A NEW DEVICE FOR CRICOTHYROIDOTOMY (AIRFREE®): MEASUREMENTS OF FLOW AND AIRWAY RESISTANCE

A. Schiri pour Tscharlou[1], J. Klappenberger[1], S. Klappenberger[2]
W. Firbas[1] and H. Gilly[3]

[1]Center for Anatomy and Cell Biology, Department of Anatomy, Medical University of Vienna, A-1090 Vienna, Austria
[2]Department of Surgery and Policlinic – Inner City, LMU, D-80336 Munich, Germany
[3]L. Boltzmann Institut for Anaesthesiology and Intensive Care Medicine and Department of Anaesthesiology & Intensive Care (B), Medical University of Vienna, A-1090 Vienna, Austria

asghar.schiripourtscharlou@meduniwien.ac.at

Abstract: Percutaneous cricothyroidotomy can be a lifesaving procedure for airway obstruction in case if it cannot be relieved by endotracheal intubation. A new simple instrument (Airfree®) consisting of two parts, a plastic cannula with a standard connector for ventilation and a precision molded retractable cylinder, provides easy and quick access with a higher success rate than the Quicktrach® when used in human cadavers.
According to our present results the pressure drop across the Airfree® (ca. 3 mbar) and that of the Quicktrach® (ca. 4 mbar) are similar in the low flow range (20 L·min^{-1}). In the higher flow range (> 30 L·min^{-1}) the resistance of the Airfree® is up to 25% less than that of the Quicktrach® (15 mbar versus 20 mbar at 50 L·min^{-1}). Due to its short length the Airfree® device demonstrates this lower flow resistance.
A coniotomy performed by using the Airfree® should guarantee a "free" airway without critical damage to the larynx and quickly restore respiration.

Introduction

In extraordinary cases («cannot intubate, cannot ventilate››) when tracheal intubation is impossible, emergency surgical access to the trachea represents the only alternative choice [1]. Cricothyroidotomy (coniotomy) has long been described as an emergency intervention which can be performed even by inexperienced medical personnel [2]. However, sometimes the psychological barrier cannot be overcome. In the context of emergency access in a patient at risk from impending or actual upper airway obstruction, important issues such as performance anxiety over time pressure, situational uncertainty and the potential for a "high impact outcome" (the patient might die within minutes unless the airway is promptly cleared) play a crucial role. Under such circumstances success rates are lower and complications higher [3].

Several instruments for emergency cricothyroidotomy are commercially available, for example Nu-Trake® [4], the Portex Cricothyroidotomy Kit [5] and the Quicktrach® [6]. Major disadvantages are their complex design and the necessity of ongoing instructional exercises. The popular Quicktrach® consists of several parts: a plastic cannula (overall length 63 mm with an inner diameter (iØ) widening from 4 to 6 mm) including a 15 mm connector; a needle with an added conical syringe and stopper [6]. It is no wonder that the instructions for use are rather complicated.

Recently a new simple instrument (Airfree®) became available which was successfully tested in human cadavers [7]. The aim of the present investigation was to obtain data on the static and dynamic resistance of the Airfree® within the clinical range of inspiratory and expiratory flows, and to compare its characteristics with that of the popular Quicktrach® cricothyroidotomy device.

Materials and Methods

The Airfree® cricothyroidotomy instrument consists of two parts as shown in figure 1: a plastic cannula (iØ 4.6 ± 0.05 mm) with a standard conical 15 mm connector (overall length 38 mm) for ventilation

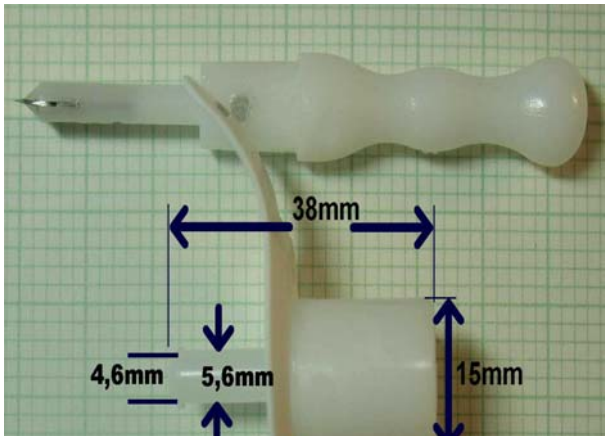

Figure 1: The Airfree® coniotomy set with its geometrical dimensions outlined. Background: 2 mm grid. The coniotomy set consists of two parts: the introducer (trocar) and the cannula (tube).

