagon, 2002). The revised definition by the CDC in 2007 included no minimum time period for the ventilator to be in place for pneumonia to be considered ventilator-associated pneumonia (CDC, 2009).

The pneumonia classification system was developed by the American Thoracic Society and the Infectious Disease Society of America based on surveillance data from 14,000 ICUs in the National Nosocomial Infection Surveillance System (American Thoracic Society and the Infectious Disease Society of America, 2005). It is an important classification system in that it indicates the type of pathogen responsible for the pneumonia and is the basis for prevention guidelines, antibiotic selection and treatment algorithms (Kollef, 2004; M. H. Kollef, 2005; Tablan et al., 2004). In this study, VAP has
been identified and defined using these accepted criteria of a clinically, radiographically and culture positive pneumonia associated with ventilator use.

**Understanding Risk Factors for Ventilator-Associated Pneumonia**

Up to half of patients entering an intensive care unit require mechanical ventilation (M. J. Grap, 2009). Based on surveillance data collected by the NNIS from 1992 to 1997 on over 180,000 ICU patients, VAP complicates the course of approximately 25% of patients receiving mechanical ventilation (M. H. Kollef, 2005; Richards, Edwards, Culver, Gaynes, & System, 1999). Two key factors, accumulation of dental plaque which acts as a reservoir for respiratory pathogens (Scannapieco et al., 1992) and micro-aspiration of bacteria into the lower respiratory tract that colonize oropharyngeal secretions accumulating around the endotracheal tube cuff have been implicated in the pathogenesis of VAP (Bonten et al., 2004; Safdar et al., 2005).

Several epidemiologic studies have demonstrated that endotracheal intubation remains the most important risk factor for the development of healthcare-associated pneumonia (Chastre & Fagon, 2002; Chevret, Hemmer, Carlet, & Langer, 1993; Davis, 2006; Horan et al., 2008b; J. L. Vincent et al., 1995). In a study done in the United States on nosocomial infections in surgical patients using NNIS data from 1986 to 1992, the pneumonia rate was 21-fold higher for patients receiving mechanical ventilation than for those not receiving mechanical ventilation (Horan, et al., 1993). Further, NNIS reported in 2002 that patients receiving mechanical ventilation had 6-21 times greater risk of developing healthcare-associated pneumonia than patients not receiving mechanical ventilation (Kleven et al., 2007). NHSN data from 2006 to 2007 indicated the incidence of VAP ranged from 2.1 to 11 per 1,000 ventilator days (Edwards et al., 2009).
Moreover, mortality rates for patients who develop ventilator-associated pneumonia range from 24-50% and can be as high as 87% in patients with multi-drug resistant pathogens (Chastre & Fagon, 2002; Garcia, 2005).

The risk of developing VAP increases by 1-3% for each day spent on the ventilator (Scannapieco, 2006; Cook et al., 1998). A risk factor analysis for VAP was identified from 21 studies involving over 16,700 patients in medical and surgical ICUs from more than 20 countries (Table 1). The risk factors identified either increase the risk of aspiration of pathological bacteria or reduce or interfere with a patient’s defense mechanisms (Chastre & Fagon, 2002). These risk factors can be divided into modifiable and nonmodifiable patient and environmental factors and treatment related risk factors (Bonten et al., 2004; Cook & Kollef, 1998).

Nonmodifiable patient related risk factors for VAP identified were: male gender, age greater than 60 years, preexisting conditions (chronic obstructive pulmonary disease, adult respiratory distress syndrome and neurologic disease), trauma, higher severity of illness, and decreased level of consciousness or coma. Risk factors that are necessary for patient care and are often nonmodifiable include surgery, ICP monitoring, transportation out of the ICU and reintubation.

Modifiable risk factors identified from the literature include aspiration of contaminated secretions, poor oral health (oropharyngeal colonization with respiratory pathogens, high dental plaque scores), use of medications (antibiotics, H2 antagonists, antacids and paralytic agents), supine positioning of patients especially during enteral feeding, intracuff pressure of the endotracheal tube <20cm H2O, aerosol respiratory treatments and prolonged mechanical ventilation for longer than 3 days (Table 2).
The variability in the results of the risk factor analysis may be explained by several factors. First, many of the studies used both medical and surgical ICU patient populations of various age groups for the risk factor analysis. Heterogeneity in the patient populations may have confounded the risk factors identified. Second, differences in VAP definition and diagnostic methods can confound results. Many of the studies used only clinical and radiographic criteria to diagnose VAP and not bronchoscopy (Table 1). Bronchoscopic techniques to obtain lower respiratory tract secretions for the diagnosis of VAP are more accurate than tracheal aspirates (Mayhall, 2001). Further, differences in risk factors considered for analysis may have contributed to the variability. For example, some of the studies only looked at VAP risk due to specific bacterial organisms such as Pseudomonas aeruginosa (Baraibar et al., 1997; M. J. M. Bonten et al., 1996). Additionally, differences in analytic methods may have contributed to the discrepancies in the risk factors identified across studies. Some of the studies used only bivariate analysis, while others used more rigorous multivariate analysis to identify risk factors.

Nonmodifiable Risk Factors

Age.

Age is a significant risk factor for VAP (Celis, Torres, Gatell, Almela, Rodriguez-Roisin, et al., 1988; M. H. Kollef, 1993). Despite the use of antibiotics, the morbidity and mortality from an infection in the older adult remain high. The aging immune system in older adults plays a key role in susceptibility to infection. People over the age of 60 have impaired immune system function known as immune senescence which is a decline in cell mediated or adaptive immunity (Liang & Mackowiak, 2007b). The depletion of T-cells with age decreases the antibody response to antigens contributing to the
susceptibility of older adults to infection. Previous studies have demonstrated that the increased incidence of bacterial infections in older adults can be attributed to immune senescence (Butcher, Killampalli, Chahal., Kaya Alpar, & Lord, 2003; Miller, 1996). Coupled with poor circulation, poor nutrition and loss of defense mechanisms such as protective cough, older adults are a vulnerable population for pulmonary infection.

In addition, older adults often have an atypical presentation of infection due to the inability to develop a febrile response, one of the classic signs of infection (Liang, 2007). In a study by Riquelme et al (1997) of elderly patients with community-acquired pneumonia, the classic symptoms for pneumonia of cough, fever and dyspnea were absent in more than two-thirds of elderly patients on admission to the hospital. A study by Trotter et al (2008), on hospital admissions for pneumonia in England demonstrated that the number of deaths from pneumonia was highest in the most elderly and those patients with more coexisting conditions.

The population of older adults in the United States is growing rapidly (Liang, 2007). By 2030, 71.5 million Americans (one in every five) will be over 65 years old with the largest growth in those over 85 years old (G. K. Vincent & Velkoff, 2010). In a study by Russo and Elixhauser (2006), older adults accounted for 13.2 million hospital admissions (one of every three) and 43.6% of national cost for hospital care with pneumonia being the most frequent illness requiring hospital admission.

Several studies have demonstrated that age is a risk factor for pneumonia in older adults. However, many of those studies were done in patients institutionalized in long term care facilities such as nursing homes and not in ICU patients. Only two studies identified advanced age as a risk factor for VAP in ICU patients and only one of those
studies was done prospectively. Since age is a nonmodifiable risk factor for VAP, and the population of older adults is increasing rapidly, gaining knowledge of risk prevention is crucial for this growing vulnerable population to avert further burden on the healthcare system. Therefore, this study will focus on VAP risk in older ICU patients.

**Gender.**

Gender is a significant nonmodifiable risk factor for VAP (Kollef et al., 1997; Rello et al., 2002). In two, large studies in over 9000 patients from more than 100 acute care hospitals, males had a higher risk for VAP. However, the study by Rello (2002) was done retrospectively and included trauma patients. Previous studies have demonstrated that trauma patients have a higher risk for VAP (Baraibar et al., 1997; Cook et al., 1998; Rello et al., 2002). Further, studies have indicated that males are at higher risk for trauma and that trauma is a major health problem especially for young black males (Demetriades et al., 1998; Godbold, Grant, Rydman, Smith, & Johnson, 1996). Nonetheless, in a study evaluating the effect of gender on trauma outcomes, males had a significantly higher incidence of pneumonia than women (5.1% vs. 3.1%, p< 0.001) (Gannon, Pasquale, Tracy, McCarter, & Napolitano, 2004). It is unclear whether males are at increased risk for VAP or whether there is a spurious relationship between trauma, gender and VAP. Therefore, this study will examine gender as a potential risk factor for VAP.

**Comorbid Conditions and Severity of Illness.**

Comorbid conditions and higher severity of illness increase vulnerability for ventilator-associated pneumonia (Apostolopoulou et al., 2003; Celis, Torres, Gatell, Almela, Rodriguezroisin, et al., 1988; Cook & Kollef, 1998; Kollef, 1993; Rello et al., 1994; Tejerina et al., 2006; Torres et al., 1990). Previous studies have demonstrated that
45% of the general population and 88% of elderly have one or more chronic conditions and 65% had multiple chronic conditions (Wolff et al., 2002). Wolff et al (2002), in a study of over one million Medicare beneficiaries aged 65 or older found that having multiple chronic conditions significantly increases the risk of avoidable hospitalizations and preventable complications during hospitalizations. Additionally, people who have more comorbidity may have more disability and rapid changes in health status (Wolff et al., 2002). Additionally, chronic conditions cluster so that a person with one chronic condition is more likely to have other chronic conditions (Wolff et al., 2002). The most common cluster of comorbid conditions in older adults with pneumonia include chronic obstructive pulmonary disease (COPD), chronic heart failure, diabetes, malnutrition, swallowing disorders which increase aspiration risk (File & Tan, 2005) and poor oral health (Scannapieco, 2006).

Several large, prospective studies in over 3000 medical and surgical ICU patients specifically identified COPD as a chronic condition with high risk for VAP (Celis et al., 1988; Torres et al., 1990; Rello et al., 1994; Terejina et al., 2006). COPD is one of the most prevalent chronic diseases in adults affecting more than 18 million Americans and is characterized by inflammation and a dysregulated response of the immune system to noxious agents (Sharma, Hanania, & Shim, 2009). Chronic inflammatory diseases such as COPD set in motion an increased risk for infection (Sethi, 2000). While other chronic conditions increase risk for VAP, COPD has the most significant effect on VAP risk (Celis et al., 1988; Torres et al., 1990; Rello et al., 1994; Terejina et al., 2006). Though, patient acuity and comorbid conditions cannot be eliminated, understanding and controlling for their effect on VAP is important when evaluating VAP risk.
Surgery.

Patients who undergo surgery are at high risk for VAP (Celis et al., 1988; Beck-Sague et al., 1994; Cunnion et al., 1996; Baraibar et al., 1997). VAP accounts for up to one third of the pulmonary infiltrates in postoperative patients (Baraibar et al., 1997; Beck-Sague et al., 1996; Chastre & Fagon, 2002). In a study by Cunnion (1996), comparing adult ICU patients, postoperative patients who had thoracic or upper abdominal surgery or long surgical procedures had higher rates of VAP than medical ICU patients. However, this study had a small sample size of only 20 patients. Nonetheless, larger studies have been done such as a study by the Centers for Disease Control and Prevention (CDC, 1997), and have demonstrated that 75% of patients with pneumonia were infected after surgery. There were methodological issues with some of these studies. One study was done only retrospectively (Celis et al., 1988), while other studies focused only on VAP in surgical patients with respect to specific organisms such as Pseudomonas aeruginosa (Baraibar et al. 1997).

In summary, there is a lack of studies focusing on VAP in elective surgical populations. While there are many factors that predispose a person for increased risk for VAP, having a surgical procedure clearly puts patients at risk. However, it is a risk factor that is necessary for the treatment of the patient. Therefore the focus of this study will be on VAP risk in elective postoperative patients for two reasons; postoperative patients are at greater risk for VAP and they can be evaluated earlier in the process of risk during preoperative testing.
Modifiable Risk Factors

Oral Health.

Poor oral health has been linked to the development of VAP (Johanson et al., 1972; Kerver et al., 1987; Bonten et al., 1996; Fourrier et al., 1998; Ewig et al., 1999). Oral health is defined as the status of the oropharynx to include the teeth, gums, oral mucosa, and oral immunity provided by saliva and accumulation of dental plaque (Munro & Grap, 2004; Treloar & Stechmiller, 1995). In patients with poor oral health, dental plaque accumulates along gingival surfaces leading to bacterial colonization, infection and inflammation of the gingiva and surrounding structures known as periodontal disease (Li et al., 2000). Periodontal disease is the most common oral infection occurring in 10% to 15% of adults and has been found to be associated with systemic diseases such as atherosclerotic heart disease, stroke, chronic obstructive pulmonary disease, endocarditis, bacteremia, oral cancer and diabetes (Li et al., 2000; Taylor, 2001; Warren, 2001; Perkins & Perkins, 2001).

Bacterial pneumonia in patients with periodontal disease is the result of micro-aspiration of oropharyngeal bacteria, which colonize the higher plaque content into the lower respiratory tract (Munro et al., 2006; Li et al., 2000; Taylor, 2001). Those at highest risk for bacterial pneumonia are people with chronic diseases, smokers, those who are immunocompromised, hospitalized patients who are mechanically ventilated, those with poorer oral health, and the elderly (Li et al., 2000; Furr et al., 2004; Munro et al., 2006). The presence of the endotracheal tube in the oropharynx of ICU patients provides a direct route for micro-aspiration of the bacteria that colonize the dental plaque into the lower respiratory tract (Bonten et al., 2004).
Dental plaque of ICU patients has been shown to be colonized by respiratory pathogens such as Pseudomonas aeruginosa and methicillin-resistant Staphylococcus aureus (F. A. Scannapieco, Stewart, & Mylotte, 1992b). Several studies have demonstrated the link between oropharyngeal colonization and VAP (M. J. Bonten et al., 1996; Ewig et al., 1999; Francois Fourrier et al., 1998; Johanson et al., 1972b; A. J. Kerver et al., 1987; F. A. Scannapieco et al., 1992b). Fourrier et al (1992) found that approximately 40% of ICU patients had dental plaque that was colonized by respiratory pathogens and that the respiratory pathogens in the dental plaque were associated with nosocomial pneumonia. Munro (2006) demonstrated that oral health is compromised in the critically ill, worsens over time and that there is a relationship between oral health and VAP. Prior to this study, no study had been done to evaluate oral health and VAP.

Modulation of bacterial colonization through oral care and topical antiseptics to prevent VAP has been investigated in several studies (Table 3). Several randomized control intervention studies including over 3000 patients have demonstrated that providing oral care and applying a topical antiseptic for mechanically ventilated patients improves oral health status by decreasing dental plaque and decreasing oropharyngeal colonization (Table 3).

Recommendations for preventing nosocomial pneumonia in acutely ill patients from the Centers for Disease Control (CDC) and the Healthcare Infection Control Practices Advisory Committee (HICPAC) state merely to implement a comprehensive oral hygiene program which may include an antiseptic agent (Tablan et al., 2004). Consequently, variability exists from nurse to nurse and institution to institution in oral care provided. The American Dental Association (ADA) maintains that the best way to
remove dental plaque is by brushing teeth twice a day with a soft toothbrush (ADA, 2007). In spite of this, foam swabbing continues to be the standard method of oral care in intensive care units (Cutler & Davis, 2005a; M. J. Grap, Munro, Ashtiani, & Bryant, 2003; Hixson, Sole, & King, 1998; Pearson & Hutton, 2002; Sole et al., 2003). However, Munro (2009) in a randomized control trial of 249 patients receiving chlorhexidine only, tooth brushing only, chlorhexidine and tooth brushing, or standard care found that only the topical antiseptic chlorhexidine, not tooth brushing, decreased the early VAP rate. This may be because tooth brushing decreases the number of organisms adherent to the dental plaque but does not provide any bactericidal activity against the bacteria that remain in the oral cavity (Munro, Grap, Jones, McClish, & Sessler, 2009a). Further, none of these studies examined the relationship of VAP to oral health prior to hospital admission.

In summary, a gap exists in knowing which patients in the ICU have poor oral health. Moreover, there is uncertainty in the literature as to the timing, type and frequency of oral care needed to prevent or modify VAP. Further studies are needed to determine when and how it is most important to modify oral health risk.

**Aspiration of Secretions.**

Aspiration of subglottic secretions that are colonized with bacteria is a major cause of VAP (Safdar et al., 2005)Celis et al., 1988; Torres et al., 1990; Rello et al., 1996; Baraibar et al., 1997; Cook et al., 1998; Tejerina et al., 2006). Several studies have demonstrated that the oropharynx of critically ill patients is colonized with pathogenic bacteria (Johanson et al., 1972; Kerver et al., 1987; Scannapieco et al., 1992; Bonten et al., 1996; Fourrier et al., 1998; Ewig et al., 1999). Johanson et al (1972) in a study of 213
ICU patients found that 45% of the patients were colonized with gram negative bacteria on the first day in the ICU. Additionally, Kerver et al (1987) found that 60% of ICU patients were colonized with gram negative pathogens after 5 days; 85% were colonized by day 10 and 100% were colonized by day 15 of the ICU stay. Furthermore, 66% of the respiratory pathogens cultured from bronchoscopic cultures in patients with VAP were the same as the pathogens cultured from the oral cavity. Scannapieco (1992) found that the normally anaerobic Gram-positive oral flora shifts to the more virulent flora of aerobic gram-negative bacilli (Pseudomonas aeruginosa, Klebsiella pneumoniae) and Staphylococcus aureus in ICU patients. Ewig et al (1999) in a study of head injured patients established that the mean time to oropharyngeal colonization with gram negative bacteria is 43 hours after intubation. The predominant microorganisms responsible for VAP are a gram positive organism, Staphylococcus aureus and the more virulent gram negative organisms Pseudomonas aeruginosa and Klebsiella pneumoniae (Chastre & Fagon, 2002).

Supine positioning is a risk factor for VAP (Kollef, 1993) because it facilitates aspiration. Prevention strategies have been aimed at decreasing aspiration of bacterial laden secretions through semi recumbent positioning of patients and subglottic suctioning of pooled secretions from the subglottic space (Collard, Saint, & Matthay, 2003; Kollef, 2004; Tablan et al., 2004). Studies on semi recumbent positioning for reducing VAP are reviewed under the section on the ventilator bundle.

**Prolonged Mechanical Ventilation.**

Several studies have identified the duration of mechanical ventilation as an important risk factor for the development of VAP (Torres et al., 1990; Rello et al., 1994;
Bonten et al., 1996; Cunnion et al., 1996; Cook et al., 1998; Ewig et al., 1999).

Additionally, Cook et al. (1998), in a study of 1014 patients ventilated for longer than 48 hours found that risk for VAP changed over time. The daily risk for VAP increased over time until day five (3.3% per day), then decreased over the duration of stay to 2.3% per day at day ten and 1.3% per day at day fifteen and beyond (Cook & Kollef, 1998). This may be because nearly 50% of VAP is due to early onset VAP caused by gram positive aerobic oral and respiratory tract pathogens (Cook & Kollef, 1998). Late onset VAP is often caused by more virulent gram negative organisms that are less susceptible to antibiotics (Chastre & Fagon, 2009). Mortality rates for gram negative pneumonias such as Pseudomonas aeruginosa range from 70-80% (Chastre & Fagon, 2002). Cunnion et al. (1996) noted that mechanical ventilation for longer than one day increased the risk 12-fold over non-ventilated patients. Late onset VAP is VAP which occurs five or more days after initiation of intubation and mechanical ventilation. Though this study by Cunnion (1996) was a longitudinal study, the sample size was small with only 20 patients.

Studies have demonstrated that the use of noninvasive ventilation whenever possible and reduction in the duration of mechanical ventilation reduces the risk of healthcare-associated pneumonia (Safdar et al., 2005; Susan E. Coffin et al., 2008; Tablan et al., 2004). In a study of 100 medical ICU patients, (Girou et al., 2000) pneumonia rates were found to be lower in patients supported with noninvasive ventilation than in intubated and mechanically ventilated patients (8% vs. 22%, p=0.02). Further, in a meta-analysis of randomized control trials on the use of noninvasive ventilation for the treatment of respiratory failure in patients with chronic lung disease, the use of noninvasive ventilation resulted in a 62% decrease in mortality when compared
to patients who were supported by intubation and mechanical ventilation (Lightowler, Wedzicha, Elliot & Ram, 2003). Since endotracheal intubation remains the most important risk factor for the development of healthcare-associated pneumonia (Vincent et al., 1995; Chevret et al., 1993; Horan, et al., 1993; Chastre & Fagon, 2002; Davis, 2006) reducing the duration of time that the endotracheal tube is in place has been demonstrated to be important in reducing VAP risk. Therefore, studies that explore VAP risk factors must take into account the duration of mechanical ventilation in examining VAP risk.

**Medications.**

The effect of prior antibiotic use in the risk for VAP is mixed (Beck-Sague et al., 1991; Kollef, 1993; Rello et al., 1996; Ewig et al., 1999). In a review on antibiotic prophylaxis in the critically ill, it was found that antibiotic administration reduced VAP (D’Amico et al., 1998). However, the evidence suggests that prophylactic antibiotics only delay VAP or prevent early onset VAP while increasing the risk of infection with more virulent gram negative multi-drug resistant organisms (Chastre & Fagon, 2002). Early onset VAP is often associated with more antibiotic-sensitive gram positive organisms than VAP which occurs later in the hospitalization (Chastre & Fagon). Previous studies have demonstrated that prophylactic use of antibiotics in the ICU increases the risk of infection from multi-drug resistant pathogens (Rello et al., 1993; Kollef, 1993; Trouillet et al., 1998). In a study by Kollef (1993) of 320 patients, previous antibiotic use was associated with VAP. Several studies have demonstrated that rapid and accurate identification and treatment of VAP with appropriate antibiotics improves outcomes (Torres, 1990; Kollef et al., 1999; Rello et al., 1997). It is unclear whether antibiotics
increase or decrease VAP risk. Both under and overtreatment of VAP appear to have negative consequences.

In summary, extensive research on VAP over the past two decades has suggested many risk factors. Despite common themes many disparities exist. Several reasons may exist for these variable results. First, different diagnostic criteria may have led to differing results. The diagnosis of VAP consists of three components: clinical signs of infection, radiographic signs of new or worsening infiltrates, and microbiological evidence of pulmonary infection (Chastre & Fagon, 2002). Many of these criteria are nonspecific and can be attributed to other conditions especially in critically ill patients which can result in misdiagnosis of VAP. Noninfectious causes of pulmonary infiltrates may have been misdiagnosed as VAP. Studies that used noninvasive diagnosis or only clinical or radiographic diagnosis may have diagnosed VAP in a patient who had a noninfectious cause of pulmonary infiltrates (Table 1).

