B. Gottschlich

Extubation failure

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Summary

Extubation is regularly a smooth procedure. An extubation failure (or "difficult extubation") should be expected in patients with anatomical variations of or close to their airways, in patients with prolonged mechanical ventilation (such as in case of ARDS), or in patients with preexisting pulmonary diseases or respiratory insufficiency. Whenever an expected extubation failure occurs, a special algorithm should be available. On the other hand, potential life-threatening situations like a post-extubation stridor due to a laryngeal oedema or negative-pressure pulmonary oedema can occur unexpectedly as well. Defined extubation criteria and the cuff-leak-test are helpful to predict successful extubation. In the event of an expected extubation failure, the use of an airway exchange catheter should be considered. For patients with prolonged mechanical ventilation, a weaning protocol will be useful.

Keywords
Extubation Failure – Extubation Criteria – Cuff-Leak Test – Laryngeal Oedema – Post-Extubation Stridor – Negative Pressure Pulmonary Oedema

Introduction

Only few papers, guidelines or recommendations dealing with the subject of extubation can be found in the literature. This is all the more surprising as approximately one-third of all serious incidences during airway management using an endotracheal tube occur in the emergence phase and thus in connection with extubation [1].

Extubation failure, i.e. „difficult extubation", is an underestimated problem which demands just as much attention as a difficult intubation in „difficult airway" cases.

The problem usually encountered is not the actual extubation process, but the subsequent **extubation failure with respiratory insufficiency**. The prophylaxis of complications and the patients' safety primarily depend on the predictability of the phenomenon and on the availability of a structured procedure.

Risk factors and risk assessment

If a patient has to undergo endotracheal intubation and mechanical ventilation in the scope of a surgical intervention, an emergency or ICU treatment, extubation should proceed as soon as possible once the acute situation has been brought under control.

Normally, extubation proceeds without any problems and is therefore regarded as a routine procedure – this is legitimate because the great majority of patients can be extubated without complications. However, certain operative constellations and pre-existing diseases are associated with an expectably difficult extubation.

Main pathogenic factors are altered anatomical airway structures, a respiratory musculature weakness, or a permanent pulmonary insufficiency [2,3,4]. The occurrence of a potential **extubation failure** must therefore be expected in the following groups of patients (Tab. 1):

- Patients with a difficult respiratory tract during intubation, for example, craniofacial anomalies or adiposity per magna (Fig. 1),
- Patients with surgical interventions in or close to the respiratory tract (Fig. 2),
- Patients after prolonged artificial respiration, e.g. in cases of an acute respiratory distress syndrome (ARDS); acute lung failure),
- Patients with pre-existing lung diseases or respiratory insufficiency, e.g. obstructive sleep apnoea syndrome (OSAS), chronic obstructive pulmonary disease; COPD) or Parkinson's disease.

Apart from the expectable extubation failure, it occasionally happens that an unexpected extubation failure occurs despite otherwise inconspicuous patients not belonging to any risk groups.

Reasons for primarily unexpected airway problems after extubation are haemorrhages, secretions, oedemas, a laryngospasm and/or bronchospasm, a negative pressure pulmonary oedema, or technical defects, but a pneumothorax or tracheal or oesophageal perforations are also imaginable [5].

An extubation failure might result in a higher morbidity and mortality rate, prolonged ventilation and prolonged stay at the ICU and thus, ultimately, higher treatment costs as well [6,7].

The literature reports quite inconsistent **prevalence rates** [8,9,10,11] for an extubation failure – depending on the patient population values range from 0.1% in the operating theatre to 25% in case of ICU patients who underwent prolonged mechanical ventilation. Major randomized studies focusing on this subject are currently unavailable, however, it is obvious that the maximum time point for reintubation after an extubation failure – either immediately after surgery or at the ICU – lies within the first two hours [10].

In January 2012, the Difficult Airway Society (DAS) furnished an extubation guideline based on expert opinion [12].

The algorithm comprises four steps **(plan – prepare – perform – post-extubation care)**, whereby the procedures for patients with and without risk factors vary. A German version of the procedures applicable to a planned extubation has been published in the S1 Guideline **Airway Management** [5] (Fig. 3).

Tab. 1

Frequent circumstances associated with an expectable or unexpected extubation failure.

