Long-Term Tracheostomy – Outcome, Cannula Care, and Material Wear

The present thesis investigates the outcome of long-term tracheostomized patients, as well as the care and wear of tracheostomy tubes. Tracheostomy is one of the oldest surgical operations; an opening in the trachea is made to facilitate breathing and a tracheostomy tube inserted. The indications today for long-term tracheostomy could be upper airway obstruction, chronic hypoventilation, or post trauma complications.

Most persons with long-term tracheostomy lead a normal life, but do they need more hospital care than others? Which cleaning method is most appropriate for inner cannulae? Are tracheostomy tubes changed for rational reasons?

There is clearly a lack of evidence based research in the field, and clinical guidelines are often based on local hospital traditions. The research was conducted at the National Respiratory Centre (NRC) and Karolinska Institutet, Danderyd Hospital, Stockholm, in collaboration with Sophiahemmet University College, and The Royal Institute of Technology, Stockholm, Sweden.

The National Respiratory Centre (NRC)
The NRC, previously known as the Respiratory Unit, started running officially in 1982. Dr Gillis Andersson had, however, long since together with medical technician, Roland Fibbey, given patients with respiratory problems support and individual solutions, such as customized tracheostomy tubes. The goal was to help people with respiratory disability lead a more active (health improved) quality. The NRC is a national referral clinic, which also receives patients from other countries. It has authorization from the Medical Products Agency, Sweden, to design tracheostomy tubes or nasal masks for each patient. A multi professional team, consisting of physicians, nurses, respiratory therapists, assistant nurses, and medical technicians are involved in the care.
LONG-TERM TRACHEOSTOMY – OUTCOME, CANNULA CARE, AND MATERIAL WEAR

Gunilla Björling

Stockholm 2007
A wise old owl lived in an oak
The more he saw the less he spoke
The less he spoke the more he heard.
Why can't we all be like that wise old bird?
~Unknown

To Jonas and my children
ABSTRACT

Do people with long-term tracheostomy need hospital care? Which cleaning method is most appropriate for decontamination of inner cannulae? Are tracheostomy tubes changed for rational reasons? There is clearly a lack of evidence based research in this field and the clinical guidelines available are often based on local practice. A tracheostomy is a created opening in trachea to facilitate breathing. It is a direct entry to the deeper airways, e.g. for micro-organisms causing a potential risk for lung infections. Indications for long-term tracheostomy can be, e.g. upper airway obstruction, malformations, or chronic hypoventilation, when ventilation via nasal mask is not possible. The research of the present thesis was conducted at the National Respiratory Centre (NRC) at Danderyd Hospital in Stockholm, Sweden. This unit opened in 1982, with the expressed goal of supporting outpatients with long-term tracheostomy. The overall aims of the thesis were to evaluate the outcome of patients with long-term tracheostomy and to conduct evidence based studies concerning their care.

A comparison was made for the number of days in hospital care during the 2-year periods before and after the tracheostomy was established. The life expectancy of the general population and the observed life span of a cohort of tracheostomized patients from the start of NRC in 1982 were also compared. Interestingly enough, the need for hospital care was unchanged despite of the tracheostomy. The patients’ observed life spans were remarkably high and for many patients not lower than the life expectancy of Swedish people in general.

To find a practical and safe decontamination method for inner cannulae we compared two different cleaning methods; detergent followed by chlorhexidine-alcohol, or detergent alone. Samples for bacterial culture were taken before and after cleaning and the numbers of bacteria colonies were counted. The effectiveness of both cleaning methods was greater than expected and the results showed a nearly total elimination of organisms. Thus, the methods investigated were equivalent in achieving decontamination.

The duration of use in our unit for polymeric tracheostomy tubes, i.e. silicone (Si), polyvinyl chloride (PVC), and polyurethane (PU) was determined and compared. We found, that Si tubes were used for longer periods (three months) than tubes made of PU or PVC (both two months).

Whether or not surface changes could be observed on the tracheostomy tubes after 30 days’, three and six months’ exposure in the trachea were investigated in collaboration with the Royal Institute of Technology and Sophiahemmet University College in Stockholm, Sweden. The analyzing methods were Scanning Electron Microscopy, Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy, and Differential Scanning Calorimetry. All tubes, except one, showed changes in the surface after 30 days’ exposure. The surface changes had progressed significantly after three and six months' exposure, compared to the changes detected after 30 days.

The SF-36 questionnaire and a study specific questionnaire were used to describe the patients’ health-related quality of life and experiences of long-term tracheostomy. The results show that all patients were satisfied with their tracheostomy and demonstrated a numerically mean mental health status score above that of the general population.

In summary, long-term tracheostomy does not increase the need for hospital care nor does it reduce a patient’s life span. Cleaning the tracheostomy inner cannula with detergent and water is sufficient to achieve decontamination. Si tracheostomy tubes are used longer compared to those made of PVC or PU. The polymeric material investigated suffered evident surface changes after 30 days’ use. Clinical use of polymeric tracheostomy tubes beyond three months cannot be recommended, as we found extensive surface changes and degradation of the polymeric chains. All patients were, in general content, with their tracheostomy. The findings from the present thesis contribute to making the care of long-term tracheostomized patients evidence based.
LIST OF PUBLICATIONS

This thesis is based on the following four papers, referred to in the text by their Roman numerals.


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<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFM</td>
<td>Atomic Force Microscopy</td>
</tr>
<tr>
<td>ATR-FTIR</td>
<td>Attenuated Total Reflectance - Fourier Transform Infrared Spectroscopy</td>
</tr>
<tr>
<td>BC</td>
<td>Before Christ</td>
</tr>
<tr>
<td>CEN</td>
<td>Comité Européen de Normalisation</td>
</tr>
<tr>
<td>CI</td>
<td>Carbonyl Index</td>
</tr>
<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Disease</td>
</tr>
<tr>
<td>DEHP</td>
<td>Di-2-ethylhexyl Phthalate</td>
</tr>
<tr>
<td>DSC</td>
<td>Differential Scanning Calorimetry</td>
</tr>
<tr>
<td>ENT</td>
<td>Ear, Nose, and Throat</td>
</tr>
<tr>
<td>HMV</td>
<td>Home Mechanical Ventilation</td>
</tr>
<tr>
<td>HRQL</td>
<td>Health Related Quality of Life</td>
</tr>
<tr>
<td>ICU</td>
<td>Intensive Care Unit</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>LMW</td>
<td>Low Molecular Weight</td>
</tr>
<tr>
<td>MCS</td>
<td>Mental Component Summary</td>
</tr>
<tr>
<td>MIC</td>
<td>Microbial-Influenced Corrosion</td>
</tr>
<tr>
<td>NRC</td>
<td>National Respiratory Centre</td>
</tr>
<tr>
<td>PBS</td>
<td>Phosphate Buffered Saline</td>
</tr>
<tr>
<td>PCS</td>
<td>Physical Component Summary</td>
</tr>
<tr>
<td>PCU</td>
<td>Poly(Carbonate Urethane)</td>
</tr>
<tr>
<td>PDT</td>
<td>Percutaneous Dilatational Technique</td>
</tr>
<tr>
<td>PEU</td>
<td>Poly(ether urethane)</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>QoL</td>
<td>Quality of Life</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
</tr>
<tr>
<td>Si</td>
<td>Silicone</td>
</tr>
<tr>
<td>VAP</td>
<td>Ventilator Associated Pneumonia</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

The present thesis investigates the outcome of long-term tracheostomized patients as well as care and wear of tracheostomy tubes. It may hopefully contribute to increased evidence based care for these patients. The research was carried out at the National Respiratory Centre (NRC), Danderyd Hospital, Stockholm, Sweden.

1.1 A BRIEF HISTORY

Long-term tracheostomy can today be used for patients with for instance, upper airway obstruction, chronic hypoventilation due to - neuromuscular disease, trauma including spinal cord injury, surgery in the face/neck region, or post stroke complications\(^1\textsuperscript{-3}\). Tracheostomy is an age-old operation, resulting in the trachea being surgically opened in the anterior wall to facilitate ventilation. It is one of the oldest surgical procedures described and the indication was probably airway obstruction\(^4\textsuperscript{-7}\). The word tracheostomy comes from the Greek meaning “I cut the trachea”\(^8\). According to Dorland’s illustrated medical dictionary a tracheotomy is commonly referred to the surgical incision into the trachea and tracheostomy the creation of the stoma and the stoma itself\(^9\). The tracheostomy procedure was described in the Šrī Veda, a sacred book of Hindu medicine that was published approximately 2000 BC\(^10\). The procedure is also depicted on two slabs dating from the beginning of the first dynasty of the ancient Egypt (2 920-2 770 BC). It has also been told that Alexander the Great, (4\textsuperscript{th} century BC), had to, with the point of his sword, puncture the trachea of a soldier who was choking from a bone lodge in his throat\(^11\). Early indications for tracheostomy were upper airway obstruction due to infection, trauma or foreign body. In modern time, until the poliomyelitis epidemics in the 1950s, the major indication was diphtheria\(^12\). As the development of the intensive care units (ICU) progressed the need for intermittent positive-pressure ventilation grew and effective life support was conducted\(^13\). A successful mechanical ventilation of the poliomyelitis patients began in Copenhagen 1952\(^14\) and as there were not enough mechanical ventilators available, patients were hand-ventilated by nurses and medical students. Gradually the ventilators improved and long-term support by ventilator and tracheostomy helped thousands of patients\(^15\).
In the beginning of the 1970s an intensive care physician at the ICU at Danderyd Hospital, Stockholm, became especially interested in the care of patients with post-polio syndrome and other patients needing tracheostomy with or without mechanical ventilation. He provided the patients with customized silver tracheostomy cannulae and the patients were followed up on an outpatient basis. The majority of them needed nocturnal mechanical ventilation and many suffered from severe impairments, especially regarding mobility. In order to minimize the complication rate and to support patients living at home, a management routine was developed, including at least one monthly visit to the clinic. In 1982 NRC, previously known as the Respiratory Unit, was established as a separate unit of the ICU. The goal was to help people with respiratory disability live a more active life and to improve their quality of life. NRC provides a multi professional team, including physicians, nurses, respiratory therapists, assistant nurses, and medical technicians for the customization of the tubes.

In 1998, NRC was authorized by the Medical Products Agency in Sweden to customize tracheostomy tubes for the patients. The fenestration is considered very important to allow for production of sound, thereby speech. With the customization of the tracheostomy tubes the manufacturer’s responsibility is transferred to NRC. The monthly routine visit still takes place and includes a tracheostomy tube change, tracheal and stoma inspection with or without bronchoscopy, removal of granulation tissue, inspection of the tracheostomy tube, and it’s fit in the trachea. There have been very few complications after tracheostomy at NRC. Patients’ self-estimated quality of life (QoL) is high and there are no finding of decreased life expectancy or increased need for hospital care. Being the single clinic customizing tracheostomy tubes in Sweden, NRC has a responsibility for education of staff, students, and caregivers in tracheostomy and ventilation management and to conduct research in the field.
1.2 INDICATIONS AND COMPLICATIONS

1.2.1 Indications and Diagnoses

The most common reasons for performing a tracheostomy are to assist long-term ventilation in critically ill patients or in those requiring prolonged respiratory support, to relieve upper airway obstruction, to support bronchial toilette, to prevent aspiration of oral or gastric secretions, or as an adjunct to head, neck and thoracic surgery\cite{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26}. See Table I. A tracheostomy permits speech and oral eating, it eases suction, and secures the patient’s airway. These factors are believed to help reduce ventilator complications\cite{25}. Many of the patients, requiring prolonged respiratory support, receive home mechanical ventilation (HMV)\cite{26}.