Second, the difference in types of patient populations also may play a contributing factor in the mixed results. These studies have included diverse patient populations with variability in age, comorbidities, severity of illness and primary diagnosis which may confound results (Table 1). For example, patients with comorbidities and higher severity of illness have a greater risk for VAP (Celis et al., 1988; Torres et al., 1990; Rello et al., 1994; Cook et al., 1998; Terejina et al., 2006; Kollef, 1993; Apostolopoulou et al., 2003; Rello et al., 2002). Further, many of the studies included both medical and surgical patients which may confound results when evaluating VAP risk since surgical patients are at greater risk for VAP (Celis et al., 1988; Beck-Sague et al., 1994; Cunnion et al., 1996; Baraibar et al., 1997).
Another contributing factor to these mixed results may be methodological in that different analytical methods were used and different risk factors were considered for analysis. A few studies evaluated risk for VAP due to more virulent gram negative organisms (Bonten et al., 1996; Baraibar et al., 1997). Some of the studies used bivariate correlations to draw conclusions, while others used multivariate analysis such as regression and the use of covariates to draw conclusions. In studies where multivariate analysis was used, risk factors that were significant in univariate analysis were no longer significant when multivariate analysis was employed. Importantly, no studies have attempted to identify modifiable risk factors occurring before the ICU setting. A more precise understanding of risk factors in individuals and populations is still needed. Improvement in understanding of these risk factors may allow for development of better prevention strategies.

**Prevention Efforts to Decrease VAP in the ICU (Ventilator Bundle)**

Efforts to prevent or reduce the occurrence of nosocomial infections have been recommended and tested in clinical practice and in intervention studies. One example of these efforts is the Ventilator Bundle, a series of evidence-based interventions for patients receiving mechanical ventilation that when implemented together result in a significant reduction in VAP rates (IHI, 2012). Components of the Ventilator Bundle include: (1) backrest elevation, (2) daily “sedation vacations” and assessment of readiness for extubation, (3) stress ulcer prophylaxis, and (4) deep vein thrombosis prophylaxis (IHI, 2012; Resar et al., 2005). The components of the ventilator bundle were chosen because they are interventions to improve care of ventilated patients, not specifically to prevent VAP (George et al., 1998; Resar et al., 2005). However, the only
components of the ventilator bundle that have documented evidence for reducing VAP are backrest elevation and daily sedation vacations to reduce duration of mechanical ventilation (Resar et al., 2005). Although oral care is not a usual part of the Ventilator Bundle, the Centers for Disease Control and Prevention have recommended oral care for patients at risk for VAP because studies have demonstrated oral care to be effective in reducing VAP (Bergmans et al., 2001; DeRiso, Ladowski, Dillon, Justice, & Peterson, 1996; F. Fourrier et al., 2005; Robert Garcia et al., 2009; Genuit, Bochicchio, Napolitano, McCarter, & Roghman, 2001; Mary Jo Grap & Munro, 2004; Houston et al., 2002; Koeman et al., 2006; Mori et al., 2006; Munro, Grap, Jones, McClish, & Sessler, 2009; Yoneyama, Yoshida, Matsui, & Sasaki, 1999). Therefore, only the efficacy and limitations of the use of backrest elevation, sedation vacations and oral care as VAP prevention strategies will be discussed.

**Backrest Elevation**

Elevating the head of the bed reduces the risk for aspiration of oropharyngeal and gastric secretions and improves spontaneous ventilation, which reduces the risk of VAP (Institute for Healthcare Improvement, 2009). Drakulovic et al. (1999), in a randomized control trial of 86 IVU patients assigned to semi recumbent position (45 degrees) or supine body position found that semi recumbent position reduced the rate of nosocomial pneumonia by 75% (p= 0.003) and was especially advantageous in patients receiving enteral nutrition. However, keeping critically ill patients at the appropriate backrest elevation has been shown to be difficult to achieve in clinical practice (Grap et al., 2005). In a longitudinal descriptive study by Grap et al (2005), backrest elevations were less than 30 degrees 72% of the time and less than 10 degrees 39% of the time. In spite of
this, only backrest elevation on the first day of mechanical ventilation had a significant effect on incidence of VAP (Grap et al., 2005). Furthermore, a prospective multicenter study in four ICUs in three university hospitals by van Nieuwenhoven et al (2006) found backrest elevation of 45 degrees was not achieved 85% of the time. The average achieved backrest elevation was 28 degrees and this did not prevent the development of VAP (van Nieuwenhoven et al., 2006). Backrest elevation has been demonstrated to reduce VAP risk however compliance with backrest elevation has been poor (Grap et al., 2005; van Nieuwenhoven et al., 2006).

**Sedation Vacation**

Continuous infusions of sedative medications are used to decrease anxiety and agitation associated with mechanical ventilation and to maintain ventilator synchrony (IHI, 2012). However, Kollef et al (1998) found that the use of continuous sedation was associated with an increase in the duration of mechanical ventilation. Prolonged mechanical ventilation has been shown in several studies to increase VAP risk (Torres et al., 1990; Rello et al., 1994; Bonten et al., 1996; Cunnion et al., 1996; Cook et al., 1998; Ewig et al., 1999). Daily interruption in the infusion of continuous sedation is referred to as a “sedation vacation.” Interruption of sedation allows for assessment for the readiness of the patient to wean from mechanical ventilation (IHI, 2012). In a randomized control trial of 128 patients who received a daily interruption in the continuous infusion of sedation, Kress et al (2000), demonstrated a decrease in the duration of mechanical ventilation (4.9 days in the intervention group vs. 7.3 in the control group \(p=.004\)) and a decrease in ICU length of stay (6.4 days in the intervention group vs. 9.9 days in the control group \(p=.002\)). However, there are risks of interrupting continuous sedation.
Risks include the potential for increased agitation and self extubation as well as a risk for dysynchrony with the ventilator which may lead to arterial desaturation (IHI, 2012; Kress, 2000). Patients must be carefully observed during the procedure to prevent self extubation (IHI, 2012).

**Oral Care**

Bacteria that normally colonize the oral cavity are gram positive organisms. During critical illness, bacteria that colonize the oral cavity change to predominately gram negative organisms within 48 hours of admission to the intensive care unit (Scannapieco, 1992; Munro et al., 2006). Because dental plaque acts as a reservoir for gram-negative pathogens that cause ventilator-associated pneumonia in critically ill patients, oral care is an evidence-based prevention strategy to reduce the risk of VAP (Tablan et al., 2005). Modulation of bacterial colonization through mechanical interventions such as tooth brushing and pharmacological interventions such as topical antiseptics to prevent VAP have been investigated in several studies (Table 3).

There was a wide variation in what was done in most of the studies. However, intervention studies have demonstrated that providing oral care and applying a topical antiseptic for mechanically ventilated patients improves oral health status by decreasing dental plaque and decreasing oropharyngeal colonization and thus reduces nosocomial pneumonia rates. Recommendations for preventing nosocomial pneumonia in acutely ill patients from the Centers for Disease Control (CDC) and the Healthcare Infection Control Practices Advisory Committee (HICPAC) state to implement a comprehensive oral hygiene program which may include an antiseptic agent (Tablan et al., 2004). Additionally, the American Association of Critical Care Nurses has developed guidelines
for oral care in critical care (American Association of Critical Care Nurses, 2006). Nevertheless, oral care is a low priority in the care of ventilated patients (Cutler, 2005; Grap & Munro, 2003; Hixson, 1998). Binkley et al (2004), in a study examining nurses’ attitudes and beliefs about oral care demonstrated that nurses considered oral care in the ICU to be technically difficult and unpleasant. Nurses most often used foam swabs and felt that despite their efforts in oral care, the mouths of their mechanically ventilated patients got worse over time. In a study on factors affecting quality of oral care in the ICU, Furr (2003) indicated that ICU nurses lack time for oral care and find it unpleasant. Further, Munro (2009) demonstrated that only the use of the topical antiseptic chlorhexidine, but not tooth brushing reduced early VAP.

The timing of oral care interventions may have an effect on VAP rate. Grap et al (2004), in a pilot study on 34 trauma patients found that the use of chlorhexidine soon after intubation (< 24 hours) decreased oropharyngeal colonization. In two studies on the use of chlorhexidine perioperatively in elective cardiac surgery patients, chlorhexidine was found to reduce nosocomial respiratory infection (DeRiso et al., 1996; Houston et al., 2002). These findings suggest that the use of chlorhexidine earlier may delay or alleviate the development of VAP. The limited time and resources in the ICU may suggest that a strategy of oral screening and care prior to the ICU setting may be more effective and feasible.

**Older Adults, Oral Health and VAP Risk**

While poor oral health is a risk factor for VAP, it is a significant risk factor for many older adults because of disparities in oral health care of older adults. Despite an improvement in oral health status in the United States over the past thirty years by
fluoridation of community water supplies, preventative dental visits and new technologies which allow for preservation of teeth (Mertz & O'Neil, 2002), oral health disparities have been growing during this same time period for the most vulnerable and at risk populations such as the older adult (Zabos, Northridge, Ro, Trinh, Vaughan, Howard, et al., 2002). Barriers to oral health care are multifactorial; however, lack of access related to lower socioeconomic status appears to be the primary indicator of oral health disparities (Mertz & O’Neill, 2002). Yet, adequate oral health is as important for all older adults as it is for other age groups, however, oral health is frequently overlooked in the health of older adults (Vargas et al., 2001).

Older adults who live below the poverty line were 3 times as likely to report unmet oral health needs (Vargas et al., 2001). Therefore, oral health has been referred to as the hidden and neglected epidemic (M. Allukian, Jr., 2008; Zabos, Northridge, Ro, Trinh, Vaughan, Moon Howard, et al., 2002). Epidemiologic studies have shown the incidence of periodontal disease in those 65 years and older to be 41% (Vargas et al., 2001). Studies in adult outpatients with severe periodontitis showed that Pseudomonas aeruginosa, Acinetobacter baumanii, and Enterobacteriaceae (common VAP pathogens) are part of the normal oral flora of 10 to 14% of patients (Slots, Rams, & Listgarten, 1988). In a longitudinal study of older adults by Terpenning (2001), dental decay and periodontal pathogens were significant risk factors for pneumonia. In reviews by Scannapieco et al. (2003) and Azarpazhooh et al. (2006), an association was found between periodontal disease and pneumonia especially among the elderly. It is not known if the identification of preoperative older adult patients with poor oral health can lead to strategies of early selection or prevention which are more effective than later
intervention. The proposed study will be the first to examine the role of preoperative oral health in older ICU patients and will add to the empirical literature in this area of research.

**Reducing Risk Factors Prior to Hospital Admission**

Infections in hospitalized patients increase morbidity, mortality, hospital length of stay and cost (Chastre & Fagon, 2002; Bonten et al., 2004; Safdar et al., 2005). The healthcare delivery system in the United States has focused on model of treatment of disease rather than prevention. However, increasing numbers of healthcare-associated infections and antibiotic resistant pathogens has shifted the focus toward prevention. This notion of prevention is the focus of the Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee (HICPAC) in the form of guidelines for preventing and controlling healthcare-associated infections (CDC, 2009). In populations of patients particularly vulnerable to infection such as the elderly and those with pre-existing chronic conditions (Celis et al., 1988; Torres et al., 1990; Kollef, 1993; Rello et al., 1994; Cook et al., 1998; Terejina et al., 2006), preventive strategies may be more effective when begun prior to admission to the hospital. The concept of reducing risk of infections in at risk populations prior to hospitalization has been demonstrated to be effective in patients prior to undergoing cardiothoracic surgery in two areas: prevention of infective endocarditis and prevention of surgical site infections.

**Prevention of Infective Endocarditis with Preoperative Oral Health Evaluation**

Infective endocarditis is a rare condition with high morbidity and mortality despite antibiotic treatment (Wilson et al., 2007). For more than a century, bacteria that colonize the oral cavity have been recognized as a potential source of bacteria causing
infective endocarditis (Wilson et al., 2007). For this reason, antibiotic prophylaxis has traditionally been given to patients at risk for infective endocarditis prior to dental, genitourinary or invasive procedures. However, studies have indicated that most cases of bacteremia caused by oral microflora are caused by routine daily activities in patients with poor oral health such as chewing food, tooth brushing, flossing, using toothpicks and other activities (Lockhart et al., 2007; Wilson et al., 2007). In a double blind, placebo controlled study of 194 patients, Lockhart et al (2007) demonstrated that patients with poor oral hygiene had a greater association with infective endocarditis related bacteremia after tooth brushing and improving oral hygiene prior to surgery reduced the risk of infective endocarditis. Due to concerns about the risk of antibiotic prophylaxis outweighing the benefits, new AHA guidelines limit antibiotic prophylaxis to only the most high risk patients (those with prosthetic cardiac material., unrepaired congenital heart defects, cardiac transplantation recipients and those with previous history of infective endocarditis) and have shifted the focus to improving oral health (Wilson et al., 2007). Thus, identifying those at high risk preoperatively and when possible correcting poor oral health before surgery may be an appropriate strategy for VAP as well.

**Prevention of Surgical Site infections with Nasal Mupirocin**

Nasal carriage of Staphylococcus aureus is a risk factor for Staphylococcus aureus infections. Patients who are nasal carriers of Staphylococcus aureus have an increased risk of surgical site infections (Calia, Wolinsky, Mortimer, Abrams, & Rammelka, 1969; Kluytmans et al., 1995). In a prospective study on 1796 patients undergoing cardiothoracic surgery, Kluytmans et al., (1996) demonstrated a reduction in the surgical site infection rate (control group 7.3% and intervention group 2.8% p < .0001) by treating
752 patients with nasal mupirocin (antibiotic) to eliminate nasal carriage of S. aureus prior to cardiothoracic surgery. In a randomized, double blind, placebo-controlled trial by Bode (2010), 6771 patients were screened on admission for nasal carriage of S. Aureus. Of the 1250 with positive S. aureus cultures, 808 had a surgical procedure. The rate of infection was 7.7% in the control group and 3.4% in the group treated with mupirocin prior to surgery. Preoperative elimination of nasal carriage of S. aureus reduces the risk of surgical site infections (L. G. Bode et al., 2010; J. A. Kluytmans et al., 1996).

**Summary**

Healthcare-associated pneumonia is a common complication of mechanical ventilation with high morbidity and mortality despite treatment with antibiotics. Since VAP is no longer considered a consequence of treatment but a preventable healthcare error, strategies to reduce or prevent the incidence of VAP are crucial. Second, there are multiple risk factors for the development of VAP. Endotracheal intubation remains the most important risk factor for the development of healthcare-associated pneumonia and the risk increases daily. Causative microorganisms can come from exogenous environmental sources such as contaminated respiratory equipment or endogenous patient factors such as oropharyngeal colonization with respiratory pathogens. The wide range of risk factors may relate to differences in patient characteristics and diverse ICU environments. Elderly patients with poor oral health are at increased risk for developing VAP. Our understanding of risk factors is constantly changing. More information on risk factors is needed to develop effective prevention strategies. Third, efforts to prevent or reduce the occurrence of nosocomial respiratory infections that have been combined in a
bundle known as the Ventilator Bundle have resulted in a significant reduction in VAP rates. However, compliance with the components has been variable in the ICU setting. Finally, the evidence suggests that identifying and reducing risk factors prior to hospital admission, such as improving oral health prior to cardiac surgery to reduce the risk of endocarditis or administering mupirocin prior to surgery to prevent surgical infections from S. aureus, may be an effective means of decreasing risk of infection in at risk populations.
Chapter Three

Research Design and Methods

The purpose of this study was to examine pre-hospital oral health status as a risk factor for ventilator-associated pneumonia in older adult ICU patients. It focused on older adult surgical patients, a vulnerable group with higher infection risk. This chapter delineates the research methods used in this study, including the design, setting, sample and procedures. The instruments that were used and the statistical analysis will be discussed.

Research Questions

There were five research questions in this study of pre-hospital oral health as a risk factor for ventilator-associated pneumonia:

1. What is the oral health status of older adults prior to surgery?
2. What is the oral health status of older adults after intubation?
3. What is the relationship between pre-hospital oral health and oral health after intubation in older intensive care unit patients when controlling for age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use?
4. How do age, gender, acuity, comorbidity, smoking history, surgery type, and antibiotic use change oral health over time from preoperative to postoperative?
5. What is the relationship between oral health (pre-hospital and post-intubation) and ventilator-associated pneumonia in older adult intensive care unit patients when controlling for age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use?
**Research Design**

This was a prospective study of variables that may influence the risk for ventilator-associated pneumonia. A descriptive, correlational longitudinal design was used to measure the relationship between oral health (preoperative and post-intubation) and ventilator-associated pneumonia. The proposed study used repeated measures of oral health (preoperatively and post intubation) and ventilator-associated pneumonia (VAP) to examine the relationship between change in oral health status after a period of mechanical ventilation with occurrence of ventilator-associated pneumonia.

![Figure 2. Study Model](image)

- **Nonmodifiable Person Factors**
  - Age
  - Gender
  - Comorbid conditions
  - Acuity

- **Modifiable Person Factors**
  - Preadmission oral health

- **Nonmodifiable Environmental Factors**
  - Surgery Type

- **Modifiable Environmental Factors**
  - Antibiotics
  - Length of mechanical ventilation

**Clinical Therapeutics**
- Oral Intubation
- Mechanical Ventilation

**Human Responses: Pathophysiologic**
- Post-intubation oral health
- Ventilator-associated pneumonia
A descriptive correlational design was chosen and was appropriate for this study because the phenomenon of interest is the relationship of pre-hospital oral health to oral health after intubation and to ventilator-associated pneumonia. Since the aim of this study was to identify predictors or antecedents of VAP (outcome), a prospective approach was used. A prospective correlational design with a longitudinal approach has been used in other studies of variables that influence risk for ventilator-associated pneumonia. A prospective descriptive correlational design with repeated measures was used to explore the relationship between ventilator-associated pneumonia and changes in oral health status during the first seven days after intubation in a study by Munro et al (2006) and in a study examining bacterial colonization patterns in mechanically ventilated patients with head injuries as a risk factor for VAP (Ewig, et al 1999). Fourrier et al (1998) used a prospective design with repeated measures of dental plaque, saliva and tracheal aspirates every five days until discharge or patient death to study colonization of dental plaque with aerobic pathogens in a study of dental plaque as a source of nosocomial infection in ICU patients.

A prospective descriptive correlational design was chosen because it has the following advantages. It is an efficient and flexible method for investigating complex relationships among variables that cannot be manipulated (Lobiondo-Wood & Haber, 2006). Further, it lays the groundwork for future interventional studies aimed at improving oral health prior to elective surgery. The primary disadvantage of a correlational design is the inability to determine causality due to lack of manipulation of the independent variable, lack of control and no randomization (Lobiondo-Wood & Haber, 2006).
Threats to Internal Validity

Internal validity refers to the cause and effect of a relationship (Lobiondo-Wood & Haber, 2006). It is the degree to which inferences can be made that the effect on the dependent variable is only due to variation in the independent variable (Shadish, Cook, & Campbell, 2001). Three components necessary for the establishment of causality are temporal precedence, covariation of the cause and effect and no plausible alternative explanation (Burns & Grove, 2004). For the purposes of this study, internal validity refers to the extent to which it can be inferred that poor pre-hospital oral health status is associated with poor oral health after intubation and the occurrence of VAP. Threats to internal validity include history, maturation, testing, selection bias, instrumentation, experimental mortality and statistical regression. Each will be defined and considered for their significance to this study.

The threat of ambiguous temporal precedence refers to a lack of clarity about the direction of causation between two variables (Shadish et al., 2001). It can occur in correlational studies. However, it is an unlikely threat in this study because the measurement of the independent variable precedes the measurement of the outcome variable.

Covariation of the cause and effect is the process of establishing a cause and effect between two variables. The cause must be present whenever the effect occurs (Burns & Grove 1997). In this study, if there is poor oral health then VAP will occur. If oral health status is good then there will be less risk of VAP occurring. Covariation of the cause and effect may be a threat in this study because there may be alternative
explanations for the occurrence of VAP (dependent variable). This threat was minimized by controlling for other known risk factors for VAP.

The threat of history refers to events that occur during the time of a study that may have an effect on the outcome or dependent variable (Shadish et al., 2001). Much has been written by the press regarding the connection between oral health and systemic disease (Zeltner, 2010). The threat of history may occur in this study if there is a campaign to improve the oral health of the public based on this new information. One such effort is the Smiles for Seniors oral health education initiative of the Ohio Dental Association. The goal of this initiative is to educate older adults or their caregivers about the importance of continued good oral health for older adults (ODA, 2005). If there is an additional oral health initiative during the study period, potential subjects will be asked as part of study enrollment if they have participated in the initiative. Data for subjects who have participated in an oral health initiative will be tracked for differences in the groups.

Another example of a history related threat would be if there was implementation of a new oral health protocol or Ventilator Bundle in the ICU during the study period. Oral health status and VAP rates would likely be affected. If a new oral health protocol occurs in the ICU during the study period, it will be noted during data collection and analyzed for effect on study results during data analysis. The threat of history will be minimized in this study by the short interval between the first set of oral health status measures (preoperative oral health assessment) and the subsequent set of oral health status measures (day one and day three after intubation). The timing from the first measure to the final measure should occur within a two week time period minimizing the threat of history on internal validity.
Maturation refers to naturally occurring changes in human physical and psychological development that may occur within a study subject during the course of the study that could influence the outcome of the study (Lobiondo-Wood & Haber, 2006; Shadish et al., 2001). Maturation can be seen in older adults as they become fatigued more easily and have difficulty acquiring new skills (Shadish et al., 2001). However, the threat of maturation is unlikely in this study because the interval between study measures will be short, there are no skills required for participation in this study and the preoperative oral health exam requires only 10 minutes.

The threat of testing refers to the effect a pretest can have on a posttest (Lobiondo-Wood & Haber, 2006). This may become a threat in this study if the study participants improve their oral hygiene or receive a dental cleaning after the preoperative measure and before the postoperative assessment. The threat of testing will be minimized in this study by performing the preoperative assessment during preadmission testing. In this setting, preadmission testing usually occurs within a few days of the scheduled surgery date. The short interval between the preoperative measure of oral health and the postoperative measure of oral health will therefore be diminished, reducing the possibility of a dental visit or significant improvement in oral hygiene by the subjects. However, subjects or their family members will be asked if there has been a visit to a dentist or change in oral health practice since the preoperative assessment. Dental visit or change in oral care by subjects from the preoperative assessment to the postoperative period will be noted during data collection and analyzed for effect during data analysis.

Instrumentation threats are threats to the outcome of a study due to changes in an instrument used to measure variables or changes in observer technique that may result in
a measurement error (Lobiondo-Wood & Haber, 2006). Instrumentation threats may
occur in this study if the researcher changes tools or becomes more proficient in the use
of the data collection tools leading to improved accuracy in data collection. The threat of
instrumentation will be minimized in this study by training of the researcher in the use of
the data collection tools prior to study inception and by avoiding switching instruments
during the study. See the Variables/Measures/Instruments section for reliability and
validity information for each of the data collection tools to be used during data collection
and a description of the intra-rater reliability protocol.