Expectable extubation failure	Unexpected extubation failure
• Difficult intubation • Intervention into or near the airway • Prolonged respiration • Preexisting pulmonary disease or respiratory insufficiency	• Obstruction of the respiratory tract by blood or secretions, etc. • Laryngeal or other oedemas • Laryngospasm and/or bronchospasm • Negative-pressure pulmonary oedema • Technical defects

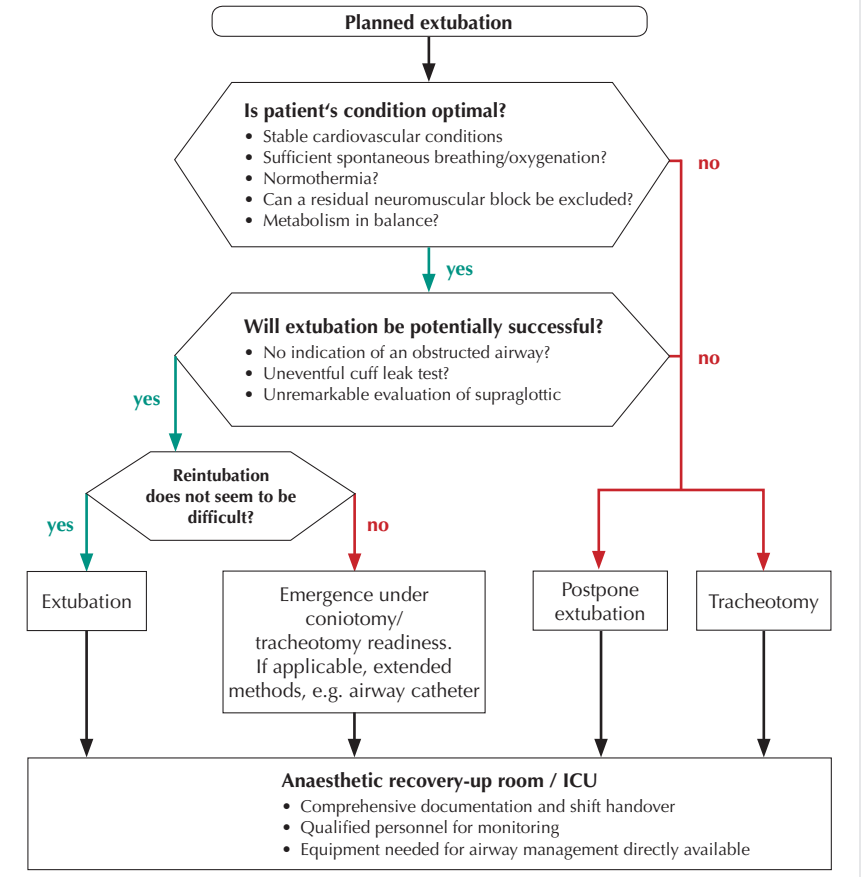
Fig. 1

Difficult airway management in a patient with adiposity per magna.

Fig. 2

Difficult airway management in a patient with marginal mandibulectomy, flap plasty, and functional neck dissection on the first postoperative day.

Fig. 3



Procedure in case of planned extubation. Derived from [5].

Tab. 2

Classical predictors for successful extubation. After [14].

Parameter	Aspired value
Tidal air	>5 ml/kg b.w.
Vital capacity	>10-15 ml/kg b.w.
Respiratory frequency	<35/min
Respiratory minute volume	<10 l/min
paO_2 (if FiO_2 <0.4)	>60 mm Hg
$paCO_2$ rise under spontaneous respiration	<8 mm Hg
pH value	7.30-7.50
paO_2/FiO_2	>200
Airway occlusion pressure	<7 cm mbar

FiO_2 = inspiratory oxygen fraction;
b.w. = body weight;
$paCO_2$ = arterial carbon dioxide tension;
paO_2 = arterial oxygen tension.

Practical procedure

General extubation criteria

General preconditions for extubation are:

- near-stability of the cardiovascular system,
- almost normothermia,
- fully intact and/or recovered protective reflexes,
- sufficient spontaneous respiration and oxygenation.

If an acute disease or an accident have caused the intubation, these causes should be eliminated and/or sufficiently treated. The patient should be ventilated with 100 percent oxygen prior to extubation, the oral and pharyngeal cavity suctioned, and the tube removed without delay after unblocking. The patient is not supposed to be in an excitation stage, but able to calmly tolerate the actions [13].