<table>
<thead>
<tr>
<th>Diagnoses</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children incl. congenital malformations and tracheal stenosis</td>
<td>23</td>
</tr>
<tr>
<td>Post-polio/scoliosis</td>
<td>19</td>
</tr>
<tr>
<td>Tumors</td>
<td>14</td>
</tr>
<tr>
<td>Upper airway obstruction incl. tracheomalacia</td>
<td>11</td>
</tr>
<tr>
<td>Neuromuscular diseases</td>
<td>10</td>
</tr>
<tr>
<td>Spinal cord injury</td>
<td>8</td>
</tr>
<tr>
<td>Tuberculosis, COPD and asthma</td>
<td>6</td>
</tr>
<tr>
<td>Other diseases incl. stroke</td>
<td>6</td>
</tr>
<tr>
<td>Infections</td>
<td>3</td>
</tr>
</tbody>
</table>

Table I. Diagnoses for patients with long-term tracheostomy at NRC in 1997, n = 106

There are several surgical techniques for performing a tracheostomy. The most common method is currently a percutaneous dilatational technique (PDT) performed at the bedside, a procedure previously most commonly performed in the operation unit\cite{19,21,22,23,24,25,26,27,28}. PDT is performed by anesthesiologists, intensivists, as well as ear, nose, and throat (ENT) specialists and is considered safe for the patients\cite{11,29,30}. The technique is also associated with lower risk for long-term complications, such as e.g. tracheal stenosis\cite{31,32}. There is no difference in complication rate for the different PDT techniques\cite{33}, but the patient’s individual characteristics must be taken into consideration\cite{33,34}. There are also indications that an early elective tracheostomy reduces the duration of mechanical ventilation or shortens the stay at the ICU\cite{25,34,35,36,37}. 
1.2.2 Complications

There are some complications due to tracheostomy. Early complications are related to the insertion of the cannula and occur in connection with the operative procedure or soon after. Late complications may occur at any time after the procedure or even after decannulation\textsuperscript{38-42}. See Table II.

<table>
<thead>
<tr>
<th>Complications</th>
<th>Early</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haemorrhage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Subcutaneous emphysema</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pneumonia</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Tube obstruction</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Tube displacement</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Tube/cuff malfunction</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Skin breakdown</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Tracheal stenosis</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Granulation tissue</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Tracheomalacia</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Fistula formation</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Accidental decannulation</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cannula fracture</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

It should be pointed out that late complications may be prevented by a regular tube change and follow up\textsuperscript{12,17,43}. A customized tube has also been proven to lower the incidence of complications and infections in long-term tracheostomized patients\textsuperscript{43}. A recently conducted study has also shown that the presence of a tracheostomy tube does not influence the swallowing function or cause aspiration, provided the patient’s swallowing function was normal before tracheostomy\textsuperscript{44}. Tracheostomy has also proven to be independently associated with decreased risk for ventilator associated pneumonia (VAP) in an ICU during a five-year period\textsuperscript{45}.

1.3 TRACHEOSTOMY CARE

One of the most important aspects of tracheostomy care is prevention and management of complications, especially among those patients who are ventilator treated\textsuperscript{46}. Routine tracheostomy care includes suction, inner cannula care, stoma site care, and stoma care with changing of the dressing and tie\textsuperscript{12,31,38,46-54}. The majority of the routines, available for tracheostomy care, has not yet been scientifically evaluated and are based on local
The methods for tracheostomy care vary from the use of sterile technique to using clean technique. The methods for tracheostomy care vary from the use of sterile technique to using clean technique.

1.3.1 Cannula Care

Cleaning the stoma site and inner cannula are important factors in preventing infections in the patient’s airway. A cannula system with an outer and an inner tube that can easily be exchanged, when clogged, is practical for long-term use. Many inner cannulae are reusable and their maintenance is essential in preventing tube occlusion. The cleaning should be performed at least twice a day or more often, if necessary. Several recommendations for decontamination of inner cannulae are available and some may even be destructive for the tube material or may cause mucosal irritation. No association was found between pneumonia and the disinfecting method of the tracheostomy inner cannula in a study of pediatric home care of children with tracheostomy. Few studies with adult patients are, however, available on the subject.

The routines recommended might differ even between units in the same hospital, which is confusing both for patients and staff. Some examples are e.g. cleaning the inner cannula with hot, soapy water, using specially designed brushes and rinsing it under running tap water and leaving it to air dry. Manufacturers’ recommendations for cleaning inner cannulae differ, even if the tubes are made of the same material. The most common recommendation is, however, cleaning with warm water and mild detergent. The current decontamination recommendation from national guidelines in Sweden, not based on scientific evidence, is to decontaminate the inner cannula with detergent and warm water, see Figure 1, immerse it in chlorhexidine-alcohol and afterwards rinse off the chlorhexidine-alcohol with sterile saline. The decision in the guideline to use chlorhexidine alcohol is in accordance with ISO/CEN (International Organisation for Standardization and Comité Européen de Normalisation) standards, where hydrogen peroxide is not recommended as a surface disinfectant and, therefore, cannot be used for cleaning/disinfection of medical equipment in a validated process in the European Union. Cleaning the inner cannula with peroxide is still a common recommendation. None of the methods mentioned, have been scientifically studied and uniform evidence based guidelines would simplify care and improve patient safety.
1.3.2 Tracheostomy Tube Change

Indications for a tube change, both inner and outer cannula, vary\textsuperscript{12,38,62} and there is a lack of evidence based studies\textsuperscript{28,47,55}. Post-operatively, the tube should not be changed before two to three days, ensuring the stoma to be well established. The first change is often performed by the surgeon\textsuperscript{62}. To avoid the formation of granulation tissue and other complications when the stoma has been established, the tracheostomy tube should be frequently changed\textsuperscript{12,17,52,54,59,62}. According to the Medical Products Agency in Sweden, a monthly tube change is recommended\textsuperscript{63}. This means that once a month the tracheostomy tube should be removed and thoroughly cleaned. If the tube is found to be in an acceptable condition after visual inspection, it can be reinserted. As a result, there is no limit today as to how many times a specific tracheostomy tube can be reused by the same patient. There is clearly a lack of evidence on how long a specific tracheostomy tube can be used, i.e. the duration of a specific tube\textsuperscript{22,28,47,55}. 
1.3.3 Specialized Staff and Education of Caregivers and Families

Patients with tracheostomy have special needs associated with their care to guarantee patient safety and well-being. As many persons with tracheostomy are living at home, it is very important to educate the patients, care-givers and families in tracheostomy management. The patients living at home have reported high QoL and have had few complications. There are special tracheostomy units with skilled staff, i.e. tracheostomy specialist nurses, providing care and education, but there is need for more such centers and staff education. A regular follow-up of the tracheostomized patient and a special education of caregivers will lower the incidence of complications. It is important that the care provided to the tracheostomised patient is of high standard to ensure patient safety.

1.4 BIOFILM

A tracheostomy means a direct entry to the deeper airways for e.g. microorganisms leading to a potential risk of developing lung infections. Within 20 minutes bacteria start to adhere the surface of the tracheostomy tube, aggregate and encase themselves in a hydrated matrix of multiple layers of cell clusters, consisting of polysaccharides and proteins. This forms an extra cellular, slimy substance called biofilm, where the bacteria are hidden and become more resistant and less accessible to antibiotics and immune defenses. A biofilm may be defined as a community of microorganisms, attached to a surface producing extra cellular polymeric substance (EPS), excreted by the cells, that is a slimy substance giving the biofilm stability and facilitates the adherence to the surface. Bacteria use either flagella or type IV pili in order to move on a surface and form new micro colonies. The biofilm exhibit an altered phenotype, as distinguished from the planktonic cells, and the organisms in the biofilm interact with each other. Once a biofilm has been formed, it is very difficult to remove and mechanical cleaning is often required. It is organized as a unique society with its own metabolism and acts as a reservoir for bacteria, where infections can develop slowly. Long-term antibiotic treatment may be required and success is not guaranteed. The biofilm can act as a bacterial reservoir, from which occasional bacteria can dislodge and follow the air stream to the deeper airways and cause pneumonia. The presence of biofilm on endotracheal tubes in patients undergoing mechanical
ventilation could, therefore, be a source for developing pneumonia\textsuperscript{80-83} and is also believed to play an important role in the development of tracheal stenosis in intubated neonates\textsuperscript{84}. Especially \textit{Pseudomonas aeruginosa}, which is a common pathogen in biofilm formation\textsuperscript{74}, is often located in the respiratory tract, formatting a biofilm and has an extreme adaptability\textsuperscript{85}. Biofilm was also found to be present on both sides of endotracheal tubes that had been in contact with the subglottis in neonates undergoing mechanical ventilation\textsuperscript{86}. In order to minimize formation of biofilm in mechanically ventilated patients, studies have been conducted with using hexiditine-impregnated endotracheal tubes\textsuperscript{87} and also with nebulized gentamicin\textsuperscript{88}, or silver coated endotracheal tubes\textsuperscript{89}, showing good results.

1.5 TRACHEOSTOMY TUBE MATERIALS

An ideal tracheostomy tube should be comfortable for the patient, give as much enough air as possible, and fit the patient properly\textsuperscript{16,54,90}. The tubes are made of different polymeric materials, such as silicone (Si), polyvinyl chloride (PVC), polyurethane (PU), or of metal, i.e. silver.

1.5.1 Silicone

Si is commonly used by the medical industry for different medical implants\textsuperscript{91}. It consists of inorganic polymers, composed of silicone-oxygen chains, to which phenyl or methyl groups are bound. It has a hydrophobic structure and can be cross-linked to modify the surface properties\textsuperscript{92}. The hydrophobic nature of Si prevents microbial formation. The surface can, however, be less hydrophobic or temporarily hydrophilic after environmental exposure, ageing, or chemical damage. The surface generally recovers by a mechanism, where the low molecular weight (LMW) compounds migrate from the bulk material to the surface, rendering the bulk material exhausted\textsuperscript{92}.

1.5.2 Polyvinyl Chloride

PVC still continues to be an important and widely used polymer for medical devices, despite that the use of PVC in other areas has proven to give environmental damages.
The use is also decreasing, as phthalates migrate from the polymer by usage\textsuperscript{93,94}. Pure PVC is a stiff and unstable material, susceptible for degradation due to heat, UV light, and oxygen\textsuperscript{95}. In order to increase flexibility plasticizer of phthalate type, i.e. stabilizers and plasticizer, are added to the material. The plasticizer is mixed with the polymer and not chemically bounded, which increases the risk for diffusion and release of phthalates to the surrounding environment during ageing\textsuperscript{95}. The Shiley\textsuperscript{®} PVC tube contains approximately 30 % (w) of the plasticizer di-2-ethylhexyl phthalate (DEHP) (oral information from the manufacture). When a biofilm is formed on a PVC material, the phthalates subsequently start to migrate and serve as nutrition to the biofilm, rendering the PVC a more brittle structure. The material also becomes more sensitive to environmental stress cracking\textsuperscript{96,97}. See Figure 2.