Selection bias refers to differences in study subjects from the general population
due to nonrandom selection of study participants (Shadish et al., 2001). Since this study
will not use a randomized protocol, selection bias is a threat. Threat of selection bias will
be minimized in this study by strict adherence to inclusion and exclusion criteria
delineated in the study protocol. The investigator will carefully monitor enrollment to
ensure a sample representative of the population as delineated in the sampling plan in the
section on Research Setting. If the sample is not representative of the population, the
investigator will enroll an additional number of subjects until the proposed proportion is
reached.

Experimental Mortality, also known as attrition, indicates a loss of subjects over
the course of the study that can be attributed to withdrawal or patient mortality.
Experimental mortality may affect the results of the study if subjects who remain in the
study differ from those that are lost from the study due to death or withdrawal (Lobiondo-
Wood & Haber, 2006). Experimental mortality may be an issue in this study because a
previous study on a similar population (Douglas, Daly, Kelley, Otoole, & Montenegro,
demonstrated that 13% of elderly intubated surgical patients who require more than 24 hours of mechanical ventilation die or were extubated within the first 3 days of mechanical ventilation. Descriptive statistics (age, gender, race/ethnicity, type of surgery, and oral health status) of the subjects lost to attrition will be compared to those that remain in the study through all three time periods to detect any differences. If a difference between groups is detected that affects the outcome measure, additional subjects will be enrolled.

Statistical Regression or regression towards the mean refers to the phenomena of selecting subjects for treatment because of extreme pretest scores. The regression of scores toward the mean in a pretest-posttest design can be mistaken for a treatment effect (Shadish et al., 2001). Statistical regression can also occur with repeated measures that are correlated (Shadish et al., 2001). The threat of statistical regression toward the mean will be minimized in this study because subjects will not be identified for participation in this study based on extreme scores on pretest measures. Further, pre-intubation and post intubation oral health status scores for individuals would be unlikely to regress to the mean. However, changes in pretest to posttest scores could occur if subjects received a dental cleaning or improved on their usual oral care between the preoperative oral exam and the postoperative oral exam. Due to the short interval between the preoperative oral exam and the postoperative measures, a dental visit would be unlikely. To evaluate for this as a possible threat during the study, subjects or their family members will be asked if there has been a dental cleaning or change in oral care practice in the time period since the initial oral exam. Regression toward the mean will be assessed during data analysis.
Threats to External Validity

External validity pertains to the extent to which the causal relationships in a study can be generalized to other populations, settings and times (Ferguson, 2004; Shadish et al., 2001). Generalizability is based on the degree to which the sample is representative of the target population and whether the data can be applied to other situations (Ferguson, 2004). Threats to external validity or “representativeness” (Ferguson, 2004, p 17) are (1) interaction of selection and treatment, (2) interaction of setting and treatment and (3) interaction of multiple treatments (Ferguson, 2004).

Interaction of selection and treatment refers to the threat of having a sample which is not representative of the population to which the researcher wants to generalize (Ferguson, 2004; Lobiondo-Wood & Haber, 2006). Potential threats to the external validity in this study are the use of a convenience sample of patients scheduled for elective surgery and a high refusal rate. Based on previous studies of ICU patients by Douglas and Daly (2007), the refusal rate in this population is 22%. However, that refusal rate is based on obtaining consent of the caregivers of mechanically ventilated patients and not obtaining consent from the patients themselves. In a study of surrogate decision makers, Azoulay (2005), found consenting to research was associated with stress by the surrogate decision makers. In a similar study on oral health status in ICU patients, Munro et al (2006) had a refusal rate of approximately 24%. However, consent was also obtained from the legally authorized representative in the Munro (2006) study. The short time frame and minimal burden on study participants will hopefully minimize the refusal rate and reduce the risk of interaction of selection and treatment as a threat. Data will be collected on the number of subjects approached and the number that refuse to participate.
Demographic characteristics (age, gender) of those who refuse to participate will be followed. Descriptive statistics (age, gender, race/ethnicity and type of surgery) of the sample will be analyzed at the beginning and at the end of the study to assure a representative sample.

*Interaction of setting and treatment* refers to changes in the response of study participants due to the effect of participating in an experiment (Lobiondo-Wood & Haber, 2006). The threat of interaction of subject and treatment can become an issue if the setting of the study is an artificial environment. This threat will be minimized by using the natural setting of the preadmission testing area for preoperative oral health exam and the natural setting of the ICU for the study.

Response of study subjects due to the effect of being studied rather than because of an experimental intervention is referred to as the Hawthorne effect (Lobiondo-Wood & Haber, 2006; Ferguson, 2004). The Hawthorne effect may be exhibited in this study by the study participants and by the caregivers of the study subjects. For example, as a result of the awareness of being in this study, the patient may improve their oral hygiene prior to ICU admission. Further, there may be increased clinical surveillance of the oral cavity of study participants by nurses and an improvement in oral care beyond the standard of care. To evaluate for the Hawthorne effect threatening external validity, subjects or their family members will be asked if they have seen a dentist or changed their oral care practices since the preoperative oral health assessment. Additionally, type and frequency of oral care provided in the ICU will be tracked.

*Interaction of multiple treatments* refers to a threat to generalizability when an outcome is due to the cumulative effects of multiple treatments and not to the
experimental intervention or treatment alone (Ferguson, 2004). This also can occur in a pretest-posttest design. When a pretest is used it can affect or “prime” individuals’ responses on a posttest (Lobiondo-Wood & Haber, 2006, p. 215). This threat is unlikely in this study because this is not an experimental study. Although this study uses a pretest-posttest design, the data will be collected by the researcher and not completed by study participants.

**Research Setting**

The study was conducted in the six adult cardiovascular intensive care units (CVICU) of the Cleveland Clinic in Cleveland, Ohio. The Cleveland Clinic is a 1400 bed quaternary care multispecialty academic medical center. This institution was chosen because it admits a diverse population of patients to its cardiovascular intensive care units, which is reflective of the national population of ICU patients. Further, it is a medical center with a high daily volume of patients, assuring availability of an adequate sample size over the enrollment period of 12 months.

**Sample**

Older adults who were scheduled for elective surgery and were expected to require an endotracheal tube and care in the ICU after surgery were the population studied. The sampling frame was older adult patients who would undergo cardiac surgery, thoracic surgery, abdominal surgery or vascular surgery. The surgical eligibility criterion was selected because postoperative patients have higher rates of nosocomial pneumonia (Bonten et al., 2004; Chastre & Fagon, 2002). The four surgical types were chosen because patients who undergo these major surgeries often require intubation and
mechanical ventilation in the postoperative period. A convenience sample was selected from the preadmission testing department daily schedule.

**Inclusion and Exclusion Criteria**

A sample of individuals who met study criteria and provided consent was obtained. Complete eligibility criteria for patients was: (1) patients over 50 years of age, (2) within four weeks of their scheduled surgery date for one of four surgeries: cardiac surgery, abdominal surgery, thoracic surgery, and vascular surgery, (3) required oral intubation and mechanical ventilation post-surgery.

Exclusion criteria were: (1) patients admitted to the ICU with a diagnosis of pneumonia on or before the first day of mechanical ventilation, (2) patients who were completely edentulous or (3) patients who would be having oral, maxillofacial or airway surgery. Patients with a previous diagnosis of pneumonia within the past 14 days were excluded because a clinical diagnosis of pneumonia prior to intubation confounds the determination of a healthcare-associated pneumonia. Edentulous patients were excluded because dental plaque accumulation could not be assessed. Patients with oral, maxillofacial and airway surgery were excluded because of the potential for instability in the airway after these types of surgeries and the risk for accidental extubation during study procedures. There were no exclusions based on the patient’s ability to read or write.

**Sampling Procedure**

In order to identify potential subjects for the study a two-phase process was employed. In the first phase a list of subjects scheduled for preoperative testing was obtained each morning from the Preadmission testing nurse coordinator in the Preoperative Admissions Testing Clinic. From this list, a smaller list of potential subjects
who met the age and surgical type eligibility criteria (cardiac surgery, abdominal surgery, thoracic surgery, and vascular surgery) was generated. Each potential subject was approached by the investigator, screened again for eligibility, and if eligible, was asked to provide written consent to participate in the study. It was explained to the potential subjects that data (clinical information and oral health status) would be obtained at three times: preadmission testing visit (Research question 1), and on day 1 and day 3 in the ICU (if they required oral intubation and mechanical ventilation post-surgery) (Research questions 2-5).

If they required oral intubation and mechanical ventilation post-surgery, consent was being requested for their participation in the second phase of the study (Research questions 2-5). Therefore, while consent was obtained at the preadmission testing phase, the potential subjects were asked to consent to pre-operative assessment of oral health and post-intubation measures (should they require oral intubation and mechanical ventilation post-operatively in the ICU).

The sampling plan was established with the expectation of obtaining a sample of women and minorities representative of the Cleveland population at the present time (52% women, 22% African American). All eligible patients who met eligibility criteria were asked to participate.

**Power Analysis for Sample Size**

The major focus of the proposed study was to examine the relationship between oral health (interval level data) and the outcome of ventilator-associated pneumonia (dichotomous variable) when controlling age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use. This relationship has been explored in two
prior studies (Fitch, Munro, Glass, & Pellegrini, 1999; Munro, Grap, et al., 2006) with large effect sizes ($r$) reported in both (0.65 and 0.85). To be conservative and avoid making a Type II error, a medium effect size ($r = .30$) was used in the proposed study.

An alpha of .05 was chosen because this is an exploratory study with little potential for harm therefore, a 5 percent chance of claiming a relationship when there is none (Type I error) is acceptable. A Type I error in this study means that the investigator might report that pre-hospital oral status is a risk factor for ventilator-associated pneumonia when there was no relationship. One implication for this Type I error is that interventions may be put into place to improve pre-hospital oral health prior to elective surgery. This could result in misuse of clinical resources.

A non-directional hypothesis was chosen because although there have been previous studies on the relationship between oral health and VAP, there have been no previous studies on the relationship between pre-hospital oral health and ventilator-associated pneumonia. Power of .80 will be utilized because a 20% chance of incorrectly establishing no relationship (Type II error) is acceptable to the investigator since this was a descriptive study with little chance of harm if the relationship between oral health and ventilator-associated pneumonia was not identified. A potential clinical implication of a Type II error is that interventions to improve oral health prior to surgery would not be implemented leading to a possible increased risk of VAP.

The primary model was examined using logistic regression. The model tested whether the independent variables (oral health status, age, and gender, acuity, smoking history, comorbidities, surgery type and antibiotic use) predicted the dependent variable (VAP). The alpha for the test of this model was set at .05. To achieve 80% power at an
alpha of .05 and a medium effect size requires a sample size of 102. This change corresponds to an odds ratio of 2.00 (Hsieh, Bloch, & Larsen, 1998).

**Ability to enroll subjects**

Based on a recently completed study by Daly and Douglas (2009), it was found that approximately 9 patients/week receive a minimum of 24 hours of continuous mechanical ventilation in the ICUs at a hospital in Cleveland, Ohio with similar patient demographics as the Cleveland Clinic. Using their data to determine age and surgical representation, it was estimated that approximately 39% of these patients will meet the age and surgical criteria for the present study. An enrollment period of 12 months would yield a potential sample size of 182 subjects. The two major sources of attrition of potential subjects would be through refusal and mortality. Of the 182 potential subjects, it was estimated that approximately 40 (22%) would refuse to participate. The refusal rate was based upon prior studies conducted by Munro (2006) and Douglas and Daly (2007) who have used mechanically ventilated patients as subjects for research. Munro (2006), in a study on oral health in mechanically ventilated patients had a refusal rate of nearly 24% however she enrolled patients in the ICU setting and obtained consent from their legally authorized representative and not from the patient. A study by Azoulay (2005) demonstrated that being asked to provide consent for research was associated with post-traumatic stress symptoms in 35% of surrogate decision makers. In addition, the data of Douglas and Daly (2007) indicated that approximately 13% of elderly intubated surgical patients who require >24 hours of mechanical ventilation (subjects who would provide T2 data) die or are extubated within the first 3 days of mechanical ventilation, reducing the sample size of those with complete data (T1, T2, T3) by another 18 patients. Thus,
the estimated final sample would be comprised of 124 subjects. The estimated final sample size would be adequate for study analyses.

**Procedures for Conducting Research**

The investigator met with the Director of the CVICU as well as the pre-operative testing and ICU nursing staff prior to subject enrollment to explain the study procedure.

**Pre-operative Testing Procedure**

After obtaining consent, the investigator obtained pre-operative demographic data and Charlson Weighted Index of Comorbidity from the pre-admission testing chart and through interviewing the participant. Arrangement was made with the patient and nurse coordinator for a time after pre-admission testing to administer the oral health assessment tool. Based on prior experience by Dr. Munro and a dental hygienist who performed the oral health assessments, it was estimated that it would take approximately 10 minutes to administer the oral health assessment tool (personal communication, November 16, 2009).

**Post-operative Administration of Study Tools**

Each day, the investigator made rounds in the Cardiovascular ICUs. If a patient who consented to the study was in the ICU, the investigator recorded the time of arrival to the ICU and noted the patient’s oral intubation status. If the patient had been intubated and required mechanical ventilation in the postoperative period, they were enrolled in the second phase of the study. The following tools were used to abstract data from their medical chart: Post-operative data collection tool, Acute Physiology and Chronic Health Evaluation Score, and the Clinical Pulmonary Infection Score assessment tool. The UM-OHI oral health assessment tool was used to assess oral health status. See
“Variables/Measures/Instruments” section for psychometric properties of all tools. As noted previously, the UM-OHI was assessed during the pre-admission testing data collection period (T1). The second assessment occurred within the first 24 hours of oral intubation within the ICU (generally ICU Day 1) which corresponds with time of admission into the second phase of the study. Oral health status was assessed a third time, occurring 48 hours after the second time point measurement; generally ICU day 3 (T3). This time period was chosen because it corresponds with early-onset VAP (Ibrahim et al., 2000; M. H. Kollef, 1999). Additional data also was collected at this time as well: the patient was assessed for presence of ventilator-associated pneumonia and the presence or absence of any antibiotic medication.

**Protection of Human Subjects**

Institutional Review Board approval and the appropriate waiver of HIPAA requirements were obtained prior to study initiation. In order to obtain informed consent, a list of subjects scheduled for preoperative testing was obtained each morning from the preadmission testing nurse coordinator. From this list, a smaller list of potential subjects who met the age and surgical type eligibility criteria was generated. All patients who met surgical type and age criteria were considered potential study patients. Non-English speaking patients were included in the study. If the person authorized to obtain informed consent in the research protocol was not fluent in the patient’s language, an interpreter or interpreter service was obtained. An in-person interpretation or the telephone language line service was used for the duration of the study procedures during the participant’s hospitalization. If a reliable interpreter was not available, then the potential subject was deemed to be ineligible to be approached for consent to participate in the study. There
were no exclusions based on the patient’s ability to read or write. The consent document was read to the participant by the investigator and subsequently signed by the participant “making their mark” on the signature section of the consent document, in order to document their understanding.

Each potential subject was approached, screened again for eligibility, and if eligible, was asked to provide written consent to participate in the study. The informed consent process took place in the single room in which patients were seen for pre-operative evaluation, thus assuring privacy. The risks and benefits of the study were explained.

This study did not involve medical treatment of the study subjects; the only study procedures were oral health assessments and questionnaires. For the study, the oral health assessments were conducted by the investigator who was trained and evaluated by a dental hygienist in the clinical setting. A visible plaque disclosing agent, HurriView II Two-Tone Plaque Indicating Swabs ® (Beutlich Pharmaceuticals) were used during the oral health assessments to indicate plaque accumulation. Plaque disclosing agents are FDA approved commercially available preparations with no known risks, used by dentists for disclosing plaque in adults and children (Munro et al., 2004).

The oral health assessment involved evaluating every tooth for the presence of plaque. The mouth was divided into 12 sections and each tooth was then divided into ten sections and stained using the plaque disclosing solution which adheres to plaque making it more visible to the investigator. The teeth were then scored ranging from 0, which is no plaque to 10 which is plaque in every tooth section. The only theoretical risk to subjects was that their endotracheal tube could become mal-positioned during the oral health
assessments in the ICU. However, the investigator is a certified Acute Care Nurse Practitioner who is very experienced in providing routine oral care to patients who are intubated and she was alert to any signs or indications of tube malposition. If the endotracheal tube did become mal-positioned, the Cardiovascular ICU was staffed with a physician who is a critical care intensivist and could ensure proper repositioning of the endotracheal tube.

This study was a descriptive study and no benefits were expected. Subjects were informed that they could choose to stop participating in the study at any time. Because this study did not involve treatment in any way, the only alternative to participation was not to participate. Subjects were told that choosing to not participate would not have any effect on the care they received. At the time of consent to the study, subjects were given a card with the name and phone number of the investigator should they have any concerns relevant to the study.

The confidentiality of the data was protected in the following ways. Each instrument was edited for completeness and clarity immediately after completion and prior to coding. Each subject was assigned a code number; names and code numbers were stored in a locked filing cabinet. Data were stored in a separate locked filing cabinet in a locked office of the Principal Investigator at the Cleveland Clinic. No subject names appeared on data files. Data were entered into an SPSS master file.

While this was not a treatment or intervention study, there was contact with patients. No patients were deprived of access or use of any therapies or resources that were recommended by the patient’s primary care provider. The risk associated with this study was minimal. As part of the data safety monitoring plan, the investigator met with
the ICU director after enrolling 25, 50, 75 & 100 subjects to review data and outcomes. They conducted a review of enrollment procedures, data management routines, and evaluation of unexpected findings. If data were obtained that revealed clinical concern, the investigator shared these data with appropriate hospital personnel. As part of monitoring the integrity and security of the data, access to the database was limited to the investigator and Dr. Douglas (faculty advisor). Data files were reviewed by the investigator every 3 months to assure that no identifying information was left with the primary data.

**Variables/Measures/Instruments**

Variables are defined and instruments described in the following section. Table 4 presents a summary of all variables and their measurement time points.
Oral health is conceptually defined as the status of the oropharynx to include the teeth, gums, oral mucosa and accumulation of dental plaque (Munro & Grap, 2004; Treloar & Stechmiller, 1995). Poor oral health is conceptually defined as dental plaque accumulation along gingival surfaces leading to bacterial colonization, infection and inflammation of the gingiva and surrounding structures (Li et al., 2000). Oral health was operationalized as dental plaque scores. Dental plaque is a biofilm found on the surface of teeth containing as many as 700 species of organisms (Kolenbrander et al., 2002). Dental plaque accumulation has been commonly used as a basic measurement of oral health (Scannapieco et al., 1992; Munro, Grap, Elswick et al., 2006; Treloar &

**Table 4.**

Variables, Tools and Time of Measurement

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tools</th>
<th>Time of Measurement Study</th>
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<tr>
<td></td>
<td></td>
<td>Pre-op</td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demographics</td>
<td>Medical record</td>
<td>X</td>
</tr>
<tr>
<td>Comorbidities</td>
<td>CCI</td>
<td>X</td>
</tr>
<tr>
<td>Patient acuity</td>
<td>APACHE II</td>
<td>X</td>
</tr>
<tr>
<td>Oral Health</td>
<td>UM-OHI</td>
<td>X</td>
</tr>
<tr>
<td>Surgery type, meds</td>
<td>Medical record</td>
<td>X</td>
</tr>
<tr>
<td>Outcome</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>VAP</td>
<td>CPIS</td>
<td>X</td>
</tr>
</tbody>
</table>

*Note.* CCI= Charlson Index of Comorbidity, APACHE II= Acute Physiology and Chronic Health Evaluation, VAP= Ventilator-associated pneumonia, CPIS= Clinical Pulmonary Infection Score.
Dental plaque was measured using the University of Mississippi Oral Hygiene Index (UM-OHI) (Silberman et al., 1998) which evaluates every tooth for the presence of plaque. The UM-OHI was developed by Silberman et al., (1998) to provide a more complete and less time consuming assessment of the oral cavity. This tool has been used in studies for measuring oral health in elderly nursing home patients (Jablonski, Munro, Grap, & Elswick, 2005) and critically ill, mechanically ventilated patients (Grap et al., 2005; Munro & Grap, 2004).

Oral health was measured prior to elective surgery by evaluating the accumulation of dental plaque and counting the number of missing teeth. The University of Mississippi Oral Health Index (UM-OHI) was used as a guide to determine the amount of plaque in five sections of each tooth for both the buccal and lingual surfaces. The UM-OHI divides the mouth into 12 sections: left and right anterior teeth and posterior teeth in each arch, subdivided into buccal (cheek) and lingual (tongue) side. Each tooth is then divided into ten sections: five sections for the buccal surface and five sections for the lingual surface. The five sections of each tooth include the mesial, middle and distal sections. The middle section is subdivided horizontally into the gingival, middle and occlusal thirds (Silberman, et al., 1998). UM-OHI was chosen because it assesses the distribution of plaque on every tooth and divides the tooth into more sections than other instruments used in research or traditional dental practice (Silberman et al., 1998). Intra-rater reliability was high with Pearson’s correlation coefficients ranging from 0.79 to 0.92. Interrater reliability for the UM-OHI was documented as r= 0.89 and scores for the tool
were highly correlated ($r=0.85 - 0.93$) with scores on clinical oral assessment tools such as the O’Leary Plaque Control Record (Silberman, et al., 1998).

Each section of tooth that had plaque was scored a 1; if no plaque was present or if it could not be determined if there was plaque, it was scored a 0. Per the UM-OHI protocol, two sets of six observations were used (Silberman, Le Jeune, Serio et al., 1998).

Observations were augmented with the use of a liquid plaque disclosing agent (HurriView II®). Disclosing agents increase visibility and accuracy of plaque assessment (Munro, Grap, Jablonski, & Boyle, 2006). All teeth were stained and each tooth section was observed and scored for the presence of plaque (see Table 5 for the definitions of the oral health study variables). A total plaque score was obtained by counting the number of tooth sections with plaque per oral cavity. The maximum number of possible tooth sections with plaque was 280. The plaque percent for each subject was determined by dividing the number of tooth sections with plaque by the total number of tooth sections present in the oral cavity and then multiplying by 100. The mean plaque score per tooth was obtained by dividing the total plaque score by the number of teeth present. Mean plaque scores were also obtained for the buccal and lingual surfaces of each participant since oral care typically varies between buccal and lingual surfaces.
Table 5.
Definition of Oral Health Study Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth Section</td>
<td>• Ten areas of each tooth (see diagram)</td>
</tr>
<tr>
<td></td>
<td>• Five buccal surface and five lingual surface</td>
</tr>
<tr>
<td>Negative Section</td>
<td>• A section with no visible plaque after staining</td>
</tr>
<tr>
<td>Positive Section</td>
<td>• A section with any visible plaque after staining</td>
</tr>
<tr>
<td>Total Sections</td>
<td>• Number of tooth sections per subject’s oral cavity ( = number of teeth x 10)</td>
</tr>
<tr>
<td>Total Plaque Load</td>
<td>• Number of positive tooth sections in subject’s oral cavity</td>
</tr>
<tr>
<td>Plaque Percent</td>
<td>• Positive sections ÷ total sections x 100</td>
</tr>
<tr>
<td>Mean Plaque Load</td>
<td>• Positive sections ÷ number of teeth present</td>
</tr>
</tbody>
</table>

Ventilator-Associated Pneumonia

Conceptually, the definition of ventilator-associated pneumonia is “pneumonia in persons who have had a device to assist or control respiration continuously through endotracheal intubation within the 48 hour period before the onset of infection” (Horan, p. 327, 2008). VAP was determined by using the Clinical Pulmonary Infection Score (CPIS) which is a noninvasive approach for VAP diagnosis (Schurink et al., 2004). It is a composite score of six easily obtainable clinical and laboratory variables: 1) patient body temperature (temperature greater than 38° C); 2) oxygenation (ratio of the PaO2 to the fraction of inspired oxygen); 3) blood leukocyte count (more than 10,000/mm³); 4)
volume and purulence of tracheal secretions; 5) findings on chest radiograph and; 6) culture of tracheal aspirate. CPIS scores range from 0-12, with a CPIS of greater than or equal to 6 indicating pneumonia (Koenig & Truwit, 2006).