Sufficient spontaneous respiration is assessed on the basis of the physiological parameters shown in Tab. 2 [14].

Apart from gas-exchange parameters and an assessment of the respiratory mechanics based on respiratory frequency and tidal air volume, further methods have been developed in recent years to assess successful extubation potential and/or extubation failure after extubation.

- The **rapid shallow breathing index (RSBI)** examines the relation of respiratory frequency (RF) and tidal air (TA) during the first minute of spontaneous breathing while receiving ventilator support (RSBI=RF [1/min]/TA [l]). A value of <105 speaks in favour of a successful extubation process, a value of >105 against it [15].
- The **airway occlusion pressure P.01** is the negative pressure (reported in [mbar]), which is generated against the closed system of the respirator within the first 100 ms. A low value is supposed to indicated a favourable weaning situation, whereby the trend is more important than the absolute numerical value. A measurement option for this parameter is integrated in some ICU ventilators. While Fernandez et al. filed to discover an unequivocal advantage of a P.01 measurement in a study conducted with 130 ventilation patients suffering from various basic diseases [16], Hilbert et al. [17] concluded that P.01 measurements were useful in the weaning of COPD-patients.

There are no unequivocally objective criteria capable of predicting a successful extubation. The decisive factor is the clinical assessment of the respective patient by an experienced physician – supported by classic extubation criteria and new methods in the individual case.

Procedure in case of extubation failure

Basics

An extubation failure must be increasingly anticipated after previous difficult intubation – for this reason preparations for a rapid new airway management must be made.

- Next to the usual instrumentation (ventilation bag with mask, laryngoscope, and endotracheal tubes, etc.) the equipment needed for an alternative airway management must also be at hand. It has proven useful to collect the necessary equipment on a special **mobile respiratory cart** (Fig. 4), so that it must not be searched for in a case of an emergency. This module contains the entire material needed for the alternative management of the patient's airway; among which are, for example, a fibre bronchoscope with light source, a self-sufficient second suction apparatus, laryngeal tubes, laryngeal masks, a simple coniotomy set, guiding rods, hollow airway exchange catheters, endoscopy masks and, if available, special laryngoscopes.
- A pertinent emergency training and the provision of a stand-by algorithm (perhaps clinic-specific) will prove valuable.

Application of an airway exchange catheter

In case of an expectable extubation failure a reversible or guided extubation using an airway exchange catheter (AEC) must always be taken into consideration [18,19].

- The airway exchange catheter (Fig. 5) is inserted through the indwelling tube, the tube is then removed and the catheter is left **in situ** until the patient has regained a stable condition.
- Patients normally tolerate an orally inserted airway exchange catheter well.

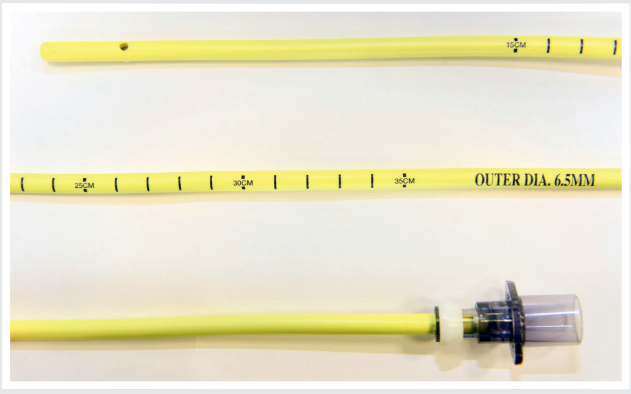
Fig. 4

Mobile respiratory cart carrying the complete equipment needed for alternative airway management.

- Reintubation can proceed via the indwelling catheter in case of respiratory insufficiency of the patient.
- Preference is to be given to hollow catheters which allow for an oxygen supply [20].

However, specific risks are also associated with the use of the airway exchange catheter [21], for which reason the indication for its application must weighed critically and its application with caution. The patient's trachea might become injured when the catheter is pushed forward, and the perhaps necessary reintubation via the catheter might then fail because of a massive swelling in the upper airways. McLean et al. [22] were unable to use the indwelling airway exchange catheter successfully in the reintubation of 73 patients (13.9 %), saw injuries of the airways in 41 (7.8 %) and a pneumothorax in 8 (1.5 %) out of the 527 patients who had been treated with such catheter.

