Aerodynamic characteristics of the Nijdam voice prosthesis in relation to tracheo-esophageal wall thickness

A. Veenstra · F. J. A. van den Hoogen · H. K. Schutte
H. F. Nijdam · J. J. Manni · G. J. Verkerke

Abstract Tracheo-esophageal speech using various prostheses is currently the most successful form of voice and speech rehabilitation for laryngectomees. Main inter-device differences are durability and trans-device pressure loss during speech. The valveless indwelling Nijdam voice prosthesis is a new voice prosthesis. A barrier mechanism is created by a combination of the esophageal mucosa and the umbrella-like “hat” of the prosthesis that covers the esophageal side of the tracheo-esophageal fistula. The Nijdam prosthesis can be used clinically for longer periods of time when compared to such other indwelling voice prostheses as the Provox prosthesis and the low-resistance Groningen prosthesis. However, trans-device pressure loss during speech has been unknown. Adjustment of the shaft length of the Nijdam voice prosthesis to tracheo-esophageal wall thickness was expected to affect trans-device pressure loss during speech. We report the results of in vitro tests to quantify the effect of tracheo-esophageal wall thickness on trans-device pressure loss. In the present study pressure loss was measured at different air flow rates in relation to tracheo-esophageal wall thickness. Findings demonstrated that when shaft length of the Nijdam prosthesis corresponded exactly to tracheo-esophageal wall thickness, trans-device pressure loss was comparable to that of the Provox prosthesis. If a relatively shorter Nijdam prosthesis was chosen to prevent aspiration from occurring, the pressure loss across the prosthesis increased to that of the low-resistance Groningen prosthesis.

Key words Nijdam voice prosthesis · Total laryngectomy · Voice rehabilitation · Aerodynamics

Introduction

Voice prostheses (VPs) have now been employed over the last 16 years to restore speech after total laryngectomy. The first commercially available prosthesis was developed by Blom and Singer [1] in 1979. VPs are inserted in a surgically created fistula in the tracheo-esophageal wall (TEW). At initiation of voice, the tracheostoma has to be occluded manually or by means of a valve [2]. Expiratory air then flows into the esophagus to activate the pharyngo-esophageal (PE) segment.

Two types of VPs can be distinguished: i.e. non-indwelling and indwelling devices. The former device can be replaced by the patient; the latter remains in place until the end of its clinical usefulness, which is generally indicated by either leakage or increased air flow resistance. The indwelling VP then requires replacement as an outpatient clinic procedure.

The indwelling Nijdam VP is produced and distributed by Medin Instruments (Groningen, The Netherlands) and has been used clinically in the ENT Department of the University Hospital Nijmegen (The Netherlands) since 1988 [5]. This VP differs from other indwelling devices [3, 8] by its unique valveless construction. Its barrier mechanism is created by an umbrella-like silicone “