The CPIS was retrospectively validated by Pugin et al. (1991), in 28 ICU patients with and without suspicion of VAP undergoing 40 invasive direct examinations of bronchoscopic samples by bronchial alveolar lavage (BAL) for quantitative microbiological analysis. Microbiological cultures of samples obtained by fiber optic bronchoscopy are considered to be the most specific measure for diagnosing VAP however; bronchoscopy is an invasive procedure not without risks to the patient such as cardiac arrhythmias, hypoxemia or bronchospasm (Chastre & Fagon, 2002). The CPIS in the study by Pugin (1991) had a sensitivity of 93% with a specificity of 96%.

Validation of the CPIS has been attempted in seven studies; however variability exists in study results due to modifications made in CPIS criteria and differences in patient populations. In two studies the CPIS was compared to histological criteria done post-mortem (Fabregas et al., 1999; Papazian et al., 1995). Sensitivities were 72% and 77% with specificities 85% and 42% respectively using a CPIS cutoff for VAP of > 6. However, CPIS in these studies were calculated at the time of death when post-mortem examination was done and not at time of infection. In the remaining studies, the CPIS was used in a different population (children) or criteria were modified. In three studies (Acourt et al., 1993; Flanagan et al., 2000; Garrard & Acourt, 1995) the variable on ‘culture result’ was deleted and the CPIS cutoff for VAP of >7 was used which improved sensitivity to 85% and specificity to 91%. 
At the present time, there is a lack of a true “gold standard” for diagnosing VAP (Koenig and Truitt, 2006). The best noninvasive tool available for the diagnosis of VAP at the present time is the CPIS. Therefore, the CPIS was used for baseline assessment of patients for pneumonia during preoperative testing. The CPIS was used on postoperative day one, three, five and seven to determine the development of VAP.

**Demographic Variables**

Patient demographic data was obtained from the patient and from the medical record preoperatively and recorded on the Preoperative Demographic Data Form. Of these, the following variables were used as covariates: age, gender, smoking history, comorbid conditions, acuity, surgical type, and antibiotic use. The remaining variables obtained were obtained for the purpose of describing the sample. Demographic variables included patient age in years, gender, and race/ethnicity, admission date to the hospital, surgery type and use of antibiotic medications both preoperatively and after the postoperative day three (beyond the period of surgical prophylaxis).

Demographic data obtained postoperatively was abstracted from the medical record and recorded on the Postoperative Demographic Data Form. Postoperative demographic variables included ICU admission date and time, ICU discharge date and time, length of ICU stay (days), length of mechanical ventilation (hours) and use of antibiotic medications beyond the period of surgical prophylaxis. Additionally, family members of patients or the patients were asked if they received dental care between the preoperative oral health assessment and the surgery date to evaluate for a change in oral health status not attributable to oral intubation.
Comorbidity

Comorbidity is conceptually defined as diseases that coexist in the patient at the same time as the primary condition (Valderas, et al., 2009). Comorbidity was measured to control for confounding variables for VAP risk using the Charlson Weighted Index of Comorbidity (CCI) which is a tool used for measuring comorbid conditions in patients (Charlson, Pompei, Ales, & MacKenzie, 1987). The Charlson Comorbidity Index was originally developed in 1987 as a tool to predict one year mortality from a cohort of internal medicine patients (Charlson et al., 1987). The index uses 19 medical conditions weighted 1 to 6 with greater scores given to comorbid conditions with higher relative risk for death. The scores are then summed from the weighted conditions to yield total comorbidity scores ranging from 0-37. Higher scores indicate greater 1-year mortality risk. The CCI can also be adapted to account for advancing age. One point can be added to the total score for each decade of life over the age of 50 to account for the effects of aging (Hall, Ramachandran, Narayan, Jani, & Vijayakumar, 2004).

Concurrent validity of the CCI with the Cumulative Index Rating Scale, (CIRS), Kaplan-Feinstein Index (KFI) and Indexes of Coexistent Disease (ICED) yielded correlation coefficients exceeding 0.40. Significant relationships with criterion such as mortality, disability, readmission and length of stay confirm predictive validity (de Groot, Beckerman, Lankhorst, & Bouter, 2003; Hall et al., 2004). The test-retest reliability ranged from 0.86 among elderly cancer patients to 0.92 among surgical patients and inter-rater reliability ranged from 0.74 to 0.945 (Charlson et al., 1987; deGroot et al.,
The Charlson index was completed by the investigator via medical record review and discussion with the patient.

**Patient Acuity**

Acuity of the patient is conceptually defined as the risk of death based upon the severity of the patient’s disease (Knaus et al., 1991). Acuity was measured to control for confounding variables of VAP risk using the Acute Physiology and Chronic Health Evaluation II Score (APACHE II). APACHE II is a prognostic system, which predicts risk of mortality of hospitalized patients. Components to the APACHE II include selected physiological variables and Glasgow coma score. APACHE II scores range from 0-71 with higher scores indicating higher short-term risk of death. APACHE II has established reliability of 0.825 to 0.88 (Legall et al., 1993; Tempe, Wadhwa, Gupta, Bansal., & Satyanarayana, 2007).

**Intra-rater Reliability (IRR)**

The investigator was trained and used the Charlson Index of Comorbidity and the APACHE II during a research practicum with Dr. Douglas. The investigator was trained and evaluated in the use of the UM-OHI by the dental hygienist from the School of Dental Medicine at Case Western Reserve University. Prior to data collection, data was collected on five subjects under the supervision of the dental hygienist and evaluated for correctness. Acceptable IRRs of 80% agreement (Bland & Altman, 1986), r>.85, p=.037 was established prior to the beginning of data collection. Every 4 months throughout the data collection period, the investigator randomly select one week of the month for assessing intra-rater reliability. During the randomly selected weeks, the investigator conducted a second oral assessment within 24 hours of the initial assessment, on each
patient enrolled that week. Cohen’s κ was run to determine if there was agreement between the two oral assessments. There was moderate agreement between the two oral assessments, κ = .61, p = .01.

For the Clinical Pulmonary Infection Score (CPIS), points are assigned to 6 variables obtained from the medical record. Microbial cultures of tracheal aspirates for the CPIS were performed by the clinical microbiology laboratory at the Cleveland Clinic. Chest radiographs for the CPIS were interpreted by an ICU Intensivist certified in critical care medicine after the chest radiographs were de-identified. Reliability for scores on chest radiographs read by the ICU physician were checked by randomly selecting 5 radiographs per month and having them read a second time by the ICU physician. If there was disagreement between the readings, a third reading was done by another critical care intensivist. Cohen’s κ was run and demonstrated that the agreement between the two chest radiograph readings was considered good, κ = .676, p = .013.

Data Management and Statistical Analysis

Each instrument was edited for completeness and clarity immediately after completion and prior to coding. Each subject was assigned a code number; names and code numbers were stored in a locked filing cabinet in the principal investigator’s office. Data was stored in a separate locked filing cabinet. No subject names appeared on data files. Data was entered into an SPSS master file. Descriptive statistics including frequencies, means, standard deviations were calculated for all interval and ratio level variables.

Two types of analyses were used for the study questions. The first was a preliminary analysis using exploratory data techniques to examine univariate
characteristics and bivariate relationships. These exploratory techniques were based on proportions (dichotomous variables) and medians and/or means (interval variables). The appropriate parametric and non-parametric tests were utilized depending on the scale of measure and distribution of the variable being described.

**Research Question 1: What is the oral health status of older adults prior to surgery?**

This descriptive question was addressed by utilizing descriptive analytic techniques. The variable (UM-OHI) is interval level of measurement and was examined for distribution, kurtosis, and skewness. Kurtosis is the degree of the peakedness of a distribution and skewness refers to the degree of symmetry of the distribution around the mean (Corty, 2006). In a normal distribution scores for skewness and kurtosis are less than the absolute value of 3 for skewness and less than the absolute value of 8 for kurtosis (R. B. Kline, 2005). The appropriate parametric (mean, medians, confidence intervals) or non-parametric (frequency, percentages if data is skewed) tests were employed depending on distribution of the variable.

**Research Question 2: What is the oral health status of older adults after intubation?**

This descriptive question was answered by utilizing descriptive analytic techniques. The variable (UM-OHI) is interval level of measurement and was examined for distribution, kurtosis, and skewness. The appropriate parametric (mean, medians, confidence intervals) tests were employed based on the distribution of the variable post intubation oral health.

**Research Question 3: What is the relationship between pre-hospital oral health and oral health after intubation in older intensive care unit patients when controlling for age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use?**
This question was answered by regressing the outcome variable (oral health score after intubation) on the independent variable (oral health score pre-hospital). Data were evaluated for violations of linear regression assumptions as delineated by Mertler & Vannatta (2005). The first step is to assume that the independent variables are fixed, which means that the values of the independent variable would have to be used if the study were to be replicated.

The second assumption is that the independent variables were measured without error (Mertler & Vannatta, 2005). The use of reliable and valid data collection tools and techniques helped to decrease measurement error.

The third assumption is that the relationship between the independent variables and the dependent variable is a linear relationship (Field, 2013; Mertler & Vannatta, 2005). Evaluation of linearity was achieved by visual examination of the residual scatter plots of standardized residuals verses the predicted values. Residual values that were evenly distributed along the zero line indicated that the assumption of linearity was met (Mertler & Vannatta, 2005). If the assumption of linearity was not met, the variable was transformed using one of three methods: square root transformation, natural log of each of the variables or an inverse transformation for severely skewed data (Mertler & Vannatta, 2005). This assumption is robust to violation (Tabachnick & Fidell, 2006).

The fourth assumption is that the mean of the residuals for each observation of the dependent variable over numerous replications is zero (Mertler & Vannatta, 2005). One method for assessing this assumption was to examine the SPSS output for whether the standardized residual had a mean and a standard deviation of one. Since this assumption of zero mean is not robust to violation, the variables were transformed as described above.
to fix the violation. After transformation the regression was rerun to check if results were different from regression with untransformed variable.

The fifth assumption is that errors associated with any single observation on the dependent variable are not correlated with any other observations on the dependent variable (Mertler & Vannatta, 2005). This assumption is not robust to violation. It was tested with the Durbin-Watson test which tests serial correlations between errors. A Durbin-Watson value of 2 was used to indicate that the assumption was not violated (Field, 2013).

The sixth assumption is that the residuals were not correlated with the independent variables (Mertler & Vannatta, 2005). If the residual correlate with the independent variable than the residuals could predict the outcome variable making the conclusions drawn from the model unreliable (Field, 2013).

The seventh assumption relates to the homoscedasticity of the variance of the residuals (Mertler & Vannatta, 2005). This means that the residuals at each level of the predictor variables should have the same variance (Field, 2013). This assumption was evaluated for violation by plotting the standardized residuals against the predicted dependent variable and checking for an even distribution around the zero line. This assumption is also robust to violation.

The final assumption is that the errors are normally distributed (Mertler & Vannatta, 2005). Normality of the residuals was evaluated by looking at the histogram and probability plot of the data. A normal curve was overlayed onto the histogram to assess the approximation to a normal curve (Field, 2013). The next step was to examine the probability plot which compares observed to expected residuals. The expected
residuals on the probability plot are the straight line and observed residuals are the points. The observed residuals appeared as a straight line on the plot, therefore the residuals were normally distributed (Field, 2013).

In addition to the assumptions of the regression analysis, inter-item correlations were examined. There were no highly correlated, that were removed from the model. Using hierarchical regression, covariates (age, gender, acuity, smoking history, comorbidity, surgical type, and antibiotic use) were entered as the first block and pre-hospital oral health status was entered as the second block. The significance of the change in $R^2$ was tested after entering pre-hospital oral health status.

**Research Question 4: How do age, gender, acuity, comorbidity, smoking history, surgery type, and antibiotic use change oral health over time from preoperative to postoperative?**

This question was answered using multiple linear regression analysis. Data were evaluated again for violations of linear regression assumptions as delineated by Mertler & Vannatta (2005). The outcome variable (change in oral health) was regressed on the predictor variables (age, gender, acuity, comorbidity, smoking history, surgery type and antibiotic use).

**Research Question 5: What is the relationship between oral health (pre-hospital and post-intubation) and ventilator-associated pneumonia in older adult intensive care unit patients when controlling for age, gender, acuity, smoking history, comorbidity, surgery type and antibiotic use?**

This question was answered by using logistic regression analysis since the outcome variable (development of ventilator acquired pneumonia) is dichotomous
A series of logistic regression analyses were run using the various methods of operationally defining oral health (e.g., mean plaque, total plaque, and plaque change) and the variable ventilator-associated pneumonia as a dichotomous dependent variable while controlling for the covariates age, gender, acuity, smoking history, comorbidity, type of surgery and antibiotic use. Before proceeding with the analysis, data were examined for variability, influence, and multicollinearity (Landis & Koch, 1977). Cook’s D was used to examine the influence of outliers; values >1 indicate that the outlier is considered influential and analyses was conducted with and without the influential data points included in order to determine the most appropriate approach to the overall analysis. Variance Inflation factors (VIF) were examined to assess for the presence of multicollinearity (VIF’s >10). There was no multicollinearity. Logistic analyses were conducted to address this question. In the first, covariates (age, gender, acuity, smoking history, comorbidity, surgery type, antibiotic use) were entered as the first block and pre-hospital oral health status was be entered as the second block. The Nagelkerke $R^2$ was examined for statistical significance of the model and the Wald statistic and associated odds ratio were examined to determine the significant unique contributions of variables. The Step statistic was also evaluated to examine the improvement in the predictive power of the model with the addition of the second block variable (pre-hospital oral health). The second logistic analysis was identical to the first; however post-intubation oral health was added as the second block. The third logistic regression was identical to the second; however change in oral health over time was added as the second block.

In summary, this was a prospective, descriptive, longitudinal study of oral health as a risk factor for ventilator-associated pneumonia. A correlational design was used to
test the relationship between pre-hospital oral health and the outcome variable, ventilator-associated pneumonia. The sample consisted of 96 older adults who underwent undergo cardiac or vascular surgery and required mechanical ventilation in the postoperative period. Subjects completed the Charlson Comorbidity Index and received a pre-operative oral health assessment using the University of Mississippi Oral Health Index (UM-OHI) prior to admission. Subjects that remained intubated postoperatively were enrolled in the second phase of the study. The following tools were administered on postoperative day one: Acute Physiology and Chronic Health Evaluation score, and the Clinical Pulmonary Infection Score (CPIS). Oral assessments occurred on postoperatively using the UM-OHI. Data on length of mechanical ventilation and length of ICU stay as well as use of antibiotic medications were extracted from the medical chart on postoperative day one and three. The CPIS was repeated again on postoperative day three, day five and day seven. The study used repeated measures of oral health (preoperatively and post-intubation) and ventilator-associated pneumonia (VAP) to examine the relationship between change in oral health status over a period of mechanical ventilation with the occurrence of ventilator-associated pneumonia.
CHAPTER IV

Results

This is the first study to examine pre-hospital oral health status as a risk factor for ventilator-associated pneumonia in older adult ICU surgical patients. A longitudinal correlational research design was used to determine whether a significant relationship existed between oral health (pre-hospital and post-intubation) and ventilator-associated pneumonia. Repeated measures of oral health (preoperatively and post-intubation) and ventilator-associated pneumonia risk were used to examine the relationship between oral health status over time with the occurrence of ventilator-associated pneumonia.

Two types of analyses were used for the study questions. First, descriptive statistics were used to describe the older adult population demographics, medical and surgical characteristics, postoperative course and oral health characteristics. Continuous variables are presented as mean with standard deviation and median with interquartile range when appropriate. Categorical variables are presented as count and percentage. Secondly, inferential statistics were used to test the hypotheses that the determination of preoperative oral health status is important in determining VAP risk, both directly and through the calculation of postoperative change. Oral health was measured as both the percent of surfaces with plaque (mean plaque) and the total number of surfaces with plaque (total plaque) in each person. The results pertaining to each research question are presented for both mean plaque and total plaque scores. Since the CPIS was used as a dichotomous measure of VAP where CPIS $\geq 6$ indicated pneumonia and CPIS $< 6$ indicated no pneumonia, the primary endpoint of VAP was analyzed using logistic regression.
Demographic Characteristics of the Study Sample

The study sample consisted of 96 adults scheduled for elective surgery.

Demographic characteristics of the sample are presented in Table 6. The subjects ranged from 53 to 88 years of age (\(M=72.01, SD= 8.9\)) and were primarily Caucasian (89.6%) and male (62.5%).

Table 6. Sample Demographic Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>96 (100)</td>
<td>72.01 (8.9)</td>
<td>53-88</td>
</tr>
<tr>
<td>50-59 year olds</td>
<td>7 (7.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60-69 year olds</td>
<td>32 (33.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-79 year olds</td>
<td>33 (33.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80-89 year olds</td>
<td>26 (26)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>60 (62.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>36 (37.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>86 (89.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>1 (1.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>2 (2.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Eastern</td>
<td>5 (5.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>2 (2.1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Potential subjects. To identify potential subjects for this study a list of subjects scheduled for preadmission testing was obtained each morning from the Preoperative Admission Testing Clinic. From this list, a smaller list of potential subjects who met the
age and surgical type eligibility criteria (cardiac surgery, abdominal surgery, thoracic surgery and vascular surgery) was generated. Finally, a smaller list was generated of those potential subjects who would likely require oral intubation and mechanical ventilation post-surgery. Since the target population for this study was those at risk for pneumonia after receiving mechanical ventilation, potential subjects were considered ineligible if they were not likely going to need oral intubation and mechanical ventilation in the postoperative period.

**Consent rate.** Study enrollment occurred from September 2011 to October 2012. Potential subjects were identified by the investigator as previously described. Of the 136 patients assessed as eligible for the study based on the age criteria of greater than 50 years old, 27 did not fully meet the inclusion criteria and 11 refused to participate. Of the 27 who did not meet inclusion criteria, 22 were edentulous. The refusal rate for this study was 10%. Patients who refused to participate in the study cited lack of time in their preadmission testing schedule or lack of interest in the study topic. Of the 136 patients, 109 were approached for consent, 98 were eligible and were enrolled in the study; however, two were dropped due to cancellation of their surgery. The final sample size for the study was $N = 96$; this was a 90% consent rate (Figure 3).
**Medical and surgical characteristics of the study sample.** Comorbid conditions were obtained from the medical chart and from patient responses using the Charlson Comorbidity Index (CCI). Comorbid conditions of the sample population are...
presented in Table 7. The mean comorbidity score for the sample was 4.06 ($SD = 2.98$, $Mdn = 3.0$). The most frequently reported comorbid condition was chronic obstructive pulmonary disease (55.2%), with 61 of the 96 subjects (63.5%) reporting that they were current (12.5%) or former (51%) smokers. In addition, many of the study participants also had congestive heart failure (46.9%) as comorbidity. The most frequently reported non-pulmonary related illnesses were cancer (36.4%), cerebrovascular disease (29.2%), diabetes (28.1%), moderate or severe renal disease (21.9%), and organ damage from diabetes (16.7%).
The two main types of surgery represented in this sample were cardiac surgery \((n=70)\) and vascular surgery \((n=26)\). Prior to surgery, participants scheduled for cardiac surgery \((72.9\%)\) were examined by a dentist for evaluation and treatment of oral

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
<th>M (SD, Mdn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking History</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>35 (36.5)</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>12 (12.5)</td>
<td></td>
</tr>
<tr>
<td>Former</td>
<td>49 (51.0)</td>
<td></td>
</tr>
<tr>
<td>Comorbid Conditions</td>
<td>96 (100)</td>
<td>4.06 (2.98, 3.0)</td>
</tr>
<tr>
<td>Chronic Obstructive Pulmonary Disease</td>
<td>53 (55.2)</td>
<td></td>
</tr>
<tr>
<td>Congestive Heart Failure</td>
<td>45 (46.9)</td>
<td></td>
</tr>
<tr>
<td>Cancer</td>
<td>35 (36.4)</td>
<td></td>
</tr>
<tr>
<td>Cerebrovascular Disease</td>
<td>28 (29.2)</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>27 (28.1)</td>
<td></td>
</tr>
<tr>
<td>Moderate/Severe Renal Disease</td>
<td>21 (21.9)</td>
<td></td>
</tr>
<tr>
<td>Peripheral Vascular Disease</td>
<td>20 (20.8)</td>
<td></td>
</tr>
<tr>
<td>Myocardial Infarction</td>
<td>17 (17.7)</td>
<td></td>
</tr>
<tr>
<td>Diabetes with End Organ Damage</td>
<td>16 (16.7)</td>
<td></td>
</tr>
<tr>
<td>Connective Tissue Disease</td>
<td>11 (11.5)</td>
<td></td>
</tr>
<tr>
<td>Ulcer</td>
<td>9 (9.4)</td>
<td></td>
</tr>
<tr>
<td>Liver Disease</td>
<td>7 (7.3)</td>
<td></td>
</tr>
</tbody>
</table>
infections and received decontamination of the oropharynx with 0.12% chlorhexidine gluconate and Listerine antiseptic mouthwash as part of the routine care prior to cardiac surgery. All of the subjects (100%) who underwent cardiac surgery had open-heart surgical procedures. Of the subjects who had vascular surgery, 15.6% (n=15) underwent open thoracic surgery, 8.4% (n=8) underwent endovascular surgery, and 3.1% (n=3) underwent open abdominal surgery (see Table 8).
Table 8.