(e.g. by a self-inflating bag) and a molded retractable

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cylindrical trocar. The retractable trocar (Ø 4.3 ± 0.05 mm) is made from solid plastic with a sharp pointed blade (Ø 4 mm) on its tip. Because of the short length of the plastic cannula (16 mm) and that of the sharp blade (3 mm), laceration of the posterior wall of the larynx is most unlikely and has not yet been observed [7]. The instrument is fastened to the neck of the patient by a fixation plate. The instrument´s dimensions are given in figure 1.

The Airfree® must be inserted in a strict horizontal direction and its placement is rather simple. Figure 2 shows the instrument in situ.

In order to obtain data on the static and dynamic resistance of the Airfree®, the pressure drop across the plastic cannula was measured (flow range 4 to 60 L·min^{-1}). Flow was measured by an ultrasonic flowmeter (Spiroson Scientific; Isler Bioengineering, Switzerland), and pressure drop (difference between pressure signals) was measured using two pressure sensors (24PC, Honeywell, USA) located at the proximal and the distal site of the Airfree®. For calibration of the ultrasonic flowmeter a calibrated syringe was used (1 and 3 L volume calibration syringe; Rudolph Inc., Kansas City, MO, USA). The pressure sensors were calibrated in reference to a Keller digital manometer (Keller ManoGauge, 0-30mbar; Keller, Switzerland). Continuous airflow was provided by mass flow controllers (MKS 1259 C-50000SV, MKS Instruments, Munich, GER) connected to the hospital gas supply. Inspiratory and expiratory flow were generated either using an Ohmeda Modulus CD

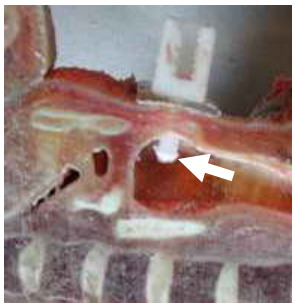

Figure 2: Airfree® in situ in a male cadaver. The position of the cannula inside the larynx is shown on a plastinated specimen. A small 0.5 mm lip on the outer end of the cannula (arrow) prevents its sliding out of the larynx.

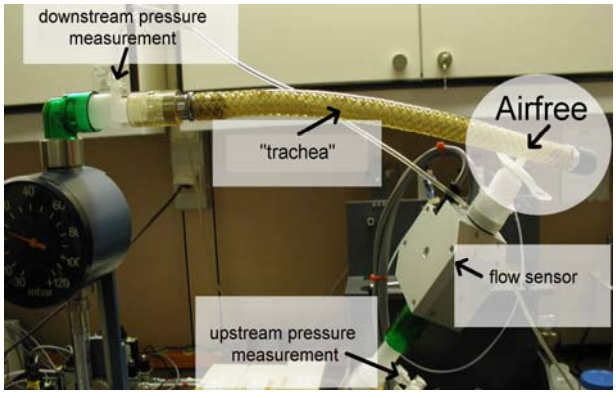

Figure 3: Experimental setup. Pressure indicator, "trachea", flowmeter and pressure connectors for measurement of the pressure drop are shown.

0.5 L). The coniotomy devices were connected to a lung model LS800 (Draeger, Lübeck, GER): compliance was set to 0.1 and 0.05 L·mbar$^{-1,}$ with lung resistance set to 2 mbar·sec·L^{-1}.

Data were collected with a datalogger program (P. Hamm, Dept. of Anaesthesia; Medical Univ. Innsbruck) and an 8 channel 16-bit analog-digital PCMCIA data acquisition system (DAQCard-AI-16XE-50; National Instruments, USA), and processed using FAMOS software and MS-EXCEL® spreadsheets.

Measurements were repeated three times with two different Airfree® devices and with one Quicktrach®.

Figure 3 shows the measurement set up with the Airfree®.

Results

Figure 4 shows the flow resistance of the Quicktrach® and the Airfree® for continuous flow, and figure 5 depicts its characteristics during pressure controlled ventilation of the test lung with a high tidal volume.