\textbf{Figure 2.} Scanning electron microscopic images of two Shiley\textsuperscript{®} tracheostomy tubes

To the left there is an image of a new unused tube, whereas the image to the right exhibits a tube that has been used by a patient for approximately three months. The tube material has become brittle due to the loss of additives. Magnification X 1,000.

\subsection{1.5.3 Polyurethane}

Polyurethane (PU) has been used in medical application since the 70s. Poly(ester urethane) was the first generation of PU in this field, but it was susceptible for hydrolysis and was replaced by more stable poly(ether urethane) (PEU). To increase the oxidative stability, a new class of PU was later developed - a poly(carbonate urethane) (PCU)\textsuperscript{98}. The tracheostomy tube Tracoe Twist\textsuperscript{®} is made of PEU. The heterogeneous distribution of both soft and hard segments in the PU creates a complex polymeric system, in which the degradation processes occur at different rates and to different extent. Under normal conditions, PU is relatively stable towards oxidation due to various kinds of antioxidants supplied. In a complex environment the protection against oxidation is reduced\textsuperscript{98}.
1.5.4 Silver

Silver has been used for many years for manufacturing medical devices\textsuperscript{4}. It is very durable and has an anti-microbial effect, when oxidation of the material occurs. The silver tracheostomy tubes are usually made of Sterling Silver consisting of 92.5% silver and 7.5% other metals such as copper, germanium, zinc, platinum, silicon and boron. These alloying elements are required to strengthen the pure silver material, although a pure silver tube would be less liable to the chemical erosion\textsuperscript{99}.

1.5.5 Material Degradation

The tracheostomy tubes in use are, as previously mentioned, exposed not only to bacteria but also the lining fluids, which is a first defence against toxicity in inhaled gases. It contains several antioxidants\textsuperscript{100}. The complex bacteriological environment in the trachea, as well as the formation of a biofilm covering the tube surface, is believed to affect the mechanical and chemical properties of the tube material\textsuperscript{101,102}. In the case of polymeric materials, the formation of a biofilm through colonization of bacteria has been recognized as a source of infection by playing an important role in the pathogenicity of the infecting organism\textsuperscript{82,103}. It has also been found to affect the material in both peritoneal catheters and endotracheal tubes\textsuperscript{87,104-106}.

As a result of the material degradation, substances from the tube dissolve and leave the material surface, leading to changes in its structure and as a result in the strength of the material\textsuperscript{96}. See Figure 3. In contact with a liquid, the degradation of a polymeric material can be caused either by dissolution or swelling. Degradation may also occur by rupture of covalent bonds due to exposure to e.g. chemical agents\textsuperscript{96}. 
In the case of implanted metals, microbial-influenced corrosion (MIC) can take place. The biofilm formed on the surface of the metallic material is believed to alter the interfacial electrochemical processes, leading to an increased MIC. There are, in general, two main effects of corrosion that can be observed on implanted metals; the strength of the material may decrease, which in turn may lead to failure of the device in question and a discharge of corrosion products from the material to the body tissue. See Figure 4.

Figure 3. A schematic image of biodegradation of a polymeric material caused by biofilm

<table>
<thead>
<tr>
<th>Process</th>
<th>Fouling</th>
<th>Degradation of leaching components</th>
<th>Corrosion</th>
<th>Hydration Penetration</th>
<th>Colour Odour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofilm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td>Additives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td></td>
<td></td>
<td>Loss of stability</td>
<td>Conductivity, Swelling</td>
<td>Change in appearance</td>
</tr>
<tr>
<td></td>
<td>Change in surface properties</td>
<td>Loss of stability</td>
<td>Loss of stability</td>
<td>Conductivity, Swelling</td>
<td>Change in appearance</td>
</tr>
</tbody>
</table>

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Figure 4. Scanning electron microscopic image of two tracheostomy tubes made of sterling silver.

The image to the left exposes a new tube. Note the dark spots in the silver material that probably are the added copper. To the right there is an image of a silver tube that was used by a patient for several years. Clear fissures in the material surface indicate severe MIC. Magnification X 5,000.
Several reports of fractured tracheostomy tubes made of either polymeric materials or metals, some with fatal outcome, have been found in the literature\textsuperscript{110-116}. Knowledge and understanding concerning corrosion mechanisms of sterling silver products used as medical devices is, however, very poor. What impact the reactions between the body fluids and/or tissues, as well as, the release of products from the silver device has on the material properties, has not yet, by the knowledge of the present author, been investigated in detail. As pointed out in an official statement by the American Thoracic Society, there is also an extensive lack of knowledge, when it comes to the mechanisms involved in the ageing of the different polymeric materials, used in tracheostomy tubes\textsuperscript{47}.

\subsection*{1.6 HEALTH-RELATED QUALITY OF LIFE}

Health-related quality of life (HRQL) is stated as the patient’s optimum levels of mental- and physical health. Broader measures of health status generally focus on individual’s subjective perceptions of health\textsuperscript{117}. According to a declaration made by The World Health Organization (WHO) in 1948, health is “a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity”. The theoretical framework for HRQL is based on this declaration. HRQL determines how patients’ perceptions of mental and physical health status impact on different areas of their lives\textsuperscript{117}. It could also measure patients’ level of satisfaction with a treatment, outcome following an intervention, its effect on their lives, and future perspective of health\textsuperscript{118}.

\subsection*{1.7 RESEARCH AREA}

The care of patients with long-term tracheostomy is still based on local tradition and the recommendations can sometimes be contradictory. The lack of evidence based studies is obvious and there is a clear need for clinical treatment recommendations, which are evidence based\textsuperscript{12,28,47,55}.
2 AIMS

2.1 GENERAL AIMS

General aims of the present thesis were to evaluate the outcome of long-term tracheostomy and to conduct evidence based studies concerning the care of patients with long-term tracheostomy.

2.2 SPECIFIC AIMS

The specific aims were:

- To compare the need for hospital care in long-term tracheostomized patients during a 2-year period before and after the tracheostomy (I)
- To determine whether the long-term tracheostomy influenced life expectancy of the patients (I)
- To compare two different decontamination procedures, i.e. decontaminating the inner cannula with detergent and afterwards disinfecting it in chlorhexidine alcohol compared with detergent only (II)
- To compare the duration of use of polymeric tracheostomy tubes, i.e. Si, PVC and PU in a major outpatient clinic (III)
- To determine whether surface changes could be observed after 30 days of clinical use (III)
- To determine the material wear of polymeric tracheostomy tubes after three and six months of clinical use and compare the obtained results with previously reported data (IV)
- To study patients’ health-related quality of life (HRQL), as well as their experiences of long-term tracheostomy (IV)
3 METHODS

3.1 STUDY DESIGN (I-IV)

The designs used in this thesis were descriptive, comparative design (I), randomized, single blinded, comparative, crossover design (II), descriptive design (I, III and IV), and prospective design (II, III, and IV). Study II was a collaboration project between Karolinska Institutet, Danderyd Hospital, Uppsala University Hospital, Karolinska University Hospital, and Sophiahemmet University College, and study III and IV were a collaboration between Karolinska Institutet, Danderyd Hospital, Royal Institute of Technology (KTH), and Sophiahemmet University College.

3.2 PATIENTS (I-IV)

All patients were selected from an outpatient clinic for tracheostomized patients at NRC, Danderyd Hospital in Stockholm, Sweden. The patients included in the studies were at least 18 years of age and not suffering from severe cognitive dysfunction. In study I, the inclusion criteria were that the patient attended NRC at 1982 or at 1997 and that the patient was tracheostomized for at least four years after the creation of the stoma. In study III and IV, the maximum age was 80 years. All patients were tracheostomized more than one month previously. In study II, the participants had a dual tracheostomy cannula, i.e. a tracheostomy tube consisting of both an inner and an outer tube and were not treated by any antibiotics during the study period. In study III and IV, only patients with a tracheostomy tube made of Si, PVC, or PU were eligible to participate. Another inclusion criteria was that only patients wearing a Shiley®, a Bivona TTS®, or a Tracoe Twist® tracheostomy could participate in the studies of material wear. Exclusion criteria for study III and IV were smoking, hematological diseases, or a life expectancy of less than 12 months. See Table III.
Table III. The demographical data of patients included in study I-IV.

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of patients</th>
<th>No. of Females</th>
<th>No. of Males</th>
<th>Mean age in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Group 1</td>
<td>27</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
<td>106</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>50</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>III</td>
<td>Clinical use</td>
<td>119</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Surface study*</td>
<td>19</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td>19</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

Several patients participated in more than one study. *There were the same participants in Study III as in Study IV.

3.3 PAPER (I) – OUTCOME OF LONG-TERM TRACHEOSTOMY

In order to compare need for hospital care for long-term tracheostomized patients, data were collected from patient medical records at NRC, from the Hospital Discharge Register, and the Death Certificate Register, both from the National Board of Health and Welfare, Stockholm, Sweden. The number of days of hospital care in a two-year period before and after tracheostomy for each patient was collected and compared. The data were divided into two groups, i.e. Group 1; patients who attended NRC in 1982 and Group 2; patients who attend NRC in 1997. To determine whether long-term tracheostomy influenced the patients’ life expectancy, data were collected from the National Register Life Expectancy 1751-2003 from Official Statistics of Sweden. This data collection only concerned Group 1, as the time of observation would have been too short for Group 2.

3.3.1 National Registers (I)

The registers used in the study were two registers from the National Board of Health and Welfare, Stockholm, Sweden; the Hospital Discharge Register and the Death Certificate Register, as well as the Life Expectancy Register 1751-2003 from Official Statistics of Sweden. The Hospital Discharge Register is a compilation of all hospital discharge records, first collected at regional level and then forwarded to the National Board of Health and Welfare, Sweden. The register gives details of each episode of
hospital care, dates of discharge, and length of stay. The death Certificate register covers death of Swedish citizens, irrespective of death taking place at home or abroad.

### 3.4 PAPER (II) – CANNULA CARE

To find a practical and safe decontamination method for tracheostomy inner cannulae, two different decontamination procedures were compared, i.e. detergent and chlorhexidine-alcohol (procedure A) and detergent (procedure B).

#### 3.4.1 Chlorhexidine-Alcohol Procedure (A)

The cannula was first decontaminated with detergent as described below, see Detergent Procedure (B). After decontamination it was immersed in 0.5% chlorhexidine/60% w/v ethanol (Fresenius Kabi Norge AS, Halden, Norway) for 1 min. Then it was soaked in sterile saline 0.9% for 1 min in order to remove the chlorhexidine.

#### 3.4.2 Detergent Procedure (B)

The inner cannula was decontaminated on the in- and outside by soaking for 30s in warm water with a fragrance free detergent containing anionic and non-ionic tensides, thickening, and water (Nilfisk-Advance, Stockholm, Sweden). Wet gauze pads were pulled through it, at least four times, until all visible secretions were removed. The cannula was then rinsed under running warm tap water for 30 s.