*Surgical Characteristics of Sample*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical Condition</td>
<td>96 (100)</td>
</tr>
<tr>
<td>Valvular Heart Disorder</td>
<td>54 (56.3)</td>
</tr>
<tr>
<td>Coronary Artery Disease</td>
<td>33 (34.4)</td>
</tr>
<tr>
<td>Aortic Aneurysm/Dissection</td>
<td>25 (26)</td>
</tr>
<tr>
<td>Hypertrophic Obstructive Cardiomyopathy</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>Pulmonary Fibrosis</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>Type of Surgery</td>
<td></td>
</tr>
<tr>
<td>Cardiac</td>
<td>70 (72.9)</td>
</tr>
<tr>
<td>Vascular</td>
<td>26 (27.1)</td>
</tr>
<tr>
<td>Open Thoracic</td>
<td>15 (15.6)</td>
</tr>
<tr>
<td>Endovascular</td>
<td>8 (8.4)</td>
</tr>
<tr>
<td>Open Abdominal</td>
<td>3 (3.1)</td>
</tr>
<tr>
<td>Surgical Procedure</td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>14 (14.7)</td>
</tr>
<tr>
<td>Valve Repair/Replacement</td>
<td>35 (36.5)</td>
</tr>
<tr>
<td>CABG &amp; Valve Repair/Replacement</td>
<td>19 (19.8)</td>
</tr>
<tr>
<td>Open Aorta Repair/Replacement</td>
<td>17 (17.7)</td>
</tr>
<tr>
<td>Endovascular Aorta Repair</td>
<td>8 (8.3)</td>
</tr>
<tr>
<td>Lung Transplant</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>Myectomy</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>Ventricular Assist Device</td>
<td>1 (1.0)</td>
</tr>
</tbody>
</table>
Acuity of the study sample was measured in all subjects within the first 24 hours of ICU admission using the Acute Physiology and Chronic Health Evaluation II (APACHE II) severity of disease classification system. The average score for the APACHE II in this study group was 16.59 ($SD = 5.64, Mdn = 16$) with scores ranging from 7 to 41. The approximate mortality risk for postoperative patients with APACHE II scores ranging from 15-19 is 12% (Knaus et al., 1985).

**Postoperative course of the study sample.** Table 9 presents the postoperative course of the 96 study participants who underwent surgery. All study participants were intubated and received mechanical ventilation in the postoperative period. Length of intubation and mechanical ventilation ranged from 1 hour to 136 hours ($M=21.2, SD=20.2, Mdn=16$) or 5.44 days. The average length of time spent in the intensive care unit (ICU) was 3.47 days ($SD=4.32, Mdn=2$) with a range of 1 to 38 days.
The ventilator-associated pneumonia bundle (VAP bundle) is a group of evidence-based practices that have been used to improve outcomes in patients receiving
mechanical ventilation (Institute for Healthcare Improvement, 2012). The VAP bundle includes (a) head of bed elevation to 30 degrees, (b) daily sedation vacation, (c) assessment of readiness for extubation (d) peptic ulcer disease prophylaxis (e) deep vein thrombosis prophylaxis, and (f) daily oral care with 0.12% chlorhexidine gluconate. The VAP bundle was implemented in the postoperative period for all study participants undergoing mechanical ventilation with the exception of the head of bed elevation to 30 degrees in 8.3% \( (n=8) \) due to hemodynamic instability; and daily sedation vacation in 2.1% \( (n=2) \) due to postcardiotomy open-chest management. Daily oral care with 0.12% chlorhexidine gluconate was provided to patients who were intubated and mechanically ventilated for 12 hours or more \( (n=59, 61.5\%) \).

Nearly one third (32.3%) of the subjects had an uncomplicated postoperative course. Vasopressors or inotropic support was required in 62.8% of the participants as well as temporary epicardial (26%) or a permanent pacemaker (11.5%) to improve hemodynamic function in the first 24 hours after surgery. For those patients who had complications, the most frequent complication noted was due to respiratory failure (25%) requiring the need for noninvasive ventilation (22.7%), reintubation (6.2%) and in rare instances, a tracheostomy (2.1%). Additional complications included coagulopathy or bleeding (21.9%), cardiac arrhythmias including atrial (5.2%) and ventricular arrhythmias (2.1%), acute kidney injury (2.1%) and postoperative myocardial infarction (1%). There were multiple complications, defined as greater than three complications, in 7.3% of the study sample and one death (1%) during the study period.
Research Question One

What is the oral health status of older adults prior to surgery? The intent of this research question was to describe the oral health of patients being admitted to the hospital for elective surgery. Oral health was measured prior to elective surgery by evaluating the accumulation of dental plaque and counting the number of missing teeth (see Table 10).
The University of Mississippi Oral Health Index (UM-OHI) was used as a guide to determine the amount of plaque in five sections of each tooth for both the buccal and lingual surfaces. All teeth were stained and each tooth section was observed and scored for the presence of plaque (see Table 5 for the definitions of the oral health study variables). A total plaque score was obtained by counting the number of tooth sections.
with plaque per oral cavity. The mean plaque score was obtained by dividing the total plaque score by the number of teeth present. Mean plaque scores were also obtained for the buccal and lingual surfaces of each participant since oral care typically varies between buccal and lingual surfaces. The impact of gender and age on plaque accumulation was also evaluated.

Preoperative plaque scores were assessed for normality by evaluating skewness, kurtosis, visual inspection of their histograms, and lack of s-shaped curve of the normal Q-Q plots. Preoperative mean plaque, preoperative buccal mean plaque and preoperative total plaque load were normally distributed with a skewness of .734 (SE=.246); .604 (SE=.246); .372 (SE=.246) respectively. Preoperative lingual mean plaque was slightly positively skewed with a skewness of .894 (SE=.246) and a Shapiro-Wilk test p = .04. All preoperative plaque scores had a normal kurtosis. The lingual plaque score was not transformed because the skewness was not severe as determined by visual inspection of their histograms and no s-shaped curve on the normal Q-Q plots. Further, the sample size was greater than thirty, decreasing the concern for violating the assumption of normality (Field, 2013).

Seventy-five percent (n=72) of the participants had at least one missing tooth with the average number of missing teeth being 7.07 (SD=7.63, range 0-24). Females, on average (M = 7.72, SD = 7.52), had more missing teeth than males (M = 6.68, SD = 7.73). However, an independent samples t-test demonstrated that there was no significant difference in mean missing teeth between males and females, t(94) = .644, p = .521. There was no correlation between age and missing teeth, r (94) = -.114, p = .267.
The preoperative group mean total plaque score for the study sample was 72.7 (SD=30.65) out of 280 possible total tooth sections. The group mean plaque score per tooth was 3.78 (SD=1.55) with a group mean of 2.20 (SD=.93) for the buccal surface and a group mean of 1.58 (SD=.74) for the lingual surface. Using a paired sample t test, buccal plaque scores were found to be statistically significantly higher by a mean of 2.19, [95% CI 2.01 to 2.38], than lingual plaque scores, t(95) = 9.58, p < .001.

Using an independent samples t-test to evaluate gender differences in plaque, males had both a higher total plaque score (M= 77.05, SD=32.1) and mean plaque per tooth score (M=3.94, SD=1.55) than females for total plaque (M=65.38, SD= 26.88) and mean plaque per tooth (M=3.49, SD=1.53). However, the differences were not found to be significant across gender groups for either total plaque, t(94) = -1.827, p = .071, or mean plaque, t(94) = -1.388, p = .168. On average, the percent of plaque per oral cavity prior to surgery was 37%, with males having an average of 39% plaque and females having an average of 35% plaque (see Figure 4).
A linear regression was conducted to explore the impact of age on plaque scores.

Subjects were divided into four age groups as used in the Acute Physiology and Chronic Health Evaluation tool: (a) 45 to 54, (b) 55 to 64, (c) 65 to 74 and (d) greater than 74. The age groups were dummy coded prior to regression analysis. There was no statistically

Figure 4. Mean and total plaque by gender. Error bars represent standard error.
significant difference on plaque scores for the different age groups: $F(3, 92) = .479$, $p=.698$ (see Table 11).

Table 11.

*Oral Health Characteristics of Sample by Age  N=96*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
<th>Mean Plaque (SD)</th>
<th>Total Plaque (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preoperative Plaque Scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45-54</td>
<td>4 (4.1)</td>
<td>3.49 (.933)</td>
<td>78.5 (13.89)</td>
</tr>
<tr>
<td>55-64</td>
<td>15 (15.6)</td>
<td>4.2 (1.81)</td>
<td>64.73 (27.55)</td>
</tr>
<tr>
<td>65-74</td>
<td>41 (42.7)</td>
<td>3.72 (1.66)</td>
<td>73.07 (33.46)</td>
</tr>
<tr>
<td>&gt;74</td>
<td>36 (37.5)</td>
<td>3.69 (1.37)</td>
<td>74.88 (30.23)</td>
</tr>
<tr>
<td><strong>Postoperative Plaque Scores</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45-54</td>
<td>4 (4.1)</td>
<td>5.48 (.411)</td>
<td>121 (28.01)</td>
</tr>
<tr>
<td>55-64</td>
<td>15 (15.6)</td>
<td>5.53 (2.32)</td>
<td>85.7 (39.87)</td>
</tr>
<tr>
<td>65-74</td>
<td>41 (42.7)</td>
<td>4.52 (1.69)</td>
<td>91.92 (48.12)</td>
</tr>
<tr>
<td>&gt;74</td>
<td>36 (37.5)</td>
<td>4.77 (1.48)</td>
<td>94.19 (35.06)</td>
</tr>
</tbody>
</table>

*Summary.* Three fourths of participants had missing teeth. There was a statistically significant difference in plaque accumulation with plaque tending to
accumulate along buccal surfaces compared to lingual surfaces. There was no statistically significant gender or age-related differences in preoperative oral health or missing teeth.

Research Question Two

**What is the oral health status of adults after intubation?** The intent of this research question was to evaluate and describe oral health after having an endotracheal tube in place and a period of mechanical ventilation for elective surgery. The means and standard deviations of plaque accumulation are provided below. The impact of gender and age on plaque accumulation for the study sample is also described.

Postoperative plaque scores were assessed for normality by evaluating skewness, kurtosis, visual inspection of their histograms, and lack of s-shaped curve of the normal Q-Q plots. Postoperative mean plaque was slightly positively skewed with a skewness of .764 (SE=.246) and Shapiro Wilk’s test $p=.004$. Postoperative mean buccal and lingual plaque were normally distributed with a Shapiro-Wilk’s test $p=.44$ and $p=.19$ respectively. Total plaque load had normal skewness (.411) and a significant $p$-value for Shapiro-Wilk’s statistic ($p=.03$). All postoperative plaque scores had normal kurtosis. None of the plaque scores were transformed because the skewness was not severe as determined by visual inspection of their histograms and no s-shaped curve on the normal Q-Q plots. Since the sample size was greater than thirty, there was less concern for violating the assumption of normality (Field, 2013).

The postoperative group mean total plaque score for the study sample was 93.02 (SD=41.58) out of 280 total possible tooth sections with plaque. The group mean plaque score per tooth was 4.80 (SD=1.71), with a group mean of 2.70 (SD=.90) for the buccal surface and a group mean of 2.17 (SD=1.0) for the lingual surface (see Table 10).
A paired samples t test demonstrated that postoperative buccal plaque scores were also found to be statistically significantly higher by a mean of 2.7 [95% CI 2.52 to 2.88] than postoperative lingual plaque scores, \( t(95) = 6.5 \ p < .001 \). Using an independent samples t-test, it was again noted that males had a higher total plaque score \((M=96.78, SD=44.58)\) and mean plaque score per tooth \((M=4.94, SD=1.84)\) than did females, for total plaque \((M=86.75, SD=35.77)\) and mean plaque per tooth \((M=4.54, SD=1.42)\). However the gender differences were not significant for total plaque, \( t(94) = -1.14, \ p = .255 \), or mean plaque, \( t(94) = -1.11, \ p = .269 \). The average percent of plaque per oral cavity in the postoperative period was 48%. Males on average had 49% plaque and females on average had 45% plaque (see Figure 5).
A linear regression was conducted to explore the impact of age on plaque scores. Subjects were divided into four age groups as used in the Acute Physiology and Chronic Health Evaluation tool: (a) 45 to 54, (b) 55 to 64, (c) 65 to 74 and (d) greater than 74. The age groups were dummy coded prior to regression analysis. There was no statistically significant difference on postoperative plaque scores for the different age groups $F(3, 92)= 1.66, p = .18$.

*Figure 5. Mean and total plaque by age group.*
Summary. Postoperatively, buccal surfaces had statistically significant higher accumulation of plaque than lingual surfaces. There was no statistically significant gender or age-related differences in postoperative oral health. The percent of plaque per oral cavity increased from 37% preoperatively to 48% in the postoperative period.

Research Question Three

What is the relationship between pre-hospital oral health and oral health after intubation in older intensive care unit patients when controlling for age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use?

The intent of this research question was to determine how much of the variation in postoperative oral health can be explained by preoperative oral health. Multiple regression analysis was conducted to examine how much variance in postoperative oral health can be explained by preoperative oral health controlling for age, gender, smoking history, acuity, comorbidity, type of surgery and the use of antibiotics. These control variables were chosen based on theory and empirical evidence in the literature.

Bivariate correlations using preoperative mean plaque per tooth as the independent variable and postoperative mean plaque per tooth as the dependent are presented in Table 12.
Table 12.

**Pearson Correlations Between Variables in Regression with Mean Plaque Score as Dependent Variable Hierarchical Regression (N=96)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Post Plaque</th>
<th>Age</th>
<th>Gender</th>
<th>Surgery Type</th>
<th>Pre-Antibiotic</th>
<th>Comorbid Condition</th>
<th>Acuity</th>
<th>Smoker</th>
<th>Post-antibiotic</th>
<th>Preop Plaque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postoperative Plaque</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Age</td>
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<tr>
<td>Gender</td>
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<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery Type</td>
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<td>.270**</td>
<td>.109</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Antibiotics</td>
<td>.101</td>
<td>.185*</td>
<td>-.262**</td>
<td>-.075</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbidity</td>
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<td>.022</td>
<td>.045</td>
<td>.005</td>
<td>-.063</td>
<td>1.000</td>
<td></td>
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</tr>
<tr>
<td>Acuity</td>
<td>-.003</td>
<td>.122</td>
<td>-.129</td>
<td>.135†</td>
<td>.044</td>
<td>.203*</td>
<td>1.000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>.120</td>
<td>-.055</td>
<td>.029</td>
<td>-.169*</td>
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<td>.057</td>
<td>-.023</td>
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<tr>
<td>Post-Antibiotics</td>
<td>-.078</td>
<td>-.115</td>
<td>-.158†</td>
<td>-.176*</td>
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<td>.004</td>
<td>.274**</td>
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<tr>
<td>Preoperative Mean Plaque</td>
<td>.698***</td>
<td>-.075</td>
<td>.142†</td>
<td>-.067</td>
<td>.108</td>
<td>.158†</td>
<td>.010</td>
<td>.169*</td>
<td>-.034</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Note. Surgery type categorized into cardiac surgery coded as 1 and vascular surgery coded as 0. **p<.001, *p<.01, *p<.05, †p<.1*
Preoperative mean plaque was positively correlated with postoperative mean plaque. Older subjects were more likely to have undergone cardiac surgery. Older women more often received preoperative antibiotics. Smokers were more likely to have had higher preoperative mean plaque scores and to have undergone a vascular surgery procedure. Subjects with more comorbidity had higher acuity. Subjects with higher acuity were more likely to have had vascular surgery and were more likely to have received postoperative antibiotics. Vascular surgery patients had higher postoperative mean plaque scores (see Figure 6).
Bivariate correlations using preoperative total plaque load as the independent variable and postoperative total plaque load as the dependent variable are presented in Table 13. Preoperative plaque load was positively correlated with postoperative plaque load. Males had higher plaque load preoperatively than females.

*Figure 6.* Mean and total plaque scores by type of surgery. Error bars represent standard error.
Table 13.

Pearson Correlations between Variables in Hierarchical Regression with Total Plaque Load as Dependent Variable (N=96)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Postop Plaque Load</th>
<th>Age</th>
<th>Gender</th>
<th>Surgery Type</th>
<th>Preop Antibiotics</th>
<th>Comorbid Conditions</th>
<th>Acuity</th>
<th>Smoker</th>
<th>Postop Antibiotics</th>
<th>Preop Plaque Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postoperative Plaque Load</td>
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<td></td>
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</tr>
<tr>
<td>Age</td>
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<td>1.000</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>.117</td>
<td>-.074</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery Type</td>
<td>-.006</td>
<td>.270**</td>
<td>.109</td>
<td>1.000</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>.079</td>
<td>.185*</td>
<td>-.262**</td>
<td>-.075</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>-.181*</td>
<td>.022</td>
<td>.045</td>
<td>.005</td>
<td>-.063</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>-.111</td>
<td>.112</td>
<td>-.129</td>
<td>.135†</td>
<td>.044</td>
<td>.203*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-.073</td>
<td>-.055</td>
<td>-.006</td>
<td>-.169*</td>
<td>.049</td>
<td>.057</td>
<td>-.023</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative Antibiotics</td>
<td>-.150†</td>
<td>-.115</td>
<td>-.158†</td>
<td>-.176*</td>
<td>.091</td>
<td>.004</td>
<td>.274**</td>
<td>-.091</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Preoperative Plaque Load</td>
<td>.728***</td>
<td>.108</td>
<td>.185*</td>
<td>.156†</td>
<td>.039</td>
<td>-.158</td>
<td>-.073</td>
<td>-.074</td>
<td>-.159†</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note. Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). ***p<.001, **p<.01, *p<.05, †p<.1
Four linear regressions analyses were conducted to determine how much of the variation in postoperative oral health could be explained by preoperative oral health after controlling for age, gender, smoking history, acuity, comorbidity, type of surgery and antibiotic use. In the first linear regression, oral health was operationally defined as mean/tooth scores. In this regression, the dependent variable, oral health after intubation (postoperative), was regressed on the predictor variable pre-hospital oral health (preoperative). In the second linear regression, oral health was operationally defined as total plaque scores. In this analysis, the dependent variable postoperative oral health was regressed on the predictor variable preoperative oral health. Next, two hierarchical multiple regressions were conducted to determine whether the independent variable, oral health prior to hospital admission, had an impact on the dependent variable, oral health after intubation, after controlling for age, gender, smoking history, acuity, comorbid conditions, type of surgery, and the use of antibiotics. In the first hierarchical multiple linear regression analysis, oral health was defined as mean plaque score. In this analysis, pre-operative oral health was entered first. Age, gender, acuity, comorbid conditions, smoking history, type of surgery, and systemic antibiotic use were then entered into the second step of the regression as control variables. Postoperative oral health was entered for the dependent variable. The second hierarchical multiple regression analysis was the same as the first, except total plaque load was used to operationally define the variable oral health.

Preliminary analyses were conducted to examine normality, linearity, homoscedasticity of residuals and multicollinearity of the data. The Durbin-Watson coefficients were examined to insure that the assumption of independence of error terms
had been met; a Durbin-Watson coefficient less than one or higher than three indicate that the assumption has been violated (Rosenthal & Rosnow, 2008). The Durbin-Watson coefficient values were 2.21, 2.41, 2.33, and 2.41 respectively for each of the regression analyses. The tolerance values of .830 to .925, respectively, and the VIF values of 1.089 to 1.209, respectively, indicated that there were no problems with multicollinearity with regard to the models. The means of the standard residuals (M = 0, SD = .95), demonstrated a normal distribution.

**Linear regression 1. Oral health defined as mean plaque**
A linear regression established that preoperative oral health made a statistically significantly contribution towards predicting postoperative oral health. Preoperative oral health accounted for 50% of the explained variability in postoperative oral health. The effect size for this result was large, $R^2_{(adj)} = .496$, $F(1, 94) = 94.44$, $p = .001$.

**Linear regression 2. Oral health defined as total plaque load**
A linear regression established that preoperative oral health as measured by total plaque per participant’s oral cavity could statistically significantly predict postoperative oral health. Preoperative oral health accounted for 53% of the explained variability in postoperative oral health as measured by total plaque scores. The effect for this result was large, $R^2_{(adj)} = .525$, $F(1, 94) = 105.8$, $p = .001$.

**Hierarchical multiple linear regression 1. Oral health defined as mean plaque**
A hierarchical multiple linear regression to determine whether preoperative oral health had an impact on predicting postoperative oral health after controlling for age, gender, acuity, comorbid conditions, smoking history, type of surgery, systemic antibiotic use is
summarized in Table 14. The full model (Model 2) with covariates included was statistically significant, $F(9, 86)=11.89, p < .001, R^2 (adj) = .508$. Preoperative oral health explained 64% of the variance in postoperative oral health after controlling for age, gender, acuity, comorbid conditions, smoking history, type of surgery, systemic antibiotic use. The addition of the covariates to the prediction of postoperative oral health led to an increase in $R^2$ of .053, $p = .000$. When examining the individual predictive value of the variables, only preoperative mean plaque score ($\beta = .676, t(95) = 8.91, p = .001$) and type of surgery ($\beta = -.220, t(95) = -2.79, p = .006$) made a significant contribution to understanding variability in postoperative oral health with vascular surgery having a stronger association with poor postoperative oral health than cardiac surgery.
Table 14.

**Summary of Hierarchical Regression Analysis for Variables Predicting Postoperative Oral Health with Mean Plaque Score as Dependent Variable (N=96)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE B$</th>
<th>$\beta$</th>
<th>$R^2_{adj}$</th>
<th>$\Delta R^2$</th>
<th>Part $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Mean Plaque Score</td>
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<td>.081</td>
<td>.708***</td>
<td>.496</td>
<td>.501***</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
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<td>.015</td>
<td>-.053</td>
<td>.508</td>
<td>.053</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>.176</td>
<td>.273</td>
<td>.050</td>
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<tr>
<td>Surgery type</td>
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<td>-.220**</td>
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<tr>
<td>Preoperative Antibiotics</td>
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<td>.417</td>
<td>.039</td>
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<td>Comorbidity</td>
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<td>.035</td>
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</tr>
<tr>
<td>Acuity</td>
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<tr>
<td>Smoker</td>
<td>-.130</td>
<td>.266</td>
<td>-.037</td>
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<td>Postoperative antibiotics</td>
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<td>.441</td>
<td>-.075</td>
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<td>Preoperative Mean Plaque Score</td>
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<td>.084</td>
<td>.676***</td>
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<td>.641</td>
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</tbody>
</table>

*Note.* Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). ***$p < .001$, **$p < .01$. 
Hierarchical multiple linear regression 2. Oral health defined as total plaque load

The full regression model (Model 2) using total plaque load to predict postoperative oral health and with the covariates included was significant, $F(9, 86)=12.01, p = .001$. $R^2_{(adj)} = .510$. Preoperative oral health explained 68.5% of the variance in postoperative oral health. The addition of the covariates to the prediction of postoperative oral health led to an increase in $R^2$ of .027, $p = .000$. Of the nine variables in the full model, preoperative plaque load was the only significant predictor of postoperative oral health (see Table 15).
Table 15.