Fig. 5



Airway exchange catheter (AEC) with lumen for the application of oxygen.

Photography: T. Figiel and K. Suchodolski, Hannover Medical School (MHH).

The cuff leak test

The cuff leak test is used to evaluate the extent of airway obstruction if a laryngeal oedema – occurring in association with a potential post-extubation stridor – is suspected.

The qualitative **cuff leak test** dates back to a publication by Potgieter and Hammond from 1988 – the procedure is easy [23]:

- The cuff is unblocked and the tube closed with the thumb.
- If air audibly emerges from the side of the tube during expiration, this will be considered as a positive criterion for extubation.

We apply this test to all patients with potentially difficult airways (e.g. after extensive oral, mandibular, maxillofacial or cervical surgery) in our own ICU work area, or when there is a risk of an oedematous swelling of the cervical soft tissues with laryngeal oedema etc. Conditional is a rather cooperative patient and a sufficient number of qualified nursing staff, for which reason the test is usually carried out during the early shift. The consistent performance of the test is coupled with a steep learning curve for both the medical and the nursing staff.

In addition, a **quantitative cuff leak test** can be carried out by measuring the cuff leak volume of the first six breaths with an unblocked tube as the difference between inspiratory and expiratory tidal volume. If the cuff leak air volume is greater than 110 ml, the risk of a clinically significant laryngeal oedema is considered to be low, whereas no general conclusion can be drawn if the volume is less than 110 ml [24,25,26]. In addition to this procedure, a number of test variations have been described which, however, are all distinguished by a low sensitivity, a low positive predictive value and a considerable interindividual variability.

In summary, vigilance for the problem and an algorithm for therapy of the post-extubation stridor are more important than the performance of a perhaps unreliable test [27,28].

Furthermore, it must not be forgotten that weaning or a weaning protocol – with structured procedures – is considered to be standard procedure in patients after long-term mechanical ventilation [29]. The internal circumstances prevailing at the ward and the individual condition of the patient must also be observed.

Procedure in case of an unexpected extubation failure

General considerations

In case of an unexpected extubation failure **technical reasons** – e.g. an endotracheal tube that cannot be unblocked or an accidentally sewed-on tube – are of rather seldom occurrence. Technical problems can only be solved individually and, if necessary, by surgery. More common are **irritations of the respiratory tract** such as a laryngeal oedema with post-extubation stridor, a laryngospasm and/or bronchospasm, or a negative pressure pulmonary oedema.

The object of all measures is to secure the oxygenation of the patient. Both extubation failure and delayed reintubation increase mortality [7].

Laryngeal oedema and post-extubation stridor

A post-extubation stridor can neither be predicted nor reliably excluded.

A laryngeal oedema with post-extubation stridor is the result of a direct mechanical damage of the mucous membranes caused by the tube. It appears particularly in women of advanced age, after prolonged intubation, and in cases in which the ratio between tube and tracheal diameter are unfavourable [25]. The duration of mechanical ventilation and an increased cuff pressure promote a damage of the mucous membranes as well as concomitant swelling and consecutive stenosis. Pluijms et al. [28] found that strongly varying incidence rates were reported in the literature; for the laryngeal oedema, the post-extubation stridor and the reintubation rate, the ranges amounted to 5.0-54.4%, 1.5-26.3% and 10.0-100%, respectively. A stridor characteristically develops within a period of 30 minutes after extubation, in fifty percent of all patients within the first 5 minutes [30].

Clinically, glucocorticoids and vasoconstrictor agents have proved valuable in the prevention and therapy of the laryngeal oedema and/or the post-extubation stridor, even though the study evidence is not yet unequivocal.

- By a **preventive** administration of methylprednisolone (starting 12 hours prior to the planned extubation with 20 mg IV every 4 hours and an overall dose of 80 mg), François

et al. [30] were able to lower the incidence rate of laryngeal oedemas significantly, from 22 percent to 3 percent, within a population of 698 ICU patients who had been mechanically ventilated for more than 36 hours; the rate of reintubations had also significantly decreased in the treatment group.