#### 3.4.3 Study Procedure

Patients with a dual tracheostomy tube were consecutively included and randomly assigned to begin with one of two different treatment sequences. In sequence AB, detergent and chlorhexidine-alcohol (A) was used at the first visit and detergent (B) was used at the second visit. In sequence BA detergent (B) was used at the first visit and detergent followed by chlorhexidine-alcohol (A) at the second visit. See Figure 5.
Using this study design the patient was his/her own control. The randomization was made by a computer sequence with closed, numbered envelopes and each patient was randomized once. Samples for bacterial culture were taken before and after decontamination, cultured on blood and CLED (cysteine lactose electrolyte deficient medium) agar plates, and incubated for 48 h at 36°C. The number of bacteria colonies was counted. Growth was expressed as colony forming unit (cfu)/mL. Microorganisms were typed by standard methods.¹²⁰

Figure 5.  
A flowchart over of randomization process of the study of tracheostomy inner cannula care

Randomized patients  
n = 50

Allocated to treatment sequence A, detergent and chlorhexidine-alcohol  
n = 25

- Allocated to treatment sequence B, detergent  
n = 25
  - Discontinued  
n = 2  
    - (n = 1 died, n = 1 was unable to attend the second visit)

- Allocated to sequence A, detergent and chlorhexidine-alcohol  
n = 23  
  - Discontinued  
n = 1  
    - was unable to attend the second visit
3.5 PAPER (III AND IV) – MATERIAL WEAR

To compare the duration of use of polymeric tracheostomy tubes, i.e. Si, PVC, and Pu (III) data were gathered from patient- and technical records for all tracheostomized patients, attending NRC. Data from patient- and technical records from a two-year period were collected and investigated. The type of tracheostomy tube each patient used, i.e. brand and material, the dates at which each patient received new tubes, and the number of tubes received by each patient per year was information retrieved from the records. Based on this information, the duration of use of the different tube materials was determined and compared.

To determine the material wear of polymeric tracheostomy tubes after 30 days (III), three, and six months (IV) of clinical use, 19 patients with long-term tracheostomy were included, i.e. n = 6 with Bivona TTS® Si tubes, n = 8 with Shiley® PVC tubes, and n = 5 with Tracoe Twist® PU tubes. See Figure 6. The tubes were exposed in the trachea for 30 days, three, or six months before being analyzed. At the initial stage, each patient received a new tracheostomy tube. The patient visited NRC monthly for routine and cannula control. During the first, third, and sixth visit the patient received a new tube. The patients were instructed not to clean the tube during the study period. For patients having a tracheostomy tube consisting of an inner and outer tube, the inner tube was, however, to be routinely cleaned. New tubes and new tubes exposed in Phosphate Buffered Saline (PBS) were used as reference. All technical analyses were performed as a blind study at KTH, Stockholm, Sweden, using standardized equipment. Only the outer surface of the outer tubes was studied. From every tracheostomy tube nine samples, with a size of approximately 6 x 6 mm, were secured from different locations of each tube, i.e. three samples from area I (proximal part), three from area II (mid part), and three from area III (distal part). The material wear of each tube material was determined and compared. Paper (III).

To evaluate the patients HRQL and experiences of long-term tracheostomy, two questionnaires were adopted (IV), i.e. the Swedish version of the SF-36 short-form health survey questionnaire and a study specific questionnaire about experiences of long-term tracheostomy. Both questionnaires were sent out together at the end of the study period and were administrated by postal mail.
Figure 6. Polymeric tracheostomy tubes.

An example of the three brands of the polymeric tracheostomy tubes included in Paper (III and IV). There is a Bivona TTS® silicone tube to the left, in the middle a Shiley® PVC tube, and a Tracoe Twist® polyurethane tube to the right.

3.5.1 Scanning Electron Microscopy (SEM) (III, IV)

To analyze the microscopic features of the tubes a Jeol JSM-5400 Scanning Electron Microscopy (SEM), (Tokyo, Japan) was used. Prior to analysis, the samples secured from each tube were mounted on specimen stubs and coated with palladium/gold (60%/40%), using a Desk II sputter Denton Vacuum (Moorestown, NJ, USA) (coating time = 18 seconds). The entire outer surface of the samples was examined systematically at a magnification of X 350 and X 1,500 at an acceleration voltage of 15 kV (spot size = 2). The SEM findings were scored of degradation using a scale 1 to 4 (1 being the lowest.)

SEM is a method for high-resolution imaging of surfaces. A SEM uses electrons for imaging, such as a light microscope uses visible light. A highly concentrated beam of electrons causes ejection of secondary electrons from the studied specimen. A detector counts the secondary electrons and the result is an image. The advantages of SEM over
light microscopy include greater magnification (up to X 100,000) and much greater depth of field. Morphological changes on the surface of a sample may be investigated by several different techniques. SEM is, however, a widely utilized method for detection of surface changes on organic and inorganic materials. As the technique allows for high magnification it gives great images of the morphology of the material surfaces investigated\textsuperscript{121}.

### 3.5.2 Attenuated Total Reflectance (ATR) – Fourier Transform Infrared Spectroscopy (FTIR) (III, IV)

In order to analyze the surface changes of the chemical bonds (functional groups) of the polymeric chains a Perkin-Elmer 2,000 FTIR-spectrophotometer (Wellesley, MA, U.S), equipped with a Golden Gate Diamond ATR accessory from Graseby Specac (Kent, U.K), was used. All samples were entirely scanned (number of scans = 16) and the peak area investigated was 4,000-600 cm\textsuperscript{-1}. The baselines of the obtained spectra were corrected and normalized in accordance with the reference peaks. Standardized procedures were adopted to evaluate the obtained spectra. To measure the degree of degradation in PVC and PU the Carbonyl Index (CI) was used and for Si an index was obtained by a comparison of the coating and of the normalized methyl area.

Fourier Transform Infrared Spectroscopy (FTIR) is a chemically analytical technique, used for analyzing organic and inorganic materials. In polymer technology, the technique is commonly used to identify functional groups in the material. From this information, the type of polymer, additives, and degree of degradation can be obtained. FTIR works on the premise of energy absorption within the infrared spectrum. This technique measures the absorption of various infrared light wavelengths by the material of interest. These infrared absorption bands identify specific molecular components and structures. The specificity of these bands allows computerized data searches to be performed against reference libraries to identify a material. The method is used for bulk material identification as well as identification of constituents in multi-layered materials\textsuperscript{122}. In order to investigate surfaces, as well as surface coatings, the FTIR technique is commonly used in conjunction with Attenuated Total Reflectance (ATR-FTIR). In Paper (III and IV) the ATR-FTIR was used.
3.5.3 Differential Scanning Calorimetry (DSC) (IV)

To analyze the thermal properties of the samples, a Mettler Toledo Differential Scanning Calorimetry (DSC) 820 (Schwerzenbach, Switzerland) was used. Prior to analyses, the samples (3-6 mg) were placed in a 40µg aluminium pan and a lid was placed on top (an empty pan of the same type was used as reference). The sample and reference were subjected to a predetermined temperature program (scanning rate = 10-20ºC/min) in an atmosphere of nitrogen (80 ml/min). An indium standard was used to calibrate the system. Transition temperatures ($T_g$) of the samples were determined from the midpoint of the endothermic rise.

DSC is an analytical technique, most useful in the analyses of polymers, as it examines the melting temperature ($T_m$), the glass transition temperature ($T_g$), and other thermal transitions, such as phase changes. The difference between the amounts of heat required to increase the temperature of a sample and reference sample, are measured as a function of temperature. Both the sample and reference are maintained at the same temperature throughout the experiment. By observing the difference in heat flow between the sample and reference, differential scanning calorimeters are able to measure the amount of heat absorbed or released during such transitions. The DSC can be used to measure a number of characteristic properties of a sample. Using this technique, it is possible to observe fusion and crystallization events as well as glass transition temperatures ($T_g$). DSC is used to get an indication of whether properties of the material investigated have changed. It can also be used to study oxidation as well as other chemical reactions.

3.5.4 Health-Related Quality of Life (HRQL) and Patient Experiences (IV)

HRQL was assessed with the SF-36 questionnaire. This self-administered measure of health status with 36 questions is well validated and widely used. The questionnaire measures different aspects of general health through eight multi-item scales, i.e. PF (physical functioning), RP (role physical), BP (bodily pain), GH (general health), VT (vitality), SF (social functioning), RE (role emotional) and MH (mental health). The SF-36 is scored from 0 to 100 (where 100 represent optimal functioning and well-being), The eight scales are summarized into two different summary
measures, i.e. physical component summary (PCS) and mental component summary (MCS). The obtained values were compared with normative values for the general Swedish population, age 15-93 years\textsuperscript{124,125,128}.

The SF-36 was adopted together with a study specific questionnaire. The authors and two respiratory nurses, who had more than 20 years’ experience within the field, developed the study specific questionnaire. The questions were devoted to each patient’s experience of long-term tracheostomy. There were 12 questions, designed in such a way that it was possible to answer and to write additional comments.

### 3.6 STATISTICAL ANALYSES

The statistical methods used are described in the Papers (I-IV). For a summary, see Table IV. Continuous parametric data were subjected to a Wilcoxon-Mann-Whitney test. For the material studies, a Kruskal-Wallis test was adopted followed by a Wilcoxon-Mann-Whitney test to test for differences between the materials investigated. To perform intra-group comparisons, a Wilcoxon signed rank test was applied. A p-value < 0.05 was considered significant. To compare the mean value scores for the SF-36 questionnaire obtained for the studied group with those obtained from a normative Swedish population, Students unpaired t-test was used.

<table>
<thead>
<tr>
<th>Study</th>
<th>Statistical methods</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study I</td>
<td>Wilcoxon signed rank test one-sided and two-sided</td>
<td>Stat-View, 4.5 (SAS Institute, Cary, NC) and SPSS, 13.0 (SPSS Inc. Chicago, IL)</td>
</tr>
<tr>
<td>Study II</td>
<td>Wilcoxon-Mann-Whitney test two-sided</td>
<td>SPSS, 14.0 (SPSS Inc. Chicago, IL)</td>
</tr>
<tr>
<td>Study III</td>
<td>Kruskal-Wallis test and Wilcoxon-Mann-Whitney test two-sided</td>
<td>SPSS, 14.0 (SPSS Inc. Chicago, IL)</td>
</tr>
<tr>
<td>Study IV</td>
<td>Kruskal-Wallis test, Wilcoxon-Mann-Whitney test two-sided, Wilcoxon signed rank test one–sided, and Students t-test</td>
<td>The JMP Software (version 3.1.5, SAS Institute Inc., Cary, NC)</td>
</tr>
</tbody>
</table>
3.7 PROCEDURES AND METHODS FOR ADDITIONAL MATERIAL OBSERVATIONS

In order to study surface changes of silver tracheostomy tube materials, six out-patients (three women and three men) with a tracheostomy tube made of sterling silver, were consecutively included. Three patients had a tracheostomy tube of the brand La Barré® and three of the brand Bauer Häselbarth®. The inclusion and exclusion criteria were the same as in Paper (III and IV) with the exception of the material of the patient’s tracheostomy tube.

3.7.1 Procedures

At the initial stage, each patient received a new tracheostomy tube of the same type and brand as the patient usually used. A physician inserted the tube and the patient came on regular controls (every 30 days) to NRC. At this scheduled control, the tube was removed, cleaned according to standardized procedures, inspected, and reinserted. Note that all patients in the study had a dual cannula. The patients routinely cleaned their inner cannula. Each tube was exposed in the patient during six months. After the last study visit the patient received a new tracheostomy tube and the study cannula was cleaned, put in a separate sample bag, and sent to KTH for analysis. Further analyses were made of one PVC tracheostomy tubes that was exposed in the trachea for 30 days.