Summary of Hierarchical Regression Analysis for Variables Predicting Postoperative Oral Health with Total Plaque Load as Dependent Variable (N=96)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>R² adj</th>
<th>Δ R²</th>
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<tbody>
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<td><strong>Model 1</strong></td>
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<tr>
<td>Preoperative Total Plaque Load</td>
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<td>.096</td>
<td>.728***</td>
<td>.525</td>
<td>.530***</td>
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<td><strong>Model 2</strong></td>
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<td>-.048</td>
<td>.510</td>
<td>.027</td>
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<td>-11.082</td>
<td>7.349</td>
<td>-.119</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>7.226</td>
<td>9.969</td>
<td>.056</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbidity</td>
<td>-.775</td>
<td>1.043</td>
<td>-.056</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>-.079</td>
<td>.581</td>
<td>-.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-3.634</td>
<td>6.372</td>
<td>-.042</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative antibiotics</td>
<td>-9.194</td>
<td>10.691</td>
<td>-.068</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Total Plaque Load</td>
<td>.985</td>
<td>.103</td>
<td>.726***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). ***p < .001.*
Summary. Preoperative oral health explained 64% of the variance in postoperative oral health after controlling for age, gender, acuity, comorbid conditions, smoking history, type of surgery, systemic antibiotic use. Older subjects were more likely to have undergone cardiac surgery. Participants with a smoking history had higher preoperative mean plaque scores and were more likely to have undergone a vascular surgery. Participants who had undergone vascular surgery had higher postoperative mean plaque scores and higher acuity. Of the nine variables examined, only preoperative oral health and having a vascular surgery procedure made a significant contribution to understanding variability in postoperative oral health with vascular surgery having a stronger association with poor postoperative oral health than cardiac surgery.

Research Question Four

How do age, gender, acuity, comorbidity, smoking history, surgery type, and antibiotic use change oral health over time from preoperative to postoperative?

The intent of this question was to evaluate whether age, gender, acuity, comorbidity, smoking history, type of surgical procedure, and use of antibiotics had an impact on the change in oral health from the preoperative period to the postoperative period. Two multiple linear regressions were used to evaluate whether there was a significant change in oral health over time when regressed on the predictor variables of age, gender, comorbidity, smoking history, acuity, surgery type, and antibiotic use. The first regression analysis defined change in oral health as a change in mean plaque over time. In this analysis, change in mean plaque between pre-operative and post-operative was regressed on the predictor variables age, gender, comorbidity, smoking history, acuity, surgery type, and antibiotic use. In the second regression analysis, change in oral
health was defined as a change in total plaque between pre-operative and post-operative scores. This variable was regressed on the predictor variables age, gender, comorbidity, smoking history, acuity, surgery type, and antibiotic use.

Preliminary analyses were conducted to examine linearity, normality, homoscedasticity and multicollinearity of the data. The change scores between preoperative and postoperative oral health were normally distributed as assessed by visual inspection of Normal Q-Q plots and histograms. However, the Shapiro-Wilk’s statistic had a significant p-value ($p = .004$). The variables were not transformed since the sample size was greater than thirty, thereby lessening the concern for violating the assumption of normality (Field, 2013). Change scores were normally distributed for mean plaque with a skewness of .191 ($SE = .246$) and kurtosis of 1.49 ($SE = .488$), though total plaque was positively skewed with a skewness of .882 ($SE = .246$) and positively kurtotic with kurtosis of 1.49 ($SE = .488$). Tolerance (.830-.942) and VIF values (1.061-1.204) indicated that there was no multicollinearity. The assumption of independence of error terms was met because the Durbin-Watson coefficients were 2.35 for mean plaque difference and 2.41 for total plaque difference. The Durbin-Watson ranges from 0 to 4. The residuals are uncorrelated if the Durbin-Watson is approximately 2 (Field, 2013)

**Bivariate correlations**

The bivariate correlations when evaluating change in mean plaque over time are presented in Table 16. Older subjects were more likely to have undergone cardiac surgery. Older women more often received preoperative antibiotics. Smokers were more likely to have undergone a vascular surgery procedure. A direct correlation was found between comorbidity and acuity. Subjects with higher acuity were more likely to have
had vascular surgery and were more likely to have received postoperative antibiotics. A strong correlation $r(95) = .26, p = .005$ was found between vascular surgery patients and difference in mean plaque scores from preoperative to postoperative.
Table 16.

*Pearson Correlations between Variables in Regression with Difference in Mean Plaque Score as Dependent Variable (N=96)*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean Plaque Difference</th>
<th>Age</th>
<th>Gender</th>
<th>Surgery Type</th>
<th>Preop Antibiotics</th>
<th>Comorbid Condition</th>
<th>Acuity</th>
<th>Smoker</th>
<th>Postop Antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Plaque Difference</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.102</td>
<td></td>
<td>.00</td>
<td>-.260**</td>
<td>-.002</td>
<td>-.262**</td>
<td>-.009</td>
<td>-.033</td>
<td>-.014</td>
</tr>
<tr>
<td>Gender</td>
<td>-.007</td>
<td>.074</td>
<td>1.000</td>
<td>-.009</td>
<td>.004</td>
<td>.022</td>
<td>.112</td>
<td>.055</td>
<td>-.115</td>
</tr>
<tr>
<td>Surgery Type</td>
<td>-.260**</td>
<td>.270**</td>
<td>.109</td>
<td>.185*</td>
<td>-.169*</td>
<td>.045</td>
<td>.135†</td>
<td>.069</td>
<td>.091</td>
</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>-.002</td>
<td>.185*</td>
<td>-.262**</td>
<td>-.075</td>
<td>.005</td>
<td>-.063</td>
<td>.044</td>
<td>.074</td>
<td>.091</td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>.004</td>
<td>.022</td>
<td>.045</td>
<td>.005</td>
<td>-.063</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>-.009</td>
<td>.112</td>
<td>-.129</td>
<td>.135†</td>
<td>.044</td>
<td>.203*</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-.033</td>
<td>-.055</td>
<td>-.006</td>
<td>-.169*</td>
<td>.069</td>
<td>.074</td>
<td>-.032</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Postoperative Antibiotics</td>
<td>-.014</td>
<td>-.115</td>
<td>-.158†</td>
<td>-.176*</td>
<td>.091</td>
<td>.004</td>
<td>.274**</td>
<td>-.096</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Note. Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). **p< .01, *p<.05.*
Table 17 displays the bivariate correlations when evaluating change in total plaque. Statistically significant correlations between the variables were similar when change in total plaque was examined. A strong correlation was found between vascular surgery patients and difference in total plaque scores from preoperative to postoperative.
Table 17.

**Pearson Correlations between Variables in Regression with Difference in Total Plaque Load as Dependent Variable (N=96)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total Plaque Difference</th>
<th>Age</th>
<th>Gender</th>
<th>Surgery Type</th>
<th>Preop Antibiotics</th>
<th>Comorbid Condition</th>
<th>Acuity</th>
<th>Smoker</th>
<th>Postop Antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Plaque Difference</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.091</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-.028</td>
<td>-.074</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery Type</td>
<td>-.176*</td>
<td>.270**</td>
<td>.109</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>.073</td>
<td>.185*</td>
<td>-.262**</td>
<td>-.075</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>-.094</td>
<td>.022</td>
<td>.045</td>
<td>.005</td>
<td>-.063</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>-.083</td>
<td>.112</td>
<td>-.129</td>
<td>.135†</td>
<td>.044</td>
<td>.203*</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-.018</td>
<td>-.055</td>
<td>-.006</td>
<td>-.169*</td>
<td>.069</td>
<td>.074</td>
<td>-.032</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Postoperative Antibiotics</td>
<td>-.049</td>
<td>-.115</td>
<td>.158†</td>
<td>-.176*</td>
<td>.091</td>
<td>.004</td>
<td>.274**</td>
<td>-.096</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Note.* Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0 = no, 1 = yes). **p < .01, *p < .05.
Multiple linear regression 1. Oral health defined as a change in mean plaque from preoperative to postoperative.

Table 18 displays a summary of the regression model. The regression model examining predictors of change in oral health over time using mean plaque score was not found to be significant $F(8, 87) = .988, p = .451$. Having a vascular surgery was the only significant predictor of change in oral health ($\beta = -.815, t = -2.57, p = .012$).
<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>( R^2_{adj} )</th>
<th>( Δ R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.043</td>
<td>1.171</td>
<td>-.001</td>
<td>.083</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.006</td>
<td>.015</td>
<td>-.045</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>.034</td>
<td>.281</td>
<td>.013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery type</td>
<td>-.815</td>
<td>.317</td>
<td>-.289*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>.004</td>
<td>.430</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>.001</td>
<td>.045</td>
<td>.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>.013</td>
<td>.025</td>
<td>.059</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-.130</td>
<td>.266</td>
<td>-.037</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative antibiotics</td>
<td>-.239</td>
<td>.275</td>
<td>-.092</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). *p<.05*
Multiple linear regression 2. Oral health defined as a change in total plaque from preoperative to postoperative.

The regression model examining predictors of change in oral health over time using total plaque score was not found to be significant $F(8, 87) = .666, p = .72$.

Regression coefficients and standard errors are presented in Table 19 with none of the covariates making a statistically significant contribution towards predicting change in oral health over time.
Table 19.

*Summary of Regression Analysis for Variables Predicting Change in Oral Health with Difference in Total Plaque Score as Dependent Variable (N=96)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE B$</th>
<th>$\beta$</th>
<th>$R^2_{adj}$</th>
<th>$\Delta R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>51.773</td>
<td>26.861</td>
<td></td>
<td>-0.029</td>
<td>0.058</td>
</tr>
<tr>
<td>Age</td>
<td>-0.226</td>
<td>0.359</td>
<td>-0.070</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.422</td>
<td>6.456</td>
<td>-0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery type</td>
<td>-11.180</td>
<td>7.278</td>
<td>-0.175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative Antibiotics</td>
<td>7.097</td>
<td>9.874</td>
<td>0.080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>-0.751</td>
<td>1.025</td>
<td>-0.079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>-0.078</td>
<td>0.577</td>
<td>-0.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>-3.569</td>
<td>6.320</td>
<td>-0.061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative antibiotics</td>
<td>-9.021</td>
<td>10.566</td>
<td>-0.075</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes).
Summary.

Age, gender, acuity, comorbidity, smoking history and antibiotic use did not have an impact on the change in oral health over time from the preoperative period to the postoperative period. However, having a vascular surgery procedure made a significant contribution to understanding change in oral health over time when mean plaque scores were used as the predictor variable for oral health.

Research Question Five

What is the relationship between oral health (pre-hospital and post-intubation) and ventilator-associated pneumonia in older adult intensive care unit patients when controlling for age, gender, smoking history, acuity, comorbidity, surgery type and antibiotic use?

This research question was answered with a series of logistic regression analyses using the various methods of operationally defining oral health as predictor variables (e.g., mean plaque per tooth, total plaque score, plaque change) and the variable ventilator-associated pneumonia as a dichotomous dependent variable while controlling for the covariates age, gender, smoking history, acuity, comorbidity, type of surgery, and antibiotic use. These logistic regression analyses were done to determine the effects of oral health both pre-hospital and post-intubation on the likelihood that ICU patients would develop ventilator-associated pneumonia.

For each regression, assumptions were tested and multicollinearity and influential cases were evaluated. All independent variables demonstrated adequate variance. There was no multicollinearity because the tolerance values were greater than .20 and the VIF values were less than 10. There was evidence of three influential cases with Cook’s D
greater than one (1.23, 1.6, and 2.4). The three influential outliers were removed and the regression analyses were run again. In each regression analysis, ventilator-associated pneumonia risk on postoperative day three (POD 3) was entered as the dichotomous dependent variable as determined by a CPIS score of greater than or equal to six on or after the third postoperative day. If the subject had a CPIS greater than or equal to six, they were coded as having VAP; if they had a CPIS of less than 6, then they were coded as not having VAP. The number of subjects with CPIS greater than or equal to six is displayed in Figure 7.

![Incidence of VAP](image)

*Figure 7. Number of subjects with ventilator-associated pneumonia (VAP).*

Tables 20, 21 and 22 display the results of the logistic regression analyses using the various plaque measures as the predictor variables and ventilator-associated pneumonia on or after postoperative day 3 as the dichotomous dependent variable. All of the models were statistically significant. The models explained one fourth to one third of the variance in ventilator-associated pneumonia and correctly classified 64.5% to 76.3% of the cases. Sensitivity was 60.5% to 72.1%, specificity was 74% to 82%, positive
predictive value was 63.5% to 70.4% and negative predictive value was 64.8% to 71.5% across the models.
Table 20.

Summary of Logistic Regression Analysis for Variables Predicting Ventilator-Associated Pneumonia (VAP) Risk on or After the Third Postoperative Day by Preoperative Oral Health Controlling for Background Variables (N=93)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative Mean</th>
<th></th>
<th></th>
<th>Preoperative Total</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>p value</td>
<td>OR</td>
<td>95% CI</td>
<td>p value</td>
</tr>
<tr>
<td>Plaque</td>
<td>1.14</td>
<td>.83 – 1.57</td>
<td>.417</td>
<td>.999</td>
<td>.98 – 1.01</td>
<td>.859</td>
</tr>
<tr>
<td>Age</td>
<td>.976</td>
<td>.92 – 1.03</td>
<td>.388</td>
<td>.976</td>
<td>.92 – 1.03</td>
<td>.385</td>
</tr>
<tr>
<td>Gender</td>
<td>.298</td>
<td>.11 - .85</td>
<td>.023</td>
<td>.332</td>
<td>.12 - .923</td>
<td>.034</td>
</tr>
<tr>
<td>Smoker</td>
<td>.762</td>
<td>.28 - 2.09</td>
<td>.733</td>
<td>.799</td>
<td>.29 – 2.14</td>
<td>.656</td>
</tr>
<tr>
<td>Surgery Type</td>
<td>.929</td>
<td>.22 – 2.39</td>
<td>.598</td>
<td>.896</td>
<td>.29 – 2.81</td>
<td>.851</td>
</tr>
<tr>
<td>Pre-Antibiotics</td>
<td>.677</td>
<td>.14 – 3.31</td>
<td>.630</td>
<td>.814</td>
<td>.17 – 3.83</td>
<td>.795</td>
</tr>
<tr>
<td>Post-Antibiotics</td>
<td>6.33</td>
<td>.58 – 68.37</td>
<td>.129</td>
<td>5.83</td>
<td>.56 – 60.10</td>
<td>.139</td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>1.16</td>
<td>.99 – 1.25</td>
<td>.072</td>
<td>1.17</td>
<td>.99 – 1.38</td>
<td>.061</td>
</tr>
<tr>
<td>Acuity</td>
<td>1.12</td>
<td>.99 – 1.25</td>
<td>.059</td>
<td>1.11</td>
<td>.99 – 1.24</td>
<td>.057</td>
</tr>
<tr>
<td>(X^2)</td>
<td>20.38*</td>
<td></td>
<td></td>
<td>19.75*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagelkerke</td>
<td>.263</td>
<td></td>
<td></td>
<td>.256</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. VAP (0 = no, 1 = yes). Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). OR = Odds ratio. CI = Confidence interval. *p < .05
Table 21.

Summary of Logistic Regression Analysis for Variables Predicting Ventilator-Associated Pneumonia (VAP) Risk on or After the Third Postoperative Day by Postoperative Oral Health Controlling for Background Variables (N=93)

<table>
<thead>
<tr>
<th>Plaque Type</th>
<th>Postoperative Mean</th>
<th>OR</th>
<th>95% CI</th>
<th>p value</th>
<th>Postoperative Total</th>
<th>OR</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postop Plaque</td>
<td></td>
<td>.833</td>
<td>.61 – 1.14</td>
<td>.257</td>
<td>.993</td>
<td>.98 – 1.0</td>
<td>.223</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td>.972</td>
<td>.92 – 1.03</td>
<td>.333</td>
<td>.974</td>
<td>.92 – 1.03</td>
<td>.364</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>.359</td>
<td>.13 - .99</td>
<td>.048</td>
<td>.348</td>
<td>.13 - .966</td>
<td>.043</td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td></td>
<td>.841</td>
<td>.31 - 2.26</td>
<td>.733</td>
<td>.761</td>
<td>.28 – 2.07</td>
<td>.593</td>
<td></td>
</tr>
<tr>
<td>Surgery Type</td>
<td></td>
<td>.717</td>
<td>.22 – 2.39</td>
<td>.589</td>
<td>.895</td>
<td>.28 – 2.84</td>
<td>.85</td>
<td></td>
</tr>
<tr>
<td>Pre-Antibiotics</td>
<td></td>
<td>.951</td>
<td>.19 – 4.67</td>
<td>.951</td>
<td>.896</td>
<td>.18 – 4.45</td>
<td>.893</td>
<td></td>
</tr>
<tr>
<td>Post-Antibiotics</td>
<td></td>
<td>5.48</td>
<td>.56 – 53.44</td>
<td>.143</td>
<td>5.05</td>
<td>.48 – 52.69</td>
<td>.176</td>
<td></td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td></td>
<td>1.20</td>
<td>1.0 – 1.43</td>
<td>.042</td>
<td>1.16</td>
<td>.98 – 1.38</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td></td>
<td>1.11</td>
<td>1.01 – 1.25</td>
<td>.049</td>
<td>1.11</td>
<td>.99 – 1.25</td>
<td>.057</td>
<td></td>
</tr>
<tr>
<td>$X^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagelkerke</td>
<td></td>
<td>.271</td>
<td></td>
<td></td>
<td>.273</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. VAP (0 = no, 1 = yes). Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). OR = Odds ratio. CI = Confidence interval. **p < .01.
Using change in mean plaque score in the model as the predictor variable increased the sensitivity and specificity to 72.1% and 80% (Nagelkerke $R^2 = .32$).

Table 22.

Summary of Logistic Regression Analysis for Variables Predicting Ventilator-Associated Pneumonia (VAP) Risk on or After the Third Postoperative Day by Change in Oral Health Controlling for Background Variables (N=93)

<table>
<thead>
<tr>
<th>Plaque Type</th>
<th>Change Mean</th>
<th></th>
<th></th>
<th>Change Total</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>p value</td>
<td>OR</td>
<td>95% CI</td>
<td>p value</td>
</tr>
<tr>
<td>Plaque Change</td>
<td>.740</td>
<td>.52 – 1.04</td>
<td>.086</td>
<td>.986</td>
<td>.97 – 1.0</td>
<td>.124</td>
</tr>
<tr>
<td>Age</td>
<td>.968</td>
<td>.91 - 1.03</td>
<td>.272</td>
<td>.970</td>
<td>.92 – 1.03</td>
<td>.292</td>
</tr>
<tr>
<td>Gender</td>
<td>.308</td>
<td>.11 - .88</td>
<td>.028</td>
<td>.316</td>
<td>.11 - .89</td>
<td>.029</td>
</tr>
<tr>
<td>Smoker</td>
<td>.755</td>
<td>.27 - 2.13</td>
<td>.596</td>
<td>.771</td>
<td>.28 – 2.13</td>
<td>.616</td>
</tr>
<tr>
<td>Surgery Type</td>
<td>.616</td>
<td>.18 – 2.1</td>
<td>.439</td>
<td>.802</td>
<td>.25 – 2.57</td>
<td>.711</td>
</tr>
<tr>
<td>Pre-Antibiotics</td>
<td>.727</td>
<td>.14 – 3.79</td>
<td>.705</td>
<td>.811</td>
<td>.16 – 3.99</td>
<td>.797</td>
</tr>
<tr>
<td>Post-Antibiotics</td>
<td>5.45</td>
<td>.53 – 56.44</td>
<td>.155</td>
<td>5.20</td>
<td>.49 – 55.22</td>
<td>.171</td>
</tr>
<tr>
<td>Comorbid Condition</td>
<td>1.18</td>
<td>1.0 – 1.4</td>
<td>.049</td>
<td>1.17</td>
<td>.98 – 1.38</td>
<td>.069</td>
</tr>
<tr>
<td>Acuity</td>
<td>1.14</td>
<td>1.01 – 1.28</td>
<td>.036</td>
<td>1.12</td>
<td>.99 – 1.25</td>
<td>.064</td>
</tr>
<tr>
<td>$X^2$</td>
<td>25.70**</td>
<td></td>
<td></td>
<td>22.29**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagelkerke</td>
<td>.323</td>
<td></td>
<td></td>
<td>.285</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. VAP (0=no, 1=yes). Gender (0 = female, 1 = male). Surgery type (vascular surgery = 0, cardiac surgery = 1). Smoker (0= no, 1= yes). $OR = $ Odds ratio. $CI = $ Confidence interval. **$p < .01.$
respectively. The Hosmer and Lemeshow test had a nonsignificant score ($p = .452$) indicating that the model fits the data well. The Omnibus tests of model coefficients representing the change in the -2 Log likelihood scores indicated that the model using change in mean plaque as the predictor significantly improved over the previous block ($p = .002$). Overall, this model correctly identified 76.3% of the cases.

With regard to those predictors that made the models significant, only change in mean plaque score, $\text{OR} = .6$, 95% CI [.38, .94], $p = .025$, was a significant predictor of the development of ventilator-associated pneumonia. Initial analysis revealed that as the size of the difference between preoperative and postoperative plaque increased, the odds of developing VAP decreased by 40%, an unexpected and counterintuitive result. Data were further evaluated using frequencies for all variables to explore out of range values, boxplots and graphs were used to graphically depict the relationship between variables and one way ANOVA was used to determine whether there were differences between the group with VAP versus the group without VAP in mortality or any of the explored covariates: age, race, gender, comorbidity, acuity, smoking history and antibiotic use. No errors in the data or differences between the VAP and no VAP group were found. On further analysis, using independent samples t-test to evaluate the differences between the group with VAP compared to the group without VAP, it was found that there was not a statistically significant difference between the groups on change in plaque, $t (94) = 1.76$, $p = .08$ Repeat logistic regression analysis using only change in plaque over time as a predictor of VAP risk, without the addition of the covariates, revealed that change in oral health over time was not a significant predictor of the occurrence of VAP, $p = .12$. 
Of the nine predictor variables, only gender was statistically significant in all models. Women were more likely to develop ventilator-associated pneumonia than males, \( OR = .31, 95\% \text{ CI } [.11, .88], p = .03 \). Acuity and comorbidity were statistically significant predictors in the models where postoperative mean plaque (\( OR = 1.12, 95\% \text{ CI } [1.0, 1.25] p = .049; OR = 1.2, 95\% \text{ CI } [1.0, 1.42], p = .042 \)) and change in mean plaque (\( OR = 1.14, 95\% \text{ CI } [1.0, 1.28], p = .036; OR = 1.18, 95\% \text{ CI } [1.0, 1.4], p = .049 \)) were used to explain the variance in VAP. The percent of plaque for the most common comorbid conditions are presented in Figure 8. All patients with COPD, CHF, cerebrovascular disease, cancer, diabetes and who smoked had higher preoperative and postoperative plaque scores than patients who did not have COPD, CHF, cerebrovascular disease, cancer, diabetes or who did not smoke, however only patients with a history of CHF, \( t (73.36) = -2.70, p = .009 \) and cerebrovascular disease, \( t (94) = -2.52, p = .013 \) had statistically significant differences in plaque.
The 96 patients who participated in this study were predominately Caucasian males, with a mean age of 72 years, and who had undergone cardiac or vascular surgery. Nearly two-thirds of the participants had a history of smoking. There were no age or gender differences in pre-hospital oral health; however, smokers had higher mean plaque scores preoperatively. There were no age or gender differences in oral health postoperatively. Preoperative oral health significantly predicted postoperative oral health and accounted for 64% of the variability in postoperative oral health. Preoperative mean plaque score and type of surgery made a significant contribution to understanding variability in postoperative plaque scores. Overall, oral health declined from preoperative to postoperative but deteriorated less in cardiac surgery patients. Only gender, comorbidity and acuity were significant predictors of VAP risk. Higher patient
acuity, greater number of comorbidities and being female was associated with an increased likelihood of developing ventilator-associated pneumonia.
Chapter V

Discussion

This study is the first to evaluate pre-hospital oral health status as a risk factor for ventilator-associated pneumonia (VAP). While oral health, dental plaque and oral bacteria have been suggested in the literature as linked to VAP, the association between amount of plaque before and after surgery and VAP risk has not previously been directly studied. This chapter will discuss the major findings of this study and relationship to the scientific literature as they relate to the relationship between oral health and ventilator-associated pneumonia. Predictors of ventilator-associated pneumonia will be discussed with the aim of determining individuals at risk and to identify sources of risk that may be appropriate targets for effective intervention. Though limited by the population studied and the measures taken, implications for practice can be discussed based on this study.