Figure 6 depicts the typical time course of the pressure

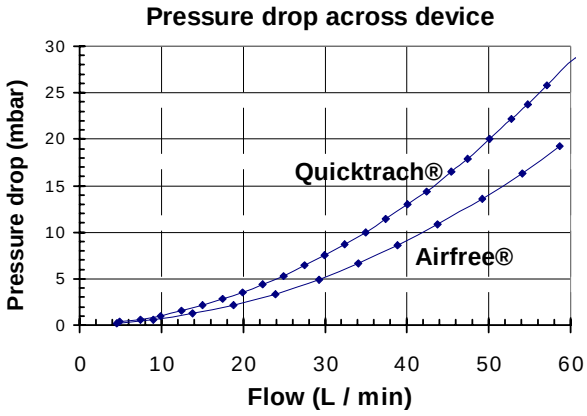

Figure 4: Comparison of the pressure drop across the two cricothyroidotomy sets versus continuous flow (static resistance). Due to its short length the pressure drop across the Airfree® is smaller.

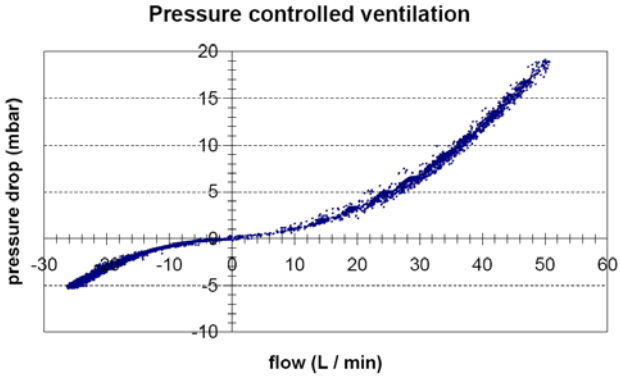

Figure 5: Pressure drop across the Airfree® (dynamic resistance) during pressure controlled ventilation. Compliance of test lung: 0.1L·mbar^{-1}; ventilation rate 12 min^{-1}, I:E=1:1; tidal volume: 1 L.

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drop and the flow during manual ventilation of the test lung, while figure 7 shows the same parameters during spontaneous breathing through the Airfree® device.

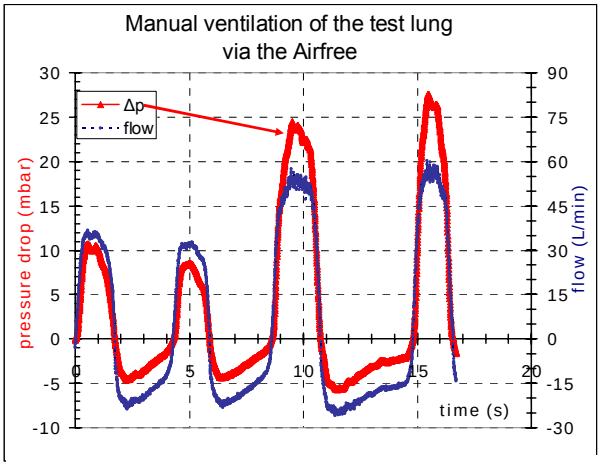

Figure 6: Time pattern of pressure drop and flow when manually ventilating the test lung via the Airfree® (Compliance: 0.1 L·mbar^{-1}; Resistance 2 mbar·s·L^{-1}).

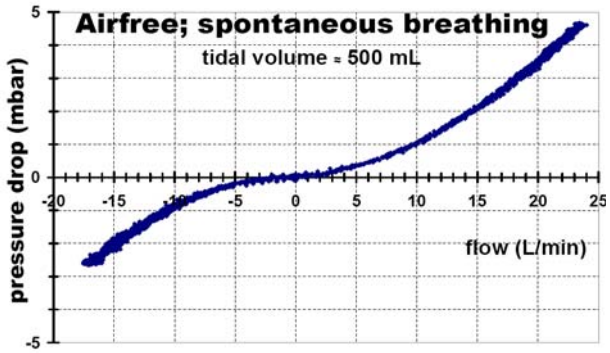

Figure 7: Spontaneous breathing through the Airfree® demonstrating a low pressure drop at a tidal volume of about 500 ml (inspiratory time: ca. 1.6 s).

Discussion

Intubating a patient with ventilation problems remains the first choice, but in rare cases when tracheal intubation is impossible, the coniotomy can be a life saving procedure. Therefore, the instrument for coniotomy has to be simple, safe and easy to use. At the same time any emergency kit enabling access to the trachea should cause minimal surgical trauma, and allow for either spontaneous respiration or smooth pressure supported ventilation, preferably with a minimal flow resistance.