3.7.2 Analyzing Methods

All analyses were performed, blinded at KTH, using standardized equipment. Samples from each tube were secured, i.e. proximal area, mid area, and distal area. To analyze microscopic features of the tubes, a Jeol JSM-5,400 SEM (Tokyo, Japan) was used. The entire surface of the samples was systematically examined at a magnification of X 350, X 1,000, X 1,500, and X 3,000 at an acceleration voltage of 15 kV (spot size = 2). In order to characterize the surface changes detected by SEM, Atomic Force Microscopy (AFM) was used. The AFM allows for high resolution, which can reach the atomic level. The AFM probes the surface by a scanning tip, i.e. probe. It is placed so close to the sample that it is able to feel small repulsive forces from the sample. The
tip can either move along the scanned subject or be still, while the subject moves. The images received can be seen 3D. It is an analyzing method that is most useful in detecting surface changes down to nanometer level, as it allows for very great magnification\textsuperscript{129}. In the present study the specific depth of a fissure in the material could be measured by AFM. Using this method, possible remainders of biofilm formation can easily be identified. The method has, by other researchers, successfully been used in the characterization of cell adhesion to different material surfaces and to study the formation of biofilm\textsuperscript{130-132}.

3.8 ETHICAL CONSIDERATIONS

All studies in this thesis have approval from The Human Ethics Committee at Karolinska Institutet, Stockholm, Sweden. Permission for data collection from the Hospital Discharge Register and the Death Certificate Register was obtained from the National Board of Health and Welfare, Stockholm, Sweden. The patients participating in study II, III and IV all gave their written consent to participate in the studies.
4 RESULTS

4.1 PAPER (I) – OUTCOME OF LONG-TERM TRACHEOSTOMY

4.1.1 Need for Hospital Care (I)

Outcome concerning the need for hospital care for long-term tracheostomized patients was determined and compared. Data were collected for two groups. Group 1; patients attending NRC in 1982, consisted of 27 persons (15 female and 12 male) and group 2; patients attending NRC in 1997, consisted of 106 persons (52 female and 54 male). Both groups had little and unchanged need for hospital care after tracheostomy compared to before. Group 1 spent $\geq 96\%$ of their time out of hospital and Group 2 $\geq 94\%$. Both groups included patients with spinal cord injury, who commonly used to be treated in hospital for a long time after the injury.

4.1.2 Life Expectancy (I)

For Group 1, life expectancy was assessed and data showed that the long-term tracheostomy did not have a decreased lifespan compared to an age-matched and gender adjusted control cohort. See Table V.

| Table V. Expected lifespan at birth and observed lifespan of patients in Group 1 |
|-----------------|-----------------|-----------------|
| Group 1 patients n = 27  | Deceased patients n = 18 (11 women and 7 men)  | Living patients n = 9 (4 women and 5 men)  |
| Expected life span (years) | Mean 63.5 Range 57-76 | Mean 67.0 Range 58-72 |
| Observed life span (years) | Mean 67.0 Range 26-86 | Mean 61.0 Range 41-94 |
| Years with tracheostomy | Mean 14.0 Range 4-27 | Mean 26.0 Range 22-34 |

Data adjusted for year of birth and gender.
4.2 PAPER (II) – CANNULA CARE

Two decontamination procedures for tracheal inner cannulae were compared in this randomized cross-over study. The primary variable was the culture count value after chlorhexidine-alcohol/detergent (A) and detergent (B). Before decontamination the inner cannulae grew high numbers of bacteria, which were parts of the normal flora of the upper respiratory tract and did not differ significantly between the two sequences (AB; BA). The effects of both methods were larger than expected and the results showed a nearly total elimination of organisms for both decontaminating procedures. See Table VI. The equivalence criterion, ratio of mean colony counts (A/B) > 0.8, was met at a significance level of $P < 0.001$. The results of the study show that effective decontamination of inner cannulae can be achieved with a simple, low cost cleaning method and that use of disinfectant has no further benefit.

### Table VI. Bacterial counts before and after decontamination expressed in cfu/mL

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Summary statistics</th>
<th>Detergent and chlorhexidine alcohol (A)</th>
<th>Detergent (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>AB</td>
<td>Mean</td>
<td>21,708.0</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>5,000.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>&gt; 100,000.0</td>
<td>60.0</td>
</tr>
<tr>
<td>BA</td>
<td>Mean</td>
<td>46,785.0</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>50,000.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>50.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>&gt; 100,000.0</td>
<td>160.0</td>
</tr>
</tbody>
</table>

4.3 PAPER (III AND IV) – MATERIAL WEAR

4.3.1 Tracheostomy Tube Use (III)

Significant differences between the duration of clinical use in number of days for the tracheostomy tube materials, Si, PVC, and PU was determined. The hypothesis of overall homogeneity was rejected at $P < 0.0001$. The Si tubes were, in mean, used for longer periods (85 days) than tracheostomy tubes made of PVC (56 days) or PU (51 days). See Table VII.
Table VII. Duration of clinical use in number of days for different tracheostomy tube materials

<table>
<thead>
<tr>
<th>Clinical use in number of days</th>
<th>Silicone (Si)\textsuperscript{a} (n = 39) \textsuperscript{(n = 14 female)}</th>
<th>Polyvinyl Chloride (PVC)\textsuperscript{b} (n = 73) \textsuperscript{(n = 31 female)}</th>
<th>Polyurethane (PU)\textsuperscript{c} (n = 7) \textsuperscript{(n = 3 female)}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>90.0</td>
<td>64.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Median (range)</td>
<td>85.0 (27.0 - 194.0)</td>
<td>56.0 (19.0 – 263.0)</td>
<td>51.0 (28.0 – 136.0)</td>
</tr>
<tr>
<td>Mean No. of tubes used per year and patient</td>
<td>4.0</td>
<td>5.7</td>
<td>6.0</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Bivona TTS\textsuperscript{®}, Bivona TrachVent\textsuperscript{®}
\textsuperscript{b} Shiley\textsuperscript{®}, Portex Blueline Ultra\textsuperscript{®}, Portex Ivory Tube\textsuperscript{®}, Rüsch Crystal Clear\textsuperscript{®}, Tracoe Comfort\textsuperscript{®}
\textsuperscript{c} Tracoe Twist\textsuperscript{®}

4.3.2 Material Wear (III and IV)

Concerning the tracheostomy tubes, exposed in the trachea for 30 days, Paper (III), no gross color changes were observed on the Si tubes before analyses, but 63% of the PVC tubes and 80% of the PU tubes exhibited both macroscopic deposits or color changes before analyses. The SEM analyses detected clear surface changes in all tubes but one, exposed in the trachea for 30 days (95%). See Figures 6-8. There were no significant differences between the materials investigated or the different locations of the tubes. The majority of the PVC and PU tubes were scored with the highest degradation index compared to 1/3 of the Si tubes. The reference samples exposed in PBS revealed only minor surface changes.

The SEM analyses in Paper (IV) revealed that all tracheostomy tubes displayed severe surface changes after three and six months’ exposure in the trachea. No significant differences were established between the times of exposure on the various materials. The surface changes detected had progressed significantly as compared to previously reported changes after 30 days. All tubes were clearly affected by the environment of trachea and 82% were scored with the highest degradation index score, i.e., (4). As can be seen from Figure 7-9, cracks, pores, pits, flaking, localized cracking, “frosting” (network of cracks), and/or other surface defects were identified on the tubes. The statistical methods, adopted on the SEM results, revealed no significant differences of
material degradation between the materials nor between the different locations on the tubes, i.e., area I (proximal), area II (mid tube) and area III (distal).

Furthermore, the SEM analyses also revealed in, Paper (IV), that the characteristic rough structure of the SuperSlick® XL-PCN™ coating on the Si tubes were partly or completely worn off. See Figure 7. Cracks and pits, as well as material flaking, existed to some extent on all tubes. Microscopic deposits, as well as bacteria colonies, were also found on the surface or within cracks and/or pits in the surface. The micrographs revealed severe degradation of the PVC tubes and in some cases large cracks, resulting in a brittle and porous outer surface layer. See Figure 8. Cracks, pits, and/or pores were also regularly found on all PVC samples. In the PU tubes, 100 % of the tubes had gross color changes, prior to analysis. Severe material degradation, as well as the existence of localized cracking were found. See Figure 9.
Figure 7. SEM Images of Bivona TTS® Si tracheostomy tubes

A) SEM image of the proximal area (I) of an unexposed Bivona TTS® silicone (Si) reference tube. The irregular outer surface seen in the micrograph is the Superslick® XL-PCN™ coating. Magnification X 1,500.

B) SEM image of a Bivona TTS® Si tracheostomy tube, exposed in the trachea of a 23-year-old ventilator treated male with Duchenne’s Syndrome for 30 days, distal area (III). Scored as 2.

C) SEM image of a Bivona TTS® Si tracheostomy tube, exposed in the trachea of the same patient for three months, magnification X 1,500. Scored as 4. There is a clear double layer in (C), displaying degradations of the polymeric chains.

D) SEM image of a Bivona TTS® Si tracheostomy tube, exposed in the trachea for six months. Scored as 4. The degradation here is even worse and deep cracks are visible. Magnification X 1,500.
Figure 8. SEM Images of Shiley® PVC tracheostomy tubes

A) SEM image of an unexposed Shiley® polyvinyl chloride (PVC) tracheostomy tube, mid area (II), here used as reference material.

B) SEM image of a Shiley® PVC tracheostomy tube, distal area (III), exposed in the trachea of a 41-year-old male with multiple sclerosis for 30 days.

C) SEM image of a Shiley® PVC tracheostomy tube, distal area (III), exposed in the trachea of the same patient as in (B) for three months.

D) SEM images of a Shiley® PVC tracheostomy tube, distal area (III) exposed in the trachea of the same patient as in (B) and (C) for six months. There are clear surface changes in all images and the top layer of the PVC has partly disappeared in (C) showing a cracked pattern. In (D) those cracks are even larger and may easily host bacteria. Both the three months’ tube and the six months’ were scored as 4 in the degradation index. These pictures clearly display the material degradation of long-term use of tracheostomy tubes. Magnification X 1,500.
Figure 9. SEM Images of Tracoe Twist® PU tracheostomy tubes

A) SEM image of the distal area (III) of an unexposed Tracoe Twist® polyurethane (PU).
B) SEM image of the proximal area (I) of the Tracoe Twist® polyurethane (PU) tube, exposed in the trachea of a 64-year-old male patient with post stroke complications for 30 days. The micrograph clearly reveals large fissures in the surface layer (score 4). The fissures originate from degradation of the soft segments of the polymer. Magnification X 1,500.
C) SEM image of the mid area (II) of the Tracoe Twist® polyurethane (PU) tube exposed in the trachea of the same patient as in (B) for three months (score 4). The micrograph reveals white “spots” on the surface, which could be remainders from the cleaned off biofilm. Magnification X 1,500.
D) SEM image of the mid area (II) of the Tracoe Twist® polyurethane (PU) tube, exposed in the trachea of the same patient as in (B) and (C) for six months. (Score 4). The micrograph reveals a typical example of a stress fracture in the material. Magnification X 1,500.
The ATR-FTIR analyses, Paper (III), revealed, in all samples from the Si, PVC, and PU tracheostomy tubes, exposed in the trachea, changes in the chemical functional groups of the polymeric chains. The presence of additives of phthalate type was seen in the PVC spectra (i.e., a characteristic peak at 1,721 cm\(^{-1}\)). To measure the degree of degradation in PVC and PU the Carbonyl Index (CI) was used. A decrease of the CI was detected in 70% of the PVC tubes, which can be related to a gradual loss of additives during exposure of the tube. Several of the Si tubes exhibited a complete loss of the top coating Super Slick XL-PCN, a coating that lowers friction and eases suction. Fewer changes were seen in the PU tubes.