- In the **acute therapy of the manifest stridor** the inhalation of adrenalin (epinephrine) is most important because of its rapid efficacy in achieving a local decongestion of the mucous membrane oedema. Adrenalin (InfectoKrupp® Inhal) is administered by an application of 7-14 strokes, each containing 0.56 mg. Alternatively, adrenalin (e.g. 0.1 mg Suprarenin® dissolved in 5 ml 0.9 % NaCl) can be given as an aerosol over a face mask. In addition, glucocorticoids are injected IV; here, a prednisolone equivalent of 0.5 mg/kg body weight (b.w.) or 4-8 mg dexamethasone are recommended [8,28] – but IV doses of 125-250 mg prednisolone (Solu-Decortin® H) are also applied to adults. While the efficacy of the adrenalin inhalation in children has been evidenced [31], the data applying to adults have not been corroborated [8].
- Drug therapy is supported by bringing the patient's upper body in an upright position, moistening the inspired air, and giving comforting motivation. The bedside presence of an experienced nurse or physician is urgently indicated in such situation.
- The application of sedative agents must be weighed very critically as a situation-dependently desired anxiolysis will all too easily pass over into a state of respiratory depression. A sedation should therefore proceed only in cases of exception and be carefully titrated; short-acting benzodiazepines (e.g. midazolam in IV boli of 1mg) and morphine (in IV boli of up to 0.05 mg/kg b.w.) come into question as substances, whereby in case of morphine a relatively large action latency and long duration of action should be observed.

Laryngospasm and/or bronchospasm

A laryngospasm and/or bronchospasm might result with varying rates of incidence from a manipulation of the airways and develop into an acutely life-threatening situation.

A **laryngospasm** is distinguished by an either incomplete or complete closure of the vocal cords [32].

- Of special importance for prevention is choosing the right time for extubation (if possible, still during general anaesthesia, but not in the excitation stage) and a quiet environment without patient manipulations („no-touch method").
- A **laryngospasm** appearing in connection with anaesthetic emergence can often be terminated by deepening the anaesthesia, whereby all available methods of supplying oxygen must be taken advantage of in order to prevent a life-threating hypoxia (especially adequate bagging). In addition, an obstruction of the upper airways is prevented by applying the jaw-thrust manoeuvre („suctioning")
- If these measures fail muscular relaxation and reintubation will be necessary.
- If oxygenation cannot be assured otherwise coniotomy will be the last resort, as in all comparable cases.

A **bronchospasm** is regularly treated by escalation [33]:

- First, β_2 mimetics are applied by inhalation, for example, four strokes each with 100 µg fenoterol (e.g. Berotec® N 100 µg dosing aerosol). In case of insufficient action, 90µg reproterol (Bronchospasmin® solution for injection) are injected very slowly intravenously under ECG control.
- Prednisolone (Solu-Decortin® H) is applied at a maximum dose of 250 mg IV.
- An IV administration of 5mg theophylline/kg b.w. (e.g. Bronchoparat®) – half of this dose in case of permanent medication – has lost significance because of its narrow therapeutic window [34].
- The last resort in case of a life-threatening respiratory insufficiency is the fractioned IV injection of adrenalin (Suprarenin®) in boli of up to 50µg in order to enforce vasoconstriction with decongestion of mucous membranes in addition to bronchodilation.

As ketamine and esketamine possess certain broncholytic properties, their application is indicated and/or should be considered in case of both necessary reintubation and perhaps subsequent analgosedation.

Negative pressure pulmonary oedema

The negative pressure pulmonary oedema (NPPE) is a rare anaesthesiological complication with an incidence rate of 0.05-0.1% [35].

Younger males (at the age of 20 to 30 years) are predominately affected; the most common cause is a laryngospasm occurring during emergence from anaesthesia in about 50 percent of the cases [36]. The characteristic symptoms are summarized in Tab. 3.