The prevention of VAP is an imperative based on the increasing morbidity, mortality and public health cost that it entails. Over the past thirty years, oral health disparities have been growing, especially in the poor, older adults, and racial and ethnic minorities (M. Allukian, Jr., 2008). With the well-known growth in the population of older adults (Kinsella & He, 2009) and disparities in oral health care (Vargas, 2001), older adults are at risk for developing pneumonia when they are hospitalized. As many as half of patients entering an intensive care unit, require mechanical ventilation (Grap, 2009). Ventilator-associated pneumonia complicates the course of up to 28% of patients receiving mechanical ventilation (Tablan, 1994; Rello, 2002; Chaste and Fagon, 2002; Kollef, 2005) and results in increased morbidity and mortality as well as increased medical costs (Chaste and Fagon, 2002). It has been suggested that a key risk factor in the
development of VAP is accumulation of dental plaque which serves as a nidus of infection for potential respiratory pathogens linked to the development of VAP (Scannapieco, et al., 1992; Fourrier et al., 1992; Munro, 2006). While many risk factors in the ICU have been studied, including oral health after intubation, this is the first study to evaluate the vulnerability relating to prehospital oral health status. This is important in that it may help identify those at most risk for VAP and therefore allow focus on prevention in these individuals.

Moreover, the purpose of this study was to evaluate the overall importance of prehospital oral health in the risk of acquiring VAP. Since VAP risk may be effected by multiple pre-existing patient conditions including oral health, many factors involving the acute disease and surgical treatment, and finally many factors involving the in-hospital experience, acuity and oral care, there is uncertainty as to when and where the most effective battle against VAP should be fought. If oral health is an important variable, does the effect of preexisting plaque outweigh the effects of the change in plaque during the hospital experience? Should we focus on pre-operative screening and treatments or on ICU oral care? This is the first study to approach this question by determining the amount of plaque as an estimate of oral health both before and after its change with intubation and in the ICU. While this study is limited in its patient population, primarily cardiac and vascular, and in its measurements, using plaque alone as the oral proxy for oral health, it nevertheless suggests that preoperative morbidity plays a major role in oral health in the ICU and that hospital acuity and chronic medical conditions are related to VAP occurrence.
Major Research Findings

There were three key findings from the results of this study. First, oral health of patients prior to hospital admission is compromised and was worse in patients with specific comorbid conditions. Second, oral health declined from the preoperative to the postoperative period and deteriorated more in vascular surgery patients compared to the cardiac surgery group. Third, as measured by the mean tooth area covered by plaque, pre-and post-operative oral health and individual change in oral health, did not predict the relative risk of ventilator-associated pneumonia. However, higher patient acuity, greater number of comorbid conditions and being female were found to be significant predictors of the occurrence of VAP.

Preoperative Oral Health

Preoperative oral health was found to be at level consistent with the general population but worse than what has been found for non-cardiac patients (Meurman, Qvarmstrom, Janket, & Nuutinen, 2003). Although one other study did evaluate the preoperative health of patients specifically prior to open heart surgery, the study did not look at change in oral health or the relationship of oral health to VAP. Our finding of 37% dental plaque accumulation in a mixed cardiac and vascular surgery preoperative group corroborates their finding of 40% in their cardiac-only group. Importantly, it is greater than that seen in age and sex matched non-cardiac patients where a 20% plaque covered surface was observed (Meurman et al., 2003). Oral health as reported in a similar age population from the National Oral Health Surveillance System Ohio data is consistent with these findings (CDC, 2010). The results are also consistent with epidemiological studies indicating that 41% of older adults have poor oral health (Vargas, et al., 2001).
While this study showed no direct relationship in the amount of pre-operative plaque to VAP risk, these results are consistent with the idea that oral health generally is compromised in this older adult patient group.

Specific to this study, patients with a history of smoking, chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), cerebrovascular disease (CVD) and diabetes had higher amounts of plaque preoperatively than patients who had never smoked and who did not have COPD, CHF, CVD or diabetes with the patients with CHF and CVD having statistically significant differences in plaque. This is key information since multiple chronic conditions cluster putting patients at risk for adverse outcomes (Kadam & Croft, 2007). The most common cluster of comorbid conditions in this study was COPD, CHF and diabetes. These findings are consistent with the literature and significant in that the most common cluster of comorbid conditions in older adults with pneumonia is COPD, CHF and diabetes (File & Tan, 2005). In addition, the prevalence of periodontal disease among smokers is three times higher than among people who have never smoked (CDC, 2011). Identifying patient populations who, in general, exhibit higher accumulation of dental plaque and thus more bacterial colonization of their oral cavity and who are also at greater risk of pneumonia based on their underlying disease is of great Almost consequence in that it expands the understanding of risk factors for VAP and may allow for targeted interventions for these more vulnerable groups.

**Oral Health Change**

Almost all participants in the study received the standard VAP prevention protocol postoperatively which included chlorhexidine mouth rinses. The percent of
plaque postoperative was 48\% with a range of 11\%-98\% which was also consistent with prior work in this area (Jones, 2010). Importantly, however, there was a significant direct correlation between preoperative and postoperative dental plaque. Thus, knowing an individual’s oral health status preoperatively can provide vital information regarding who is most likely to have poor oral health postoperatively as well. This may make possible the screening of individuals before surgery in order to detect those at risk for poor oral health postoperatively.

In this study, oral health declined from the preoperative to the postoperative period and deteriorated more in vascular surgery patients. Although the hypothesized effect size for this study was a medium effect size of .30, the actual observed effect size was large ($R^2 = .64$, CI .58, .91) with 64\% of the variance in postoperative oral health explained by knowing the individual’s preoperative oral health score. When examining the CI around the ES, it is worth noting that the smallest relationship ($R^2 = .58$) is still considered to be a large ES (Cohen, 1992).

This finding of deterioration in overall oral health status over time is consistent with the findings from other studies. In a study of ICU patients, Fourrier et al (1998) found an increase in dental plaque over 5 days and that colonization of dental plaque was significantly associated with nosocomial infections. In a study on oral health status and VAP, Munro et al (2006) found that patients presented to the ICU with oral health problems as demonstrated by high baseline counts of decayed, missing and filled teeth and that dental plaque and oral organisms increased over time.

While an overall decline in oral health has been seen in other studies and may be understood on the basis of intubation, oral stasis and decreased care among other factors,
the finding of a greater decline in vascular patients is less well explained. This study showed that having vascular surgery explained 26% of the variance in change in oral health. Cardiac patients did not differ significantly as a group in their presenting comorbidities or preoperative plaque load baseline. There were significant differences in their preoperative oral health treatment however. Unlike vascular patients, cardiac patients received a preoperative dental examination prior to surgery, and also received Listerine® and chlorhexidine prior to surgery.

While differences inherent in vascular disease and its treatment cannot be ruled out as a cause of the greater decline in oral health, in this study, the advantage of preoperative oral treatment has been suggested in the literature. Listerine® is a mouth rinse that contains essential oils and ethanol which in combination have an established antimicrobial effect (Fine et al., 2000; Okuda, Adachi, & Iijima, 1998). Chlorhexidine (CHX) is a topical oral antimicrobial rinse with demonstrated efficacy in reducing VAP by reducing bacterial colonization of the oropharynx (Chan, Ruest, Meade, & Cook, 2007; Chlebicki & Safdar, 2007; Munro et al., 2009a) and in controlling plaque (Van Strydonck, Slot, Van der Velden, & Van der Weijden, 2012). In a meta-analysis of sixteen randomized control trials, oral decontamination reduced the incidence of VAP (J. Li, Xie, Li, & Yue, 2013). Grap and colleagues (2011) found that a single, early application of CHX reduced VAP in patients intubated for up to 72 hours. In a randomized control trial evaluating mechanical and pharmacologic oral care for the prevention of VAP, it was found that CHX alone reduced VAP while tooth brushing had no effect on reducing VAP (Munro et al., 2009).
Given this literature, difference between the vascular surgery patients and the cardiac surgery patients decline in oral health may be due to the vascular surgery group not having received oral decontamination with Listerine® and chlorhexidine preoperatively. This suggests that the efficacy of this preoperative decontamination strategy may extend to a mitigation of the hospital-acquired change. This positive effect may generalize beyond its use in cardiac surgery patients.

**Predictors of Ventilator-Associated Pneumonia**

It was hypothesized that patients would present to the healthcare setting with multiple pre-existing vulnerabilities for VAP including but not limited to, compromised oral health in the form of dental plaque accumulation and that would increase their risk for VAP. Further, oral health would worsen over time in the ICU due to multiple personal and environmental factors such as artificial airways, mechanical ventilation, medications, illness severity, immune compromise, and chronic health conditions further increasing their risk of acquiring VAP. In this study as in other studies, a higher patient acuity and greater number of comorbid conditions were found to be significant predictors of VAP. (Celis et al., 1988; Chevret et al., 1993; Bonten et al., 2004; Chaste and Fagon, 2002). However, a key finding of this study is that a direct positive predictive relationship was not found between preoperative oral health, postoperative oral health or change in oral health over time and ventilator-associated pneumonia.

The post hoc power analysis, based on the main research question exploring the predictive relationship between oral health (pre-intubation and post-intubation) and ventilator-associated pneumonia was based on the actual observed effect size for this study of .32. Given the sample size of 92 patients with CPIS of greater than or equal to
six on or after postoperative day three for the regression analysis, the achieved power with nine predictors and an alpha set at .05 was calculated to be .995. This means that the sample size provided sufficient power identify statistical significance, when present in the population. In addition, given the high degree of power, the probability of making a Type II error (saying that you have not found statistical significance, when, in fact, that is not the case in the population) was very small (.005).

Initial analysis revealed that as the size of the difference between preoperative and postoperative plaque increased, the odds of developing VAP actually decreased by 40%, an unexpected and counterintuitive result. Data were further evaluated using frequencies for all variables to explore out of range values, boxplots and graphs were used to graphically depict the relationship between variables and one way ANOVA was used to determine whether there were differences between the group with VAP versus the group without VAP in mortality or any of the explored covariates: age, race, gender, comorbidity, acuity, smoking history and antibiotic use. No errors in the data or differences between the VAP and no VAP group were found. On further analysis, using independent samples t-test to evaluate the differences between the group with VAP compared to the group without VAP, it was found that there was not a statistically significant difference between the groups on change in plaque. Repeat logistic regression analysis using only change in plaque over time as a predictor of VAP risk, without the addition of the covariates, revealed that change in oral health over time was indeed not a significant predictor of the occurrence of VAP. In sum there is little evidence of a relationship between plaque change during intubation and VAP risk. There is no evidence of increased oral health deterioration associated with increased VAP risk.
Since previous studies have shown associations between VAP risk and dental plaque accumulation and thus suggests its role in VAP pathogenesis, the lack of a relationship in this study is surprising. One explanation for the findings in this study may be due to dental plaque measurement in the postoperative period with an oral endotracheal tube and orogastric tube in place. The position of the endotracheal and orogastric tubes may have resulted in postoperative plaque scores that were underrated due to difficulty in visualizing all teeth. Nevertheless, postoperative plaque scores for this study were 48% ± 17% with a range of 11% to 98% which were higher than scores of less than 25% reported by Fourrier et al (1998), 25-50% dental plaque coverage reported by El-Solh (2004) and 20% to 24% ± 20%-29% dental plaque from baseline to day seven reported by Munro (2006).

Previous studies (Fourrier et al., 1998; Munro et al., 2006) have provided evidence to support an association between increasing dental plaque accumulation and VAP; however, the evidence tends to lend more support to the importance of bacterial colonization of the plaque with virulent respiratory pathogens in the pathogenesis of VAP rather than plaque load itself. The link between plaque and oral health has been largely based on oral bacteria. Dental plaque provides a microhabitat for aerobic and anaerobic bacteria (Li, et al., 2000; Munro, et al.,2004) which make up 70% to 80% of the solid material of plaque (Fourrier, Dubois, Pronnier, Herbecq, Leroy, Desmettre et al., 2005). Even quantitation of oral bacteria is not a sufficient indicator of health since the pathogenic nature of the bacteria also plays a role. Since teeth are nonshedding surfaces, bacteria levels can reach greater than $10^{11}$ microorganisms per milligram of dental plaque in healthy people (X. Li et al., 2000). Although the oral flora of healthy people is
normally stable, studies have demonstrated that the colonization of dental plaque changes rapidly to more virulent respiratory pathogens in ICU patients ((Francois Fourrier et al., 1998; Heo, Haase, Lesse, Gill, & Scannapieco, 2008; Schleder et al., 2002).

An additional explanation of the results found in this study may be the use of plaque accumulation alone as the proxy for oral health (see limitations). Several studies have used dental plaque accumulation as a proxy for oral health but have incorporated additional parameters for measuring oral health including cultures of dental plaque for respiratory pathogens (El-Solh et al., 2004; Francois Fourrier et al., 1998; Munro, Grap, et al., 2006a) and sampling of saliva for immune components (Munro, 2006). In a study by El-Solh et al (2004), on elderly patients admitted to the ICU from a long term care facility, dental plaque was worse on patients colonized with respiratory pathogens however; there was no statistically significant relationship between those colonized with respiratory pathogens and hospital-acquired pneumonia. Munro et. al., (2006) found that dental plaque increased over time but that the differences over time from baseline to day 7 were not significant. Further, Munro found that increases in dental plaque and the occurrence of VAP was influenced by interactions among dental plaque, severity of illness and baseline CPIS. This may suggest that virulence of multidrug resistant bacteria that colonize dental plaque was more of an indicator of VAP risk than the plaque load itself. Several studies found potential VAP pathogens such as methicillin resistant Staphylococcus aureus and Pseudomonas aeruginosa in dental plaque of ICU patients (Scannapieco et al., 1992; Fourrier et al., 1998; El Solh et al., 2004; Heo et al., 2008).

Of importance, isolates of bacteria obtained from dental plaque of ICU patients undergoing mechanical ventilation were genetically indistinguishable from respiratory
pathogens isolated from the lung (Heo et al., 2008). This may alternatively suggest that
dental plaque is a marker of a vulnerability which is common to the mouth and lungs and
the actual risk factors may rest in the preoperative comorbidities and acuity. As
suggested by the difference in cardiac and vascular surgery patients, oral health decline
may be influenced by amount of preoperative bacterial load that effects subsequent
plaque development and also effects bacterial colonization of the oropharynx.

If the oral health observed is a marker of a more general vulnerability or of a
separate factor (like preoperative mouth rinse) which reduces the risk of both plaque and
VAP, the efficacy of plaque reduction in the ICU must be questioned. Further studies are
needed to validate these findings that include cultures of oral microbial flora
preoperatively and post-intubation to evaluate for the relationship between plaque
accumulation, bacterial colonization of plaque and VAP occurrence. Additionally,
replication of this study in a larger patient population other than cardiac and vascular
surgery is warranted because cardiac and vascular surgery patients are only a portion of
the surgical population and evidence suggests that neurosurgery, thoracic surgery and
trauma patients are at increased risk for VAP (Bonten, 2004).

Limitations of the Study

This study has limitations that can be generally grouped by the nature of the
population studied, the measurements taken, and the definition of the outcome, VAP.
First, the use of a convenience sample threatens external validity and limits the
generalizability of the results since the study included only cardiac and vascular surgery
patients, with a minority (29%) in the vascular group. As a result, the application to other
surgical procedures is uncertain. For example the VAP risk is higher in neurosurgical
patients and may result from disease specific factors. The smaller size of the vascular surgery group may limit the accuracy and power of analysis for this group. Although the study sample of predominately Caucasian, males with an average age of 72 years is representative of the national population of patients undergoing cardiac or vascular surgery (CDC, 2012), it is not representative of those undergoing surgery generally. Replication in a different population of patients beyond cardiac and vascular patients would provide additional strength and generalizability to the findings of this study.

Since a goal of this study was evaluate the risk of VAP, patients likely to require ventilation were by necessity targeted. Potential subjects were recruited based in part on their likelihood of requiring mechanical ventilation in the postoperative period. This eligibility criterion can introduce a selection bias. Patients were considered to likely require longer periods of intubation primarily on their surgery type and pre-assignment to the ICU. These patients may generally have a greater number and severity of underlying medical conditions and have a generally poorer health baseline than the general population of patients undergoing surgery. This may have resulted in an overestimate of the prevalence of poor oral health in the surgery population studied.

The next set of limitations has to do with measurement, the method of measuring plaque and the ability of plaque to represent oral health. The method of staining dental plaque may have resulted in patient and caregiver oral care which could alter pre-op plaque levels after (and as a result of) the pre-operative evaluation and thus go unmeasured. Further this “Hawthorne effect” may occur unevenly affecting those with greatest plaque the most. A visible plaque disclosing agent had to be used to assess dental plaque accumulation instead of a plaque disclosing agent (fluorescein) that was visible.
only under ultra-violet light because fluorescein was discontinued by the manufacturer. The use of the visible disclosing agent in the preoperative clinic allowed patients to see plaque assessment results, highlighting areas where improvement in tooth brushing should be employed. Cleaning the plaque disclosing agent from the teeth, involved brushing of their teeth focusing on those areas with plaque stain. The use of the visible disclosing agent in the ICU to assess postoperative plaque made nurses delivering oral care in the ICU aware of plaque assessment results. Similarly, mechanical oral care methods had to be employed to remove plaque stain from patient’s oral cavity after plaque assessment in the ICU. Moreover, lower plaque scores may have impacted VAP occurrence. Future studies might explore performing the oral health assessment without using a plaque disclosing agent or using a disclosing agent not visible to patients and nurses.

Another important limitation of this study is the limitations of using dental plaque as an indicator of oral health. The UM-OHI dental plaque quantitation does provide a greater discrimination in dental plaque accumulation than other dental plaque indices evaluated, however the tool does not provide a direct quantification of the amount of dental plaque accumulation. The UM-OHI is based on surface sampling for an overall estimate of the overall mean presence of plaque in a patient’s mouth. Even at its best it remains only a proxy for oral health.

Importantly, study of exposed surface plaque may yield different results than a more comprehensive assessment that includes periodontal disease. The most common cause of tooth loss is periodontal disease which affects 11.8% of people 50 to 64 years of age (NINDCR, 2014). Meurman et al., found the mean number of plaque covered
surfaces were lower in the coronary heart disease group until plaque, gingivitis and periodontitis variables were calculated per tooth. If these additional factors were included, the coronary heart disease patients showed significantly higher numbers of plaque covered surfaces and deep periodontal pockets and overall worse oral health.

Dental plaque quantitation, even at its best, cannot determine the amount of pathogenic bacteria that exists in the mouth and is a limited proxy for oral health. Consistent with the result of this study that dental plaque did not predict the risk of VAP, in a study examining the effects of tooth brushing and chlorhexidine on the development of VAP, Munro (2009) found reducing dental plaque was not sufficient in reducing the risk for VAP. However, the use of chlorhexidine which has bactericidal action did reduce the VAP rate.

Using exposed surface plaque as a measure of oral health and risk for VAP may be insufficient for assessing oral health as a risk factor for VAP. Although the UM-OHI is an index with established reliability and validity as a measurement of plaque for the purpose of determining oral health skills, there have been no studies evaluating the correlation of quantification of dental plaque using the UM-OHI with quantification of pathogenic bacteria. A study correlating the measurement of dental plaque accumulation using the UM-OHI with quantitative cultures of dental plaque would enhance the validity of this tool. Measuring additional elements of oral health such as oral microbial flora and immunity provided by saliva volume and flow may also enhance the validity of assessing oral health as a risk factor for VAP. Therefore the UM-OHI may have been insufficient alone in capturing the oral health status of critically ill patients in this study.
No oral microbial cultures or measurement of saliva were taken in this study due to resource considerations. Replication of this study with the addition of the use of cultures of oral microbial flora and salivary immune components and volume to better evaluate oral health status might add crucial information on preoperative and postoperative oral health status.

Finally the dependent outcome is measured here using a proxy probability score. The CPIS used for diagnosing ventilator-associated pneumonia in this study is a non-invasive proxy for facilitating the diagnosis of VAP. It has variability in sensitivity, specificity and substantial interobserver variability. In particular, studies have found variability in diagnosis of the presence or absence of pneumonia. Atelectasis and pulmonary inflammation of Adult Respiratory Distress Syndrome (ARDS) may be mistaken for pneumonia resulting in misdiagnosis as VAP (Rea-Neto et al., 2008). To limit some of these issues in this study, one reviewer (a critical care intensivist) who was blinded to any knowledge of the patient’s medical history evaluated all chest radiographs as originally described by the authors (Pugin, Auckenthaler, Mili, et al., 1991). Since there is no true “gold standard” for diagnosing VAP, the CPIS remains the best available surrogate at the present time for diagnosing VAP; however replication of this study might be warranted.

Third, the threat of history reduced internal validity in the following two ways. First, subjects were enrolled in the study and data was collected during a time of improvement in the implementation of the ventilator bundle due to “pay for performance” initiatives which may have resulted in a decline in VAP rates over the course of the study enrollment. “Pay for performance” initiatives are popular incentive programs with public
payers such as Medicare and Medicaid, designed to improve the quality of healthcare by paying providers for achieving better patient outcomes (James, 2012). The ventilator bundle is a series of interventions for patients receiving mechanical ventilation that when implemented together have resulted in a significant reduction in VAP rates (IHI, 2012). Second, interventions to reduce the length of mechanical ventilation have become a focus in critical care resulting in earlier extubation. Due to new ventilator weaning protocols during the study period, fewer patients stayed intubated for the 48-96 hours than anticipated considered to be early-onset VAP. Even though the length of intubation was less than expected, VAP incidence was consistent with the incidence reported in the literature (Chaste and Fagon, 2002). Future studies might include replication of this study in a different population of patients that require longer periods of intubation and mechanical ventilation.