In Paper (IV) all analyses made by ATR-FTIR for Si, PVC, and PU tubes showed moderate to extensive changes in the chemical bonds of the polymeric chains. The results vary between the different tubes of the same material, as well as between the different locations on the same tube, indicating that the degradation is heterogeneous. A decrease in the alteration index existed for all Si tubes, indicating that changes in the chemical functionality had occurred as a result of prolonged exposure in the trachea. The spectra demonstrated a partly or complete removal of the SuperSlick\(^{\text{®}}\) XL-PCN\(^{\text{TM}}\) coating in approximately 50% of the tubes. A decrease of the CI for the PVC tubes was obtained for 10 of the 11 tubes. Ninety-one% demonstrated a gradual loss of additives. In general the spectra obtained for PU tubes showed less alteration, but in one case severe material degradation was detected.

Independently of the material, the obtained DSC results indicate that small morphological changes could be identified in the tubes, exposed in the trachea for three or six months, and no difference could be established between the results obtained for the tubes exposed in the trachea for three and six months respectively.

### 4.3.3 Health-Related Quality of Life and Patient Experiences (IV)

Seventythree percent of the patients completed the SF-36 questionnaire sufficiently to be used for the calculation of the summary scores and 82% for the evaluation of the study specific questionnaire. The outcome of the SF-36 questionnaire has been analyzed and the results are presented in Table VIII together with the mean values of the general Swedish population\(^{124}\). As can be seen from the table, the physical health
status (PCS) was significant below the PCS of the general Swedish population. The mean value of mental health status (MCS) was above that of the general population but difference was not statistically significant.

Table VIII. HRQL in patients with long-term tracheostomy according to SF-36 (n = 13)

<table>
<thead>
<tr>
<th>SF-36 scales</th>
<th>Q1</th>
<th>M</th>
<th>Q3</th>
<th>Mean (SD)</th>
<th>Mean (SD)*</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Norm population</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(n = 8930)</td>
<td></td>
</tr>
<tr>
<td>Physical functioning (PF)</td>
<td>10.0</td>
<td>30.0</td>
<td>50.0</td>
<td>35.0 (31.8)</td>
<td>87.9 (19.6)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Role physical (RP)</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>44.2 (50.2)</td>
<td>83.2 (31.8)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Bodily pain (BP)</td>
<td>36.5</td>
<td>72.0</td>
<td>100.0</td>
<td>68.5 (33.2)</td>
<td>74.8 (26.1)</td>
<td>0.3847</td>
</tr>
<tr>
<td>General health (GH)</td>
<td>41.0</td>
<td>57.0</td>
<td>77.0</td>
<td>55.7 (27.2)</td>
<td>75.8 (22.2)</td>
<td>0.0011</td>
</tr>
<tr>
<td>Vitality (VT)</td>
<td>50.0</td>
<td>60.0</td>
<td>77.5</td>
<td>57.7 (27.3)</td>
<td>68.8 (22.8)</td>
<td>0.0795</td>
</tr>
<tr>
<td>Social functioning (SF)</td>
<td>25.0</td>
<td>75.0</td>
<td>100.0</td>
<td>68.3 (34.5)</td>
<td>88.6 (20.3)</td>
<td>0.0003</td>
</tr>
<tr>
<td>Role emotional (RE)</td>
<td>75.0</td>
<td>100.0</td>
<td>100.0</td>
<td>88.0 (21.7)</td>
<td>85.7 (29.2)</td>
<td>0.7765</td>
</tr>
<tr>
<td>Mental health (MH)</td>
<td>60.0</td>
<td>72.0</td>
<td>84.0</td>
<td>71.0 (13.6)</td>
<td>80.9 (18.9)</td>
<td>0.0591</td>
</tr>
<tr>
<td>MCS</td>
<td>50.6</td>
<td>52.6</td>
<td>60.0</td>
<td>53.6 (10.1)</td>
<td>50.0 (10.3)</td>
<td>0.2080</td>
</tr>
<tr>
<td>PCS</td>
<td>20.9</td>
<td>27.7</td>
<td>37.3</td>
<td>30.4 (13.9)</td>
<td>50.0 (9.7)</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

Q1 = the 25 percentile, M = median and Q3 = the 75 percentile. All eight scale range from 0-100, with 100 representing the optimal functioning and well-being. MCS= summary measures of PF, RP, BP and GH. PCS= summary measures of VT, SF, RE and MH.

*Sullivan M & Karlsson J, 1998*¹²⁴

All patients, who completed the study specific questionnaire, were very content with his or her present situation as well as the treatment received at NRC. Nine patients (64 %) thought their well-being was affected in a positive way, when the tube was cleaned and reinserted. However, 4 patients (29 %) felt that it did not make any difference and 1 patient (7 %) was experiencing a certain degree of discomfort and was affected in a negative way. In general, most patients considered their tracheostomy tube to be comfortable, i.e. the tube did not irritate or rub the skin and it gave enough air for both breathing and talking. It was also experienced as being functional, i.e. the tube was easy to remove, clean, reinsert and displayed no leakage of air. It was discreet and not an obstacle in the daily life. Some negative experiences were related to tube management being time consuming, changes in the voice, as well as difficulties in talking in large groups, which was pointed out by 2 patients (14 %). The inconvenience related to meeting inexperienced staff at the emergency units was also mentioned, as
well as the loss of ability to swim. Eight patients (57 %) meant that the information they received from NRC about management, maintenance, and cleaning of the tracheostomy tube was very good and 6 patients (43 %) considered it good.

4.4 ADDITIONAL OBSERVATIONS

4.4.1 SEM Analyses of Silver Tracheostomy Tubes

To date, two silver tracheostomy tubes of the brand La Barré® have been analyzed by SEM. In Figure 10, the SEM micrograph of one of the tubes is presented. As can be seen in Figure 9b, there are pits of various extents, as well as, valley type cracks present on the material surface. Even the sample from the reference tube reveals pits and pores, which is believed to originate from the manufacturing process. See Figure 10.

Figure 10. SEM Images of La Barré® Silver tracheostomy tubes

a) SEM image of the distal area (III) of an unexposed La Barré® Silver tracheostomy reference tube. The micrograph revealed pits and pores in the new, unexposed surface.

b) SEM image of the distal area (III) of the La Barré® Silver tracheostomy tube exposed in the trachea of a 60-year-old male patient with tracheal stenosis due to six months of radiation therapy. The micrographs revealed large pits and valley type cracks with obvious MIC. Note the bacteria colony in the largest crack in the middle of the image. Magnification X 2,500.
4.4.2 Atomic Force Microscopy (AFM) measurements of PVC Tracheostomy Tubes

Preliminary AFM measurements were conducted on two samples secured from Shiley® tracheostomy tubes; one from the reference tube and one from a tube exposed in the trachea for 30 days. An Asylum Research MPF-3D AFM apparatus was used for these measurements and the pictures were analyzed with both the Igor Pro and WSxM software. It is important to point out, that the procedure adopted, for evaluating the experimental results, needs to be further refined. Figure 11 shows the topography of the PVC (Shiley® tracheostomy tube) reference sample. As seen in the figure, the topography was very rough and several small valley type cracks existed on the analyzed surface. The highest point of the topography was 1.13µm.

Figure 11.

The topography (a) and the 3D surface picture of a Shiley® PVC tracheostomy tube. The scan size of the height trace was 20.00 µm and the scan rate 1.50 Hz. The image reveals an uneven surface with valley type cracks and rounded peaks.
Figure 12 shows the topography of the PVC (Shiley® tracheostomy tube) sample exposed for 30 days in the trachea. The analyzed sample originates from the same tracheostomy tube as in Figure 8B. As can be seen from Figure 12, a crack was found to exist in the surface. It is difficult to say whether the crack in question originates from the different steps of the manufacturing procedure, or if it is a result of material degradation. The SEM image (Figure 8B), however, reveals a flaking surface and the holes identified on the surface are therefore, most likely to be biodegradation products. The sizes of the holes are approximately 50-70 nm in depth with a width of 0,8-1,2 μm. The highest point of the area is at 455 nm.

Figure 12.

The topography (a) and the 3D surface picture (b) of a Shiley® PVC tracheostomy tube distal area (III) exposed for 30 days in the trachea of a 41-year-old male with multiple sclerosis. The sample analyzed originates from the same tracheostomy tube as in Figure 8B. A crack in the scanned surface is clearly visible as well as several holes. The scan size of the height trace was 30.00 μm and the scan rate 2.00 Hz.
5 DISCUSSION

In the present thesis the outcome and need for hospital care of long-term tracheostomized patients, different cleaning methods for tracheostomy inner cannulae, as well as material wear of tracheostomy tubes have been investigated. The research was performed at the National Respiratory Centre (NRC), Stockholm, Sweden. The focus was on patients with long-term tracheostomy.

5.1 MAIN FINDINGS

Patients with long-term tracheostomy displayed unchanged need for hospital care following recovery from the procedure, and spent \( \geq 96\% \) of their time out of hospital Paper (I). Interestingly enough, the observed life span for patients attending NRC in 1982 (Group 1), was remarkably high and for many patients not lower than the life expectancy of Swedish people in general.

Effective decontamination of tracheostomy inner cannulae can be achieved with a simple, low cost cleaning method and the use of disinfectant showed no further benefit Paper (II).

Concerning material wear of tracheostomy tubes, it was established that silicone (Si) tracheostomy tubes in general were used for a longer period than those made of polyvinyl chloride (PVC) or polyurethane (PU). Out of 19 tracheostomy tubes, exposed in the trachea for 30 days, 18 suffered evident surface changes with degradation of the polymeric chains as a result Paper (III).

In the long-term study of material wear of polymeric trachesotmy tubes, our most important finding was that evident and gross surface changes were detected on all tubes (100 %), exposed in the trachea for three or six months. In comparison with the obtained results in Paper (III), the further deterioration was statistically significant. The patients’ experiences of long-term tracheostomy and their health-related quality of life (HRQL) were evaluated and the main result was that patients’ self-reported mean score
for mental health status was higher than the mean score of the Swedish normative population. They also thought that their tracheostomy tubes were comfortable and functional and all patients were content or very content with their treatment with tracheostomy Paper (IV).

5.2 METHODOLOGICAL CONSIDERATIONS

The results in this thesis were obtained in a setting where patients had regular access to a dedicated outpatient service (NRC), with special resources for manufacturing customized devices and performing regular follow-ups on possible complications or progress of underlying illnesses.

5.2.1 Paper (I)

The number of days spent in hospital, starting from two years before the operation and ending two years after the operation were noted for each patient. The period of two years before the tracheostomy was compared with the two-year period after the tracheostomy, leaving out the year of the procedure and one full year of recovery. This was important, especially for Group 1 (1982), as the number of hospitalization days, in accordance with a surgical intervention, was in general higher by that time.