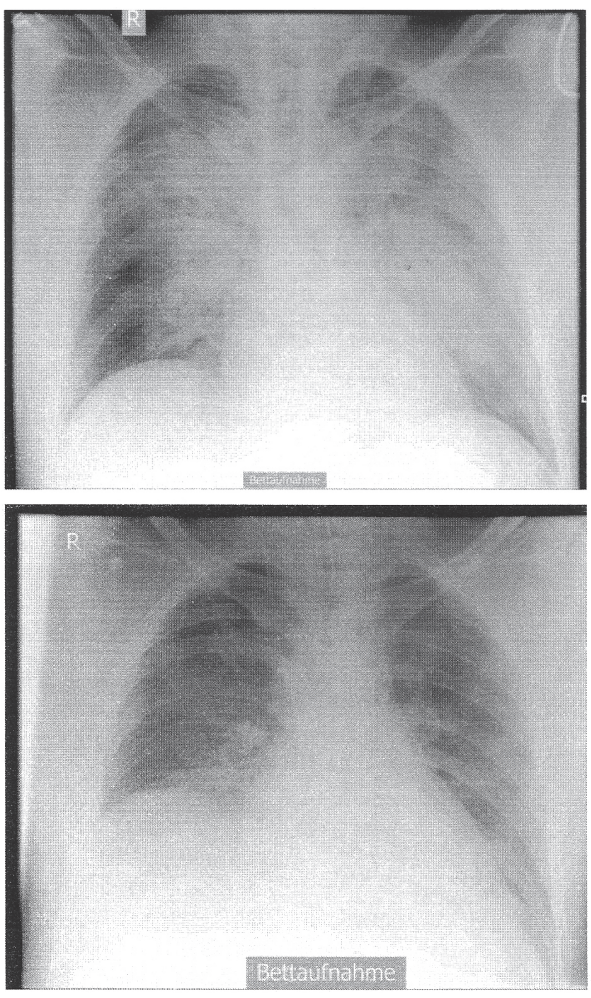
Tab. 3
Criteria for a negative pressure pulmonary oedema. After [36].

Major criteria	Minor criteria
• Reddish-frothy tracheal secretion • (Subjective) dyspnoea • Stridor • Paradoxical respiration • Radiologically manifest unilateral or bilateral pulmonary oedema not of cardiological aetiology	• Acute or delayed onset • SpO_2 <90% • Oxygen supply via mask >6 l/min. • Rale

SpO_2 = arterial oxygen saturation determined by pulse oximetry.

Clinically, a limited oxygenation is the cardinal symptom emerging despite a previously unremarkable gas exchange, in addition to an ubiquitous rale determinable by auscultation. A reddish-frothy secretion will most often be suctioned. X-ray imaging reveals pronounced alterations which in most cases are regressive within a period of 24 hours (Fig. 6). Indicated therapies are, first of

Fig. 6



Native x-ray image of the chest organs a.p. showing negative pressure pulmonary oedema after reintubation and after 24 hours.

all, non-invasive ventilation with PEEP (positive end-expiratory pressure) and an IV administration of furosemide (e.g. Lasix® 20-40mg IV); however, patients often need to be reintubated in order to secure their oxygenation [36,37].

Extubation after previous extubation failure

If a patient has to go undergo reintubation after an extubation failure, greatest care and preparation of the adequate human and material resources will be required.

- A point in time must be chosen which allows for the presence of a sufficient number of qualified personnel at the patient's bedside – including an experienced physician and experienced nurse.
- Preparations must be made for non-invasive ventilation (NIV) and/or reintubation.
- Extubation may also proceed in the individual case under light sedation and/or analgosedation – e.g. with 0.5 mg/kg b.w./h propofol or 0.3-0.5 mg/kg b.w./h esketamine – in order to decrease the immanent extubation stress.
- Manipulations of the airways should be avoided before and after extubation, therefore no endotracheal suctioning should proceed immediately before extubation, and afterwards only if a clear indication exists.

Conclusions

Extubation is usually an uncomplicated process which, due to its potential risks, should be given the same attention as intubation. An extubation failure, which can be expected on account of certain indicators, is easier to encounter by means of a structured procedure than an unexpected extubation failure, which might rapidly merge into a condition of life-threating hypoxia. For this reason, unequivocal and clinic-specific organizational provisions are as indispensable as the availability of experienced personnel and adequate material preparations.

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Correspondence address

Dr. med.
Birgit Gottschlich

Klinik für Anästhesiologie
und Intensivmedizin
HELIOS Klinikum Pirna
Struppener Str. 13
01796 Pirna, Germany

Phone: 0049 3501 7118-5106
Fax: 0049 3501 7118-5102

Mail:
birgit.gottschlich@helios-kliniken.de