The most remarkable result of the present study is the low flow resistance of the Airfree®. In correspondence with its short tube length the Airfree® device demonstrates a lower flow resistance in comparison to the Quicktrach® which shows a pressure build up of approx. 20 mbar at 50 L·min^{-1} continuous flow (fig. 4). With artificial ventilation a pressure drop of about 18-20 mbar across the Airfree® is to be expected at high tidal volumes with flow rates exceeding 50L·min^{-1} (fig. 5 and 6). However, at lower flow rates (<=25 L·min^{-1}) airway resistance decreases to a level sufficiently low even for spontaneous breathing. This may be derived from the experiments with low tidal volumes (see fig. 7) with a less than 5 mbar pressure drop across the Airfree®. Therefore, we assume that this low pressure drop may allow a victim to breath spontaneously without rapid exhaustion. However, any obstruction of the cannula, e.g. by mucous saliva or eventual blood clotting etc., must be strictly avoided.

The pressure drop we measured with the Quicktrach® is somewhat higher than has been reported previously [6]. This result can be explained by the fact that the data reported by Frei et al. [6] were measured in a Quicktrach® device with a 5 mm iØ. The present Quicktrach® design is characterized by an overall length of 63 mm of the cannula with 4 mm iØ which widens to 6 mm.

Comparing our data obtained during continuous flow with the data obtained during either pressure controlled or manual ventilation, we noted a slightly smaller pressure drop with the continuous flow. In separate experiments (not reported) we could verify that these small differences are due to the different flow patterns most probably produced in our setup. A setup similar to the one we used for our measurements was described by Haberthur et al [8]. Accordingly we are the more confident that we have correctly measured both the flow and the pressure differences. During continuous flow the pressure drop across the Airfree® was measured by attaching a 40 mm long and 5 mm wide tubing to the patient side of the Airfree® cannula, whereas in the other settings (pressure controlled, manual ventilation or spontaneous breathing) the Airfree® was stuck sideways into the "trachea" (see figure 3). In this case the flow becomes turbulent at the exit of the cannula when the diameter instantly enlarges from 4.6 mm to 10 mm and the pressure drop increases.
It is surprising that only sparse data are available on the flow resistance of routinely used emergency cricothyroidotomy sets though comparative evaluat-ions of emergency airway access equipment have been performed, at least in a simulation environment [9]. In essence, apart from the data on the Quicktrach® [6] obtained with a mechanical aneroid manometer, we could not yet find details on the other commercially available devices. We think such data should be included in the data sheets of the cricothyroidotomy sets allowing a fair comparison in respect to the flow resistance to be expected.
As the Airfree® consists of only two parts, learning the surgical technique is easy. Cricothyriodotomy with the Airfree® instrument also seems to be safer because it is inserted in a strictly horizontal direction. With other instruments the access is oblique. The necessary length of the needle for an oblique insertion could cause a lesion in the posterior wall of the larynx. The dimensions of the Airfree® were chosen with corre-

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spondence to the inner diameter of the adult larynx and so far no damage to the posterior wall of the larynx was observed in cadavers [7]. With respect to the outer diameter of the cannula one must consider the fact that an oversized tube or cannula inserted through the cricothyroid membrane (with the width of the cricothyroid ligament varying between 22-33 mm and its height between 9-10 mm [10]) will result in thyroid cartilage fracture. Our measurements of the dimensions of the human larynx showed that the distance between the skin surface and the posterior wall of the trachea (which defines the maximum penetrating depth of the coniotomy device) was about 16.5 mm in children and infants and approx. 25 mm in adults [11]. For infants or children a device with smaller geometrical dimensions than the presently available Airfree® must be constructed.

Recently we also could show that using the Airfree® the time of coniotomy varied [7], depending on the skill and professional experience of the personnel carrying out the tests [2]. However, access to the trachea is rather fast. Using the Airfree® for coniotomy, the tested persons needed 5 to 28 seconds (mean 22 sec) [7] compared to 58 sec with the Nu-Trake® [4] and 35 to 83 sec with the Quicktrach® [6]. It is also most important that the coniotomy device provides an airtight seal to the trachea. In the same investigation [7] by inflating the larynx it was demonstrated that the cannula was seated both correctly and airtight.

Conclusion

We conclude that due to the low flow resistance of the Airfree® and its anatomically based design, using this device as an emergency coniotomy kit should guarantee a "free" airway without critical damage to the larynx. Thus, quick restoration of ventilation should be feasible.

Acknowledgements

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