Data were collected from patient medical records at NRC from 1970 until 2004, from the Hospital Discharge Register, and date of death from the Death Certificate Register, both from the National Board of Health and Welfare, Sweden. The Swedish Hospital Discharge Register is a compilation of all hospital discharge records, collected electronically first at the regional level by the local health administrative authorities, and then forwarded to the National Board of Health and Welfare. Administrative data include date of admission and discharge and length of stay. The register gives details for each episode of hospital care, the number of hospitalization days, and the date for discharge. The Death Certificate Register covers deaths of Swedish citizens irrespective of place of death. The accuracy of the Swedish Hospital Discharge Register 1982 was at least 98% and from 1985 it was greater than 99%. Thus, the data presented here on mortality and hospitalization can be considered very reliable. In contrast, we
found that the old medical records assembled at NRC, regarding laboratory data and physical findings could be of more varied quality. A limitation of our study is the lack of data on the specific diagnosis of each hospitalization. We have, however, argued that a decision to retain or discharge a patient from a hospital is, complicated and influenced by a multitude of factors. As we considered that the presence of an artificial airway affects all aspects of hospitalization decisions, regardless of the nature of the complaint, we decided not to focus on which diagnosis was stated, for each period of hospital care, but to report the total number of days per 2-year period.

5.2.2 Paper (II)

Paper (II) was a randomized cross-over study, where the patient was his or her own control. Outpatients using a tracheostomy tube with an inner cannula were consecutively included and randomly assigned to two different treatment sequences AB and BA. In sequence AB, detergent followed by chlorhexidine-alcohol (A) was used at the first visit and detergent (B) was used at the second visit. In sequence BA detergent (B) was used at the first visit and detergent and chlorhexidine-alcohol (A) at the second visit. The randomization was made by a computer sequence with closed, numbered envelopes, each patient being randomized once. Before and after the two decontamination procedures (A and B) the inner cannula was flushed with 10 ml sterile saline 0.9% into a sterile test tube. The flush solutions were transported to the laboratory and processed immediately. Samples were marked with the date and patient ID, but blinded as to procedure used. The flush solutions were cultured on blood and CLED (cystein lactose electrolyte deficient medium) agar plates. Nurses, who followed the standardized study protocol, cleaned the inner tracheostomy cannulae. In between the study visits the patient cleaned their inner cannulae routinely at home.

The study design was chosen to enable an equivalence analysis, as the tracheal flora varies greatly both in quantity and quality between patients. Therefore, we considered it to be wise to use the patient as his/her own control. The primary variable was the culture count value after detergent and chlorhexidine-alcohol/detergent. The reduction before-after was not chosen as primary, since it was expected to have a larger variability than the after-values. A sample size calculation was made in order to achieve adequate power before the randomization.
5.2.3 Paper (III and IV)

Through data collection, from medical- and technical records at NRC, the duration of use of different polymeric tracheostomy tubes was obtained and compared Paper (III). The patients reuse their tracheostomy tubes, if the tubes are found to be in acceptable condition. There is today no legal limit for how many times a tracheostomy tube could be reused. One of the limitations of the study was that NRC only keeps technical records over tracheostomy tubes that have been modified in one way or another. Thus, only customized tubes were included in the study. During the data collection it became obvious that the degree of modification did not influence the length of use, which we had expected. As we, in NRC, do not treat patients with standardized tubes differently from those with customized ones, the obtained results on customized tubes ought to be applicable also for standardized tubes. The study did not address reasons for a tube change, but the most common ones at NRC are stated to be due to colour changes or cuff problems.

After obtaining the results from the study of tracheostomy tube use, where the use of Si tubes was significantly longer than the use of PVC, or PU tubes, we set out to analyze the surface of the same polymeric tracheostomy tube materials after 30 days of exposure in the trachea, Paper (III). The project was conducted in collaboration between Karolinska Institutet Danderyd Hospital (KIDS), KTH and Sophiahemmet University College. The design was descriptive/prospective. The patients were consecutively included. As there was little research done in the field, we aimed to investigate, if there were any surface changes at all in the tube materials after 30 days of use. The analyses were made with SEM and FTIR, because the aim was to investigate, whether there were any surface changes in the materials after patient use. The experimental techniques adopted allowed for high magnification of material surfaces, identification of additives, as well as degree of degradation taking place. The number of patients in each material may give the impression to be low, but from each tracheostomy tube nine samples were taken, i.e. three samples from the three different areas of the tubes. This concerns also Paper (IV), as the participants in Paper (III) and (IV) are the same.

The results from Paper (III) made it obvious that material wear of the tubes could be identified already after 30 days’ use. All tracheostomy tubes but one suffered evident
surface changes. Therefore, we aimed, in Paper (IV), to investigate the effects of long-term use of polymeric tracheostomy tubes and to determine the patients HRQL and experiences of long-term tracheostomy. In order to investigate, if the bulk material had been affected by long-term wear, we chose to use differential scanning calorimetry DSC as an additional analyzing method in Paper (IV). It is important to point out the effect that specific bacteria had on the material wear, as well as the pH in trachea, have not been considered in the present study. We decided to use SF-36 in order to determine the participants’ HRQL, because it is a well-established and widely used questionnaire and was possible to combine with the study specific questionnaire. As our patient group mainly suffers from chronic diseases, this definition of well-being applied to us, and we consider it to be appropriate to use the SF-36 questionnaire. All patients were in stable health with no cognitive dysfunction at the time of study and they all understood Swedish.

5.3 DISCUSSION OF RESULTS

5.3.1 Outcome of Long-Term Tracheostomy – Paper (I)

The main findings in Paper (I) were that patients with long-term tracheostomy had an unchanged need for hospital care after recovery from the procedure and that they spent most of their time (> 96 %) out of hospital. Patients with post polio or kyphoscoliosis displayed a decreased hospitalization after recovery. Many of the patients were able to reach old age; their life span was not shortened due to the tracheostomy. Some patients had been tracheostomized for more than 30 years and interestingly enough two of them had a spinal cord injury and were on 24 hours ventilation. In 1997 the number of patients in all diagnosis groups had increased compared to 1982. Even the diagnostic panorama had broadened. In general, the patients were older and often had several diagnoses. Also many children were being seen at NRC. This was partly due to improved general care of premature children. Again, it is necessary to point out that the results from all papers in this thesis were obtained in a setting (NRC), where the patients had regular access to a dedicated out-patient service with regular check-up visits, customized cannulae, control of stoma and tracheostomy tube, removal of granulation tissue when necessary etc. The regular check-up visits and the routines that
constitute the basis for our outpatient clinic may contribute to our low rate of complications\textsuperscript{12,17}.

5.3.2 Cannula Care – Paper (II)

The results from Paper (II) show that effective decontamination of inner cannulae can be achieved by a simple, low cost cleaning method, and that use of disinfectant has no further benefit. The effects of both decontamination methods were better than expected and the results show a nearly total elimination of organisms in both arms of the study. All cannula types grew high numbers of bacteria before decontamination. The organisms were part of the normal flora of the upper respiratory tract with additional opportunistic gram-negative bacteria, which was expected\textsuperscript{43,80,83,135-137}. Lower numbers of bacteria were obtained from the silver cannulae than from the tubes made of polymeric materials. This may indicate that the silver surface prevents biofilm formation on the tubes\textsuperscript{89}, which deserves further study.

An inner cannula does not necessarily have to be sterile, as it is reintroduced into the same patient and will then rapidly be contaminated by the flora of the respiratory tract. The objective of a decontamination procedure is to eliminate risks of contamination during the handling of the cannula and to remove secretion that may block the lumen. The cleaning agent used consisted mainly of anionic and non-ionic detergents/surfactants, which are known to be excellent detergents but have little disinfectant activity, with a low content of cationic detergent or quaternary ammonium compounds\textsuperscript{138}. In the present study the detergent used contained anionic and non-ionic tensides, thickening, water, and not active enzymes. Cleaning agents with no enzymes have proven to be more effective, not only in reducing the amount of biofilm, but also in killing off the bacteria\textsuperscript{139}. It is difficult to remove biofilm once it has been established and especially from endoscope/bronchoscope tubing without physical cleaning\textsuperscript{140}. Ethanol is, however, a well-known disinfectant, but the addition of chlorhexidine offers no advantage in surface disinfection\textsuperscript{141}. Ethanol alone or with detergent is not available to outpatients either over the counter or by prescription in Sweden, due to strict regulations of the alcohol market, whereas chlorhexidine-alcohol is. The use of disinfectants has many drawbacks, particularly against gram-negative organisms\textsuperscript{142}. Removal of the biofilm is essential for decontamination of devices contaminated by respiratory tract flora\textsuperscript{140} but this is not necessarily achieved by
disinfection\textsuperscript{143,57}. There are various techniques for decontamination of tracheostomy inner cannulae. Hydrogen peroxide and boiled rinse water for tracheal suction catheters in the home eliminated over 90\% of bacterial growth in the catheters\textsuperscript{144}. Hypochlorite solutions and other oxidizing agents, such as hydrogen peroxide, are unsuitable for disinfection of tracheostomy cannulae, as it can be destructive for the material, especially the silver cannulae\textsuperscript{99,116}. They also have only limited antimicrobial activity\textsuperscript{145}. Attempts to prevent biofilm formation by binding of chlorhexidine to the tube have been successful in vitro, but the practical use of this remains to be examined\textsuperscript{146}. The current instructions for cleaning the inner cannulae are in accordance with Swedish national guidelines. These decontamination instructions are both time consuming and expensive and when detergent and water is sufficient to make the inner cannula safe to use, the savings would be large, both in time and money. A reduction in the use of disinfectants will also lower the ecological pressure on environmental microorganisms and the risk of unwanted chemical exposure to patients and staff\textsuperscript{147}.

### 5.3.3 Material Wear – Paper (III,IV)

In Paper (III) it was established that Si tubes were used for longer periods, and that PVC tracheostomy tubes are more frequently used than the Si and especially the PU tubes. The reason for this may be economical, as the price of a PU tube, i.e. Tracoe Twist\textsuperscript{®}, is three times that of a PVC tube, i.e. Shiley\textsuperscript{®}. The length of use of a specific brand of tube varies between patients and is correlated to the patient’s diagnosis or treatment. Concerning the surface study of polymeric tracheostomy tube materials, there were evident surface changes detected after only 30 days of exposure in trachea in 95 \% of the studied tubes. But no significant differences were seen between the tube materials. In Paper (IV) all, 100 \%, of the tracheostomy tubes, exposed in the trachea for three or six months, displayed severe surface changes. No significant differences were established between three or six months’ use or between the various materials. The changes had progressed significantly as compared to the changes reported in Paper (III) after 30 days of clinical use. The experimental findings in Paper (IV) confirm the earlier clinical observations in Paper (III). Both the Si and PVC tubes exhibited the existence of new functional groups in the ATR-FTIR spectra, originating from oxidation and/or hydrolysis products, which open up for biofilm formation and thus material degradation.
The Si tubes in Paper (III) could, before analyses, have been cleared for another 30 days’ use, as no visual colour changes were seen. The SEM analyses, as well as the FTIR analyses revealed, however, that the SuperSlick\textsuperscript{®} XL-PCN\textsuperscript{TM} coating was partly or completely worn off on the majority of the tubes, exposing the under laying surface (Si) to the biological environment of trachea. It is difficult to anticipate the consequences this may have for the patients, except that the function of the coating has been lost. Prolonged clinical use could, therefore, be questioned for the tubes scored with the highest degradation index. In Paper (IV), the SEM analyses of the long-term exposed Si tubes revealed presence of cracks and pits, as well as material flaking on all tubes. Microscopic deposits and bacteria colonies were also found on the surface or within cracks and/or pits in the surface. Prior to analyses, the vast majority of the Si tubes had macroscopic colour changes. The ATR-FTIR analyses in Paper (III) and (IV) revealed that the chemical compositions of the coating most likely are of a silicone-based material with hydrophobic acryl substituents. Such surface modifications are often used in biomedical applications, giving an increase in the hydrophobicity and a reduction in the possibility of particle absorption. The hydrophobic nature of Si prevents, in general, the formation of biofilm on the surface. The surface can, however, be less hydrophobic or temporarily hydrophilic, when exposed in different environments or as a result of chemical and/or physical aging, opening up for biofilm formation.