**Implications for Practice**

Improving patient outcomes by preventing healthcare-associated infections has become a national priority. Nonetheless, ventilator–associated pneumonia continues to complicate the course of critically ill patients. Although this study did show a decline in oral health from preoperative to postoperative, it did not demonstrate that plaque load was related to VAP risk. This study did find that VAP risk is likely related to preoperative comorbidities and vulnerabilities, and to hospital acuity and course. Yet, as in the cardiac surgery group, plaque risk and VAP risk may be reduced by a preoperative rinse which reduces plaque-forming bacteria in the mouth and pathogenic bacteria in the oropharynx at intubation. However, the results of this early research indicate that the
course of oral health in the ICU may be an indicator of the patient’s more general health
and VAP risk and less likely a causative factor whose manipulation would be effectual.

Assessment of oral health prior to hospital admission provided valuable
information for determining change in oral health over time. The Centers for Disease
Control and Prevention (Tablan, 2004) recommendations for preventing healthcare-
associated pneumonia in mechanically ventilated patients discuss the importance of
prevention or reduction of oropharyngeal colonization in the development of VAP.
Recommendations include the use of oropharyngeal cleaning and use of chlorhexidine in
the perioperative period for cardiac surgery patients, however no recommendations were
made for the use of oral decontamination with chlorhexidine in all postoperative or
critically ill patients. This study may add support to the use bacterial decontamination in
preventing or reducing VAP. Currently, there are no VAP prevention protocols that exist
outside the ICU setting. VAP has the potential to be reduced by early identification of
patients with poor general and oral health. Oral health can be positively influenced by
nursing interventions preoperatively that extend to the ICU setting. Nursing interventions
that assess oral health status prior to admission, educate patients on oral hygiene skills
and implementation of therapies to improve oral health prior to surgery could be
employed in preadmission testing clinics prior to hospitalization. Interventions for
improving oral health prior to surgery could be aimed at reducing colonization of the oral
cavity with oropharyngeal cleaning and oral decontaminants to limit the opportunity of
progression to VAP. Preventative nursing interventions implemented earlier in the
process of interaction with the healthcare environment may have a greater impact on
patient outcomes. However, further research is needed to determine whether preoperative
dental plaque accumulation and manipulation and improvement in oral health prior to intubation and admission to an ICU prevents or reduces VAP risk.

**Recommendations for Future Research**

The results of this study provide preliminary data for future research on the relationship between preoperative oral health status and ventilator-associated pneumonia. However, additional research is needed to develop a better understanding of preoperative oral health status and the relationship to VAP. Future studies should be aimed at expanding the assessment and measurement of prehospital oral health and its relationship to postoperative oral health and VAP that would include assessment and measurement of dental plaque, cultures of dental plaque microbial flora using semiquantitative cultures and measurement of salivary volume and flow since normal saliva volume and flow provides mechanical removal of plaque and antimicrobial activity through its immune components (Dennesen et al., 2003). Xerostomia is commonly present in ICU patients due to inadequate hydration, oral airway devices that hold the mouth open causing continuous exposure to the air, xerostomic medications such as diuretics, anticholinergics, narcotics, benzodiazepines and antihistamines that reduce saliva production and can lead to oropharyngeal colonization with virulent gram-negative bacteria (Dennesen et al., 2003). Understanding patterns of dental plaque accumulation, oral microbial flora changes from preoperative to postoperative and changes in salivary volume and flow might help to inform the development of oral care interventions for reducing or preventing oropharyngeal colonization with pathogenic bacteria.

In addition, future research should include experimental studies that investigate the use of oral care interventions in the prehospital setting to reduce and control plaque
and oropharyngeal colonization. Data from this study indicated that patients who did not receive oral decontamination preoperatively had greater deterioration in oral health. Therefore intervention studies should be done to evaluate the use of oral decontamination mouth rinses prior to hospitalization in both dentate and edentulous patients to reduce colonization of the oral cavity and control plaque growth as recommended by the CDC (Tablan, 2004) in populations of patients other than cardiac surgery patients prior to hospitalization. Results from such studies may provide evidence for the development of preventative oral care interventions that improve preoperative oral health and reduce the risk of VAP.

**Conclusion**

This study provides the first evaluation of preoperative oral health status as a risk factor for ventilator-associated pneumonia in older adults. Results from this study provide some insight into predictors of VAP risk. Although preoperative oral health alone was not a predictor of VAP risk, preoperative oral health predicted postoperative oral health and helped to inform the change in oral health over time in the ICU. Acuity and greater number of comorbidities were predictors of VAP in this study. A more complete understanding of the relationship between preoperative oral health status and risk for ventilator-associated pneumonia is needed to help guide preventative measures. The data obtained in this study can serve as a basis for future studies investigating the impact of oral health on ventilator-associated pneumonia.
### Appendix A. Table 1.  
**Risk Factors for Ventilator-Associated Pneumonia**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample</th>
<th>Risk Factors</th>
<th>Results</th>
<th>p value</th>
<th>Comments</th>
</tr>
</thead>
</table>
| **Johanson, et al 1972**| 213 patients          | 1. Oropharyngeal colonization with gram negative pathogens (37%)  
2. Tracheal intubation  
3. Coma  
4. Hypotension          | VAP rate 12.2%                                                   | <0.001 | Tracheal/ oropharyngeal cultures not bronchoscopic diagnosis. |
|                         | MICU                  |                                                                                                     |                              |         |                                               |
|                         | Prospective           |                                                                                                     |                              |         |                                               |
| **Craven et al, 1986**  | 233 patients          | 1. ICP monitor  
2. H2-receptor antagonist  
3. Frequent ventilator circuit changes  
4. Fall-winter season | OR 4.2 (1.7-10.5)  
OR 2.5 (1.2-5.0)  
OR 2.3 (1.1-4.2)  
OR 2.1 (1.1-4.2) | < 0.002 | Clinical diagnostic criteria without bronchoscopic criteria. |
|                         | ventilated ≥ 48 h      |                                                                                                     |                              |         |                                               |
|                         | SICU, MICU, CCU        |                                                                                                     |                              |         |                                               |
|                         | Prospective           |                                                                                                     |                              |         |                                               |
| **Kerver et al, 1987**  | 39 patients           | Oropharyngeal colonization with gram negative organisms                                             | Nosocomial pneumonia 66%     |         | Clinical diagnostic criteria not bronchoscopic criteria |
|                         | SICU                  |                                                                                                     |                              |         |                                               |
|                         | Prospective           |                                                                                                     |                              |         |                                               |
| **Celis et al, 1988**   | 118 patients          | 1. Age > 60y  
2. COPD  
3. Intubation  
4. Decreased level of consciousness  
5. Large volume aspiration  
6. Thoracic surgery | OR 2.3 (1.5-3.3)  
OR 3.7 (2.6-5.3)  
OR 6.7 (4.1-10.9)  
OR 5.8 (3.6-9.3)  
OR 10.6 (4.8-23.1)  
OR 4.7 (2.9-7.5) | 0.04  
0.0003  
0.0001  
0.0002  
0.002  
0.0018 | Clinical, radiographic, and bronchoscopic diagnosis. |
|                         | ICU                   |                                                                                                     |                              |         |                                               |
|                         | Retrospective review of nosocomial pneumonia diagnosis |                                                                                                     |                              |         |                                               |
Table 1. Continued

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample</th>
<th>Risk Factors</th>
<th>Results</th>
<th>p Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torres et al, 1990</td>
<td>322 patients</td>
<td>1. Aspiration</td>
<td>OR 5.1 (3.3, 7.8)</td>
<td>0.00018</td>
<td>Bronchoscopic diagnosis.</td>
</tr>
<tr>
<td></td>
<td>ventilated ≥ 48 h</td>
<td>2. Reintubation</td>
<td>OR 5.0 (3.5, 7.0)</td>
<td>0.000012</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SICU, MICU</td>
<td>3. COPD</td>
<td>OR 1.9 (1.4-2.6)</td>
<td>0.048</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prospective</td>
<td>4. Ventilation &gt; 3 days</td>
<td>OR 1.17 (1.15-1.19)</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VAP rate 24.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beck-Sague et al,</td>
<td>145 patients</td>
<td>1. Antacid use</td>
<td>Rate ratio (95% CI)</td>
<td></td>
<td>Microbiologic diagnosis – type not mentioned.</td>
</tr>
<tr>
<td>1991</td>
<td>ventilated &gt; 24 h</td>
<td>2. Antibiotic use</td>
<td>4.9 (1.9, 12.7)</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SICU</td>
<td>3. Thoracic surgery</td>
<td>3.5 (1.2, 10.7)</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prospective</td>
<td>4. Prolonged oral intubation &gt; 12 days</td>
<td>2.7 (1.0, 7.0)</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VAP rate 10.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kollef, 1993</td>
<td>277 patients</td>
<td>1. Age &gt; 60 y</td>
<td>OR 5.1 (1.9-14.1)</td>
<td>0.002</td>
<td>Clinical diagnosis and tracheal aspirates, no bronchoscopic diagnosis.</td>
</tr>
<tr>
<td></td>
<td>ventilated ≥ 24 h</td>
<td>2. Supine positioning</td>
<td>OR 2.9 (1.3-6.8)</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SICU, MICU, CCU</td>
<td>3. Antibiotic use</td>
<td>OR 3.1 (1.4-6.9)</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prospective</td>
<td>4. Organ system failure index ≥3</td>
<td>OR 10.2 (4.5-23)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VAP rate 15.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elatrous et al, 1996</td>
<td>73 patients</td>
<td>1. Coma</td>
<td>OR 40.3 (3.3-423.1)</td>
<td>0.002</td>
<td>Bronchoscopic Diagnosis.</td>
</tr>
<tr>
<td></td>
<td>ventilated ≥ 48 h</td>
<td>2. Enteral nutrition</td>
<td>OR 31.2 (3.3-294.8)</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MICU</td>
<td>3. Reintubation</td>
<td>OR 10.9 (2.5-46.7)</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prospective</td>
<td>VAP rate 38.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>Sample</td>
<td>Risk Factors</td>
<td>Results</td>
<td>p Value</td>
<td>Comments</td>
</tr>
<tr>
<td>----------------</td>
<td>--------</td>
<td>---------------------------------------</td>
<td>------------------</td>
<td>---------</td>
<td>--------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| **Kollef et al, 1997** | 521 patients ventilated ≥ 12 h SICU, MICU, CCU, Burn ICU Prospective | 1. Male  
2. Transportation out of ICU  
3. Reintubation  
4. Tracheostomy  
5. Aerosol treatment | OR 2.0 (1.5-2.7)  
OR 3.8 (2.6-5.5)  
OR 3.1 (2.2-4.2)  
OR 3.1 (2.2-4.5)  
OR 1.9 (1.4-2.5) | 0.017  
<0.001  
<0.001  
0.002  
0.041 | VAP rate 14.8%  
Used only clinical and radiographic diagnosis for VAP. No bronchoscopic diagnosis. |
| **Cook et al, 1998** | 1014 patients ventilated ≥ 48 h ICU Prospective | 1. Aspiration of secretions  
2. Use of paralytic agents  
3. Cardiac disease  
4. Prolonged ventilation | RR 3.25 (1.62-6.50)  
RR 1.57 (1.03-2.35)  
RR 2.72 (1.05-7.01)  
RR 2.28 (1.11-4.68) | 0.006  
0.002  
0.033  
0.016 | Bronchoscopic radiographic and clinical diagnosis.  
Cumulative risk increased over time. Daily hazard rate decreased after day 5. |
| **Fourrier et al, 1998** | 57 patients ICU Prospective | Oropharyngeal colonization with resistant respiratory pathogens | Relative Risk 9.6  
Sensitivity 0.77  
Specificity 0.96  
Positive predictive value 0.87  
Negative predictive value 0.91  
Nosocomial pneumonia rate 37% | <0.05 | Dental plaque colonization on days 0 and 5 was significantly associated with nosocomial pneumonia and bacteremia. |
| **Ewig et al, 1999** | 48 patients ventilated < 24h MICU, SICU Prospective | 1. Oropharyngeal colonization with respiratory pathogens  
-early onset VAP  
-late onset VAP  
2. Prolonged intubation  
3. Antibiotics | OR 4.1 (0.7-23.3)  
OR 5.4 (1.0-29.6)  
OR 7.7 (1.4-41.6)  
OR 11.1 (2.0-61.9) | 0.02  
0.03  
<0.01  
<0.01 | Bronchoscopic diagnosis for risk of early and late onset VAP. |
<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample</th>
<th>Risk Factors</th>
<th>Results</th>
<th>p Value</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Rello et al, 2002         | 9080 patients ventilated > 24 h SICU, MICU, trauma | 1. Male gender  
2. Trauma  
3. Increased severity of illness | Adjusted Odds Ratio  
AOR 1.58 (1.3-1.8)  
AOR 1.75 (1.4-2.1)  
AOR 1.48 (1.1-1.9) | <0.001  
<0.001  
0.015 | Data from large US database of > 100 acute care hospitals on 750,000 inpatient admissions. |
| Apostolopoulou et al, 2003| 175 patients ventilated > 24 h ICU Prospective | 1. Bronchoscopy  
2. Tube thoracostomy  
3. Tracheostomy  
4. APACHE II score ≥18  
5. Enteral nutrition | AOR 2.95 (1.1-8.3)  
AOR 2.78 (1.1-6.6)  
AOR 3.56 (1.7-8.4)  
AOR 2.33 (1.1-5.1)  
AOR 2.89 (1.3-7.7) | 0.036  
0.023  
0.002  
0.033  
0.026 | Used only noninvasive diagnosis of VAP. |
| El-Solh et al, 2004       | 49 ventilated elders ICU Prospective         | Oropharyngeal colonization with respiratory pathogens | 57% of dental plaque colonized with pathogens causing VAP. | VAP rate 29% | Bronchoscopic diagnosis. |
| Tejerina et al, 2006      | 2897 patients ventilated > 12 h 361 ICU from 20 countries Retrospective analysis of prospective study of 5183 patients | 1. Aspiration of secretions  
2. COPD  
3. ARDS  
4. Sepsis | OR 3.8 (1.4-10.6)  
OR 3.9 (2.2-6.9)  
68.8 (47.5-99.7)  
14.0 (9.5-19.9) | 0.007  
<0.001  
<0.001  
<0.001 | No bronchoscopic diagnosis. Clinical and radiographic diagnosis only. |
| Munro et al, 2006         | 66 patients ventilated > 24 h Medical ICU Prospective | 1. Higher dental plaque  
2. Decreased salivary volume  
3. Increased APACHE scores | VAP rate 26% | 0.01  
0.02  
0.007 | No bronchoscopic diagnosis |
### Appendix B. Table 2.
*Risk Factors for Ventilator-Associated Pneumonia by Type*

<table>
<thead>
<tr>
<th>Risk Factor Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient</strong></td>
<td></td>
</tr>
<tr>
<td>Nonmodifiable</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>Kollef et al, 1997</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 2002</td>
</tr>
<tr>
<td>Age &gt; 60y</td>
<td>Kollef, 1993</td>
</tr>
<tr>
<td></td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td>Pre-existing conditions</td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td></td>
<td>Torres et al, 1990</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 1994</td>
</tr>
<tr>
<td></td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Kollef, 1993</td>
</tr>
<tr>
<td></td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td></td>
<td>Torres et al, 1990</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 1994</td>
</tr>
<tr>
<td>Higher severity of illness</td>
<td>Kollef, 1993</td>
</tr>
<tr>
<td></td>
<td>Apostolopoulou et al, 2003</td>
</tr>
<tr>
<td></td>
<td>Tejerina et al, 2006</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 2002</td>
</tr>
<tr>
<td>Central nervous system disease</td>
<td>Johanson et al, 1972</td>
</tr>
<tr>
<td>Coma</td>
<td>Craven et al, 1986</td>
</tr>
<tr>
<td></td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td></td>
<td>Elatrous et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td>Trauma</td>
<td>Baraibar et al, 1997</td>
</tr>
<tr>
<td></td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 2002</td>
</tr>
<tr>
<td><strong>Modifiable</strong></td>
<td></td>
</tr>
<tr>
<td>Aspiration of secretions</td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td></td>
<td>Torres et al, 1990</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Baraibar et al, 1997</td>
</tr>
<tr>
<td></td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Tejerina et al, 2006</td>
</tr>
<tr>
<td>Oropharyngeal colonization</td>
<td>Johanson et al, 1972</td>
</tr>
<tr>
<td></td>
<td>Kerver et al, 1987</td>
</tr>
<tr>
<td></td>
<td>Bonten et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Fourrier et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Ewig et al, 1999</td>
</tr>
<tr>
<td>Risk Factor Type</td>
<td>Reference</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
</tr>
<tr>
<td>Nonmodifiable</td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td>Celis et al, 1988</td>
</tr>
<tr>
<td></td>
<td>Beck-Sague et al, 1994</td>
</tr>
<tr>
<td></td>
<td>Cunnion et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Baraibar et al, 1997</td>
</tr>
<tr>
<td>ICP monitor</td>
<td>Craven et al, 1986</td>
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<tr>
<td>Transportation out of ICU</td>
<td>Kollef et al, 1997</td>
</tr>
<tr>
<td>Reintubation</td>
<td>Torres et al, 1990</td>
</tr>
<tr>
<td></td>
<td>Elatrous et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Kollef et al 1997</td>
</tr>
<tr>
<td>Modifiable</td>
<td></td>
</tr>
<tr>
<td>Antibiotic use</td>
<td>Beck-Sague et al, 1991</td>
</tr>
<tr>
<td></td>
<td>Kollef, 1993</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Ewig et al, 1999</td>
</tr>
<tr>
<td>H2 antagonist/antacid use</td>
<td>Craven et al, 1986</td>
</tr>
<tr>
<td></td>
<td>Beck-Sague et al, 1991</td>
</tr>
<tr>
<td>Use of paralytic agents</td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td>Supine position</td>
<td>Kollef, 1993</td>
</tr>
<tr>
<td>Enteral nutrition</td>
<td>Elatrous et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Apostolopoulou et al, 2003</td>
</tr>
<tr>
<td>Intracuff pressure &lt; 20cm H2O</td>
<td>Rello et al, 1996</td>
</tr>
<tr>
<td>Aerosol treatment</td>
<td>Kollef et al, 1997</td>
</tr>
<tr>
<td>Prolonged ventilation</td>
<td>Torres et al, 1990</td>
</tr>
<tr>
<td></td>
<td>Rello et al, 1994</td>
</tr>
<tr>
<td></td>
<td>Bonten et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Cunnion et al, 1996</td>
</tr>
<tr>
<td></td>
<td>Cook et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Ewig et al, 1999</td>
</tr>
<tr>
<td>Risk Factor Type</td>
<td>Reference</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Intubation/Mechanical ventilation</td>
<td>Vincent et al., 1995</td>
</tr>
<tr>
<td></td>
<td>Chevret et al., 1993</td>
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<tr>
<td></td>
<td>Horan, et al., 1993</td>
</tr>
<tr>
<td></td>
<td>Davis, 2006</td>
</tr>
<tr>
<td>Tracheostomy</td>
<td>Kollef et al, 1997</td>
</tr>
<tr>
<td></td>
<td>Apostolopoulou et al., 2003</td>
</tr>
</tbody>
</table>
### Oral Health Intervention Studies and Ventilator-Associated Pneumonia

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample and Setting</th>
<th>Study Design</th>
<th>Intervention and Description</th>
<th>Results</th>
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<tbody>
<tr>
<td>DeRiso et al., 1996</td>
<td>353 Cardiopulmonary ICU</td>
<td>RCT</td>
<td>0.12% Chlorhexidine oral rinse</td>
<td>65% reduction in nosocomial respiratory infection</td>
</tr>
<tr>
<td>Yoneyama et al., 1999</td>
<td>366 Nursing Home patients</td>
<td>RCT</td>
<td>Oral care with toothbrushing and povidone-iodine rinse</td>
<td>Pneumonia, febrile days and death from pneumonia decreased</td>
</tr>
<tr>
<td>Bergmans et al., 2001</td>
<td>226 Mixed Medical-Surgical ICU</td>
<td>RCT</td>
<td>Oral topical antimicrobial (2% gentamicin, 2% colistin, 2% vancomycin)</td>
<td>Eradicated oral colonization present on admission to ICU</td>
</tr>
<tr>
<td>Genuit et al., 2001</td>
<td>95 patients ventilated &gt;48h SICU</td>
<td>CT</td>
<td>0.12% Chlorhexidine</td>
<td>Reduced VAP 37% overall, 75% for late VAP</td>
</tr>
<tr>
<td>Houston et al., 2002</td>
<td>561 Cardiopulmonary Surgery patients</td>
<td>RCT</td>
<td>0.12% Chlorhexidine vs Listerine®</td>
<td>High risk patients intubated &gt; 24h VAP rate decreased 71% with chlorhexidine</td>
</tr>
<tr>
<td>Grap et al., 2004</td>
<td>34 patients (pilot study) ED, SICU, Neuro ICU</td>
<td>RCT</td>
<td>0.12% Chlorhexidine</td>
<td>Reduction in oral cultures</td>
</tr>
<tr>
<td>Fourrier et al. 2005</td>
<td>228 patients expected intubation &gt; 5d ICU</td>
<td>RCT</td>
<td>0.2% Chlorhexidine gel</td>
<td>Decreased oropharyngeal colonization</td>
</tr>
<tr>
<td>Mori et al., 2006</td>
<td>1666 ventilated patients MICU/SICU</td>
<td>CT</td>
<td>Oral care protocol with tooth brushing and povidone-iodine</td>
<td>Decreased VAP rate from 10.4 to 3.9 per 1000 ventilator days</td>
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Table 3. Continue

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample</th>
<th>Study Design</th>
<th>Intervention</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koeman et al.,</td>
<td>385 patients ventilated &gt;48h</td>
<td>RCT</td>
<td>3 arms (2% Chlorhexidine vs 2% Chlorhexidine with colistin or placebo)</td>
<td>VAP reduced in both treatment groups by up to 65%</td>
</tr>
<tr>
<td>2006</td>
<td>2 Mixed and 2 SICU</td>
<td>Double blind placebo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Munro et al.,</td>
<td>249 patients within 24h of intubation</td>
<td>RCT</td>
<td>3 arms (tooth brushing, chlorhexidine, and tooth brushing and chlorhexidine)</td>
<td>Chlorhexidine not toothbrushing decreased VAP</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Garcia et al.,</td>
<td>759 patients ventilated &gt;48h</td>
<td>CT</td>
<td>Oral care protocol with deep suction, tooth brushing and oral tissue cleansing</td>
<td>Decreased rate of VAP from 12 to 8 per 1000 ventilator days</td>
</tr>
<tr>
<td>2009</td>
<td>MICU</td>
<td></td>
<td>with 1.5% hydrogen peroxide &amp; 0.05% cetylpyridinium</td>
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</table>
References


Staphylococcus aureus as a major risk factor for wound infections after cardiac surgery. *Journal of Infectious Diseases, 171*(1), 216-219.


Respiratory and Critical Care Medicine, 154(1), 111-115. doi: 10.1164/ajrccm.154.1.8680665