The results from the SEM and ATR-FTIR analyses for the PVC tubes in Paper (III) and (IV) clearly indicate the presence of material degradation. As PVC in itself is a stiff and inflexible material, the use of additives results in a very flexible product, well suited for the design of tracheostomy tubes. During clinical use, the additives subsequently start to migrate from the material and could also serve as nutrients for the attached bacteria\textsuperscript{102,148}. When the additives migrate from the material a more hydrophilic surface is obtained, which gradually results in an increased brittleness, rendering the polymeric material more sensitive to environmental stress\textsuperscript{95,97,149}. The results, obtained from the SEM micrographs, revealed cracks, pores, as well as bacteria colonies. Both the DSC curves and the ATR-FTIR analyses confirm these results of material degradation. The Shiley\textsuperscript{®} PVC tubes contain approximately 30 weight % of DEHP, which is the plasticizer typically added to PVC medical devices. The plasticizer is mixed with the polymer and not chemically bounded. This increases the risk for diffusion and release to the environment during aging of the material. It is commonly known that humans are
regularly exposed to DEHP through medical device, as well as through ingestion, inhalation, and dermal exposure. DEHP is considered to be toxic to humans\textsuperscript{94,150,151} and is associated with a decline in male fertility rate, especially during childhood or foetal exposure\textsuperscript{152,153}. We note that the Shiley\textsuperscript{®} tubes made of PVC still remain the most frequently used tubes in paediatric care today\textsuperscript{154} and are sold as reusable.

In both Paper (III) and (IV) there were gross colour changes, visually observed of the PU tubes prior to analyses, maybe originating from metabolites of the microorganisms in the biofilm covering the tube. The cracking or networks of cracks revealed by the SEM micrographs are ESC\textsuperscript{149,155}. In Paper (III), 60 % of the PU tubes and in Paper (IV) 100 % were scored with the highest degradation index. Prolonged clinical use could thus not be recommended after three months’ use. As PU consists of urethane groups, composed of both hard and soft segments in their main chain, the biodegradation of this material is often referred to as an oxidation of the soft segments of the polymer and a hydrolysis of the bond between the hard and soft segments\textsuperscript{149,156}. Due to the material composition of PU, no large alterations of the material surface could be identified by ATR-FTIR analysis. The colour changes prior to analysis were most visible on the PU tubes in comparison with the other materials.

Furthermore, it was shown in Paper (IV) that all patients were satisfied with their tracheostomy and demonstrated a numerically mean mental health status above that of the general population but were physically limited, which are in line with the results of previously conducted studies, where patients reported good psychological functioning and mental well-being\textsuperscript{18,157-159}. Patients with chronic respiratory failure due to restrictive lung diseases have also earlier proven to have good mental health, despite severe physical handicaps\textsuperscript{160}. We speculate on that the high scores for well-being in our patient group were in large part due to access to a customized tracheostomy tube and regular check up visits\textsuperscript{16}. 
5.4 CLINICAL ASPECTS

Many patients with long-term tracheostomy live at home or are nursed in home care. If they are at hospital, they are often nursed in general wards. The need for education of tracheostomy care is evident both among patients and staff and there is still a lack of evidence based guidelines concerning the care of the tracheostomized patient\(^{28,47,55,68}\). It is about time that patients with tracheostomy receive competent, evidence-based care\(^{51,50,53,58,66,161,162-165}\). As the number of patients with HMV increases in society\(^{166}\), the need for learning to manage them increases as well\(^{167}\). A high quality of care is essential for the well-being and outcome of those patients\(^{168}\). There is evidence that it is cost effective to offer dedicated units for patients with long-term ventilation\(^{169}\).

Prolonged mechanical ventilation does not necessarily have a negative impact on the patient’s QoL, but is rather connected to the underlying illness\(^{160,170}\). The survival of patients with HMV was determined for a 10-year period and patients with the poorest survival were those suffering from ALS (5 % alive after five years)\(^{171}\). Patients with kyphoscoliosis, treated with HMV, have proven to have a better outcome than those treated with long-term oxygen therapy, regardless of age or gender\(^{172}\). Yet a large clinical investigation of patients, undergoing tracheostomy and mechanical ventilation showed that care of older patients is associated with poorer outcome and higher costs\(^{173}\). These results are not in line with our findings in Paper (I), where the patients live at home and are seen on an out-patient basis. This is associated with rather low costs and also with a good outcome. With the results from the studies, conducted at NRC, we believe that fitting the tube properly increases the patient’s QoL, at least mentally, and minimizes the complication rate\(^{12,16,18}\). It also makes tube changes easier which has otherwise been reported to be problematic for the patient\(^{174}\).

In Paper (II) we have shown, with a randomized controlled cross-over study that a simple, low cost cleaning method for tracheostomy inner cannulae can provide sufficient decontamination from bacteria. The estimated savings by avoiding disinfectant is about 6,500 USD per year for NRC. The cost for the patient is variable and depending on how often they clean the inner cannula. The estimated yearly saving, by avoiding disinfection with chlorhexidine alcohol, is 630 USD per patient. For our 225 outpatients the total cost saving is estimated to 142,500 USD. A reduction in the use of disinfectants will also lower the ecological pressure on environmental microorganisms and the risk of unwanted chemical exposure to patients and staff\(^{47}\).
Concerning material wear of tracheostomy tubes, formation of biofilm on polymeric surfaces has been recognized as a source of infection by playing an important role in the pathogenicity of the infecting organism. The biofilm has also been found to affect the material in both catheters for peritoneal dialysis and endotracheal tubes. There are several studies concerning different coating of polymeric materials, used in medical devices, in order to minimize the formation of biofilm. All the surface changes, detected in our studies, are believed to be the net result of biofilm formation and material degradation. The release of low molecular weight compounds from the polymer, in this case to the patient, eventually leads to instability of the tube material. The large cracks and pores even proved to host colonies of bacteria. Conveniently, this could explain, why a correlation exists between the frequency of pneumonia and the reuse of tracheostomy tubes, as established by Bahng et al. Maybe a daily cleaning of the tracheostomy tube could minimize or prevent biofilm formation and thereby slow down the process of material degradation. We have clinically, in NRC, seen fewer infections among patients, who clean their tracheostomy tubes daily. The biofilm formation may be the base for gross degradation and loss of structural integrity of the tracheostomy tube material, eventually increasing the risk of infections and fracturing of the tube itself. There are several reports of polymeric fractured tracheostomy tubes, some with fatal outcome, in the literature. As a consequence, the safety of the patient is put at risk. In paper (IV) we showed why prolonged clinical use of polymeric tracheostomy tubes beyond a three month period ought not be recommended. As all patients attending NRC, including children and patients with cognitive dysfunction, are treated with the same routines, the results from this thesis ought to be applicable to them.

With the present results, further insights on the long-term effects on prolonged clinical use of polymeric material have been gathered. More detailed clinical consequences of the identified surface changes remain, however, to be determined, i.e. measuring degradation products in the clinical setting and the effects this may have for the patients. This thesis opens for further studies concerning development of new tube materials in a unique setting. An ideal tube material should be stable to degradation, possess properties that slow down biofilm formation, and should be harmless to humans.
6 CONCLUSIONS

We have demonstrated that patients with long-term tracheostomy have little and unchanged need for hospital care after the tracheostomy and may live as long as an age- and gender matched control cohort (I).

Cleaning the tracheostomy inner cannula with detergent is sufficient to achieve decontamination and disinfection with chlorhexidine-alcohol afterwards offers no further benefit to the patient (II). Avoiding disinfection of the inner cannula with chlorhexidine-alcohol saves both time and money (II).

It was established that Si tracheostomy tubes were used longer compared with those made of PVC or PU. It was also shown that all tube materials investigated revealed evident surface changes after 30 days of exposure in the trachea (III).

Long-term studies (three and six months’ exposure in trachea) of material wear of polymeric tracheostomy tubes revealed significantly worse material degradation, compared to 30 days’ exposure (IV). Clinical use beyond three months cannot be recommended for any of the tube materials investigated. All patients were in general content with their tracheostomy tube and treatment and exhibited a numerically mean mental health score above a normative Swedish population.

In summary, the findings from the present thesis contribute to make the care of long-term tracheostomised patients evidence based.
7 POPULÄRVETENSKAPLIG SAMMANFATTNING


Trakeostomi är en öppning på halsen till luftstrupen, som gjorts för att ge fri luftväg. I öppningen sitter en trakealkanyl tillverkad i plast eller silver. Anledningen till långvarig trakeostomi kan t ex vara övre luftvägshinder, missbildning, eller kroniskt dålig andning där annan typ av andningshjälp inte fungerat. Forskningen är gjord på Nationellt respirationscentrum (NRC) i Stockholm, en mottagning som funnits sedan 80-talet, för att hjälpa människor med just långvarig trakeostomi med bl a individanpassning av kanylen.

Sjukvårdsbehovet hos patienter med långvarig trakeostomi under en tvåårsperiod före respektive efter att trakeostomin genomförts, utvärderades och resultatet visade att behovet av sjukhusvård inte ökade. Vid jämförelse av livslängden hos en del av dessa patienter med den förväntade livslängden hos normalbefolkningen, visade det sig att livslängden för dessa patienter var anmärkningsvärt hög och inte kortare än för människor i allmänhet.

För att hitta en praktisk och säker rengöringsmetod för trakealinnerkanyler jämfördes effekten av två olika rengöringsmetoder; enbart diskmedel och varmt vatten eller samma metod men med efterföljande desinfektion i klorhexidinsprit. Bakterieprov som togs före och efter rengöring visade att båda metoderna var mycket effektiva och kan betraktas som likvärdiga.

En utvärdering av användningstiden för trakealkanyler i plast genomfördes och visade att silikonkanyler användes i tre månader i snitt, men kanyler av polyvinylklorid (PVC) och polyuretan bara i två månader. I samarbete med Tekniska Högskolan och Sophiahemmet Högskola gjordes studier för att undersöka om materialet i kanylerna hade förändrats efter 30 dagars, tre månaders respektive sex månaders användning. Tekniska analyser med bl a electronmikroskop avslöjade stora förändringar i materialytan med beläggningar av bakterier. Dessutom ökade slitage signifikant över tid. Studiedeltagarna fick även skatta sin hälsorelaterade livskvalitet samt besvara en enkät om sin erfarenhet av långvarig trakeostomi. Alla patienter var nöjda med sin trakeostomi och skattade sin mentala hälsa högt.

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9 REFERENCES


25. MacIntyre NR, Cook DJ, Ely EW, Jr., et al. Evidence-based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of Chest Physicians; the American Association for Respiratory Care; and the American College of Critical Care Medicine. Chest 2001;120(6 Suppl):375S-95S.


55. Dhand R, Johnson JC. Care of the chronic tracheostomy. Respir Care 2006;51(9):984-1001; discussion 1002-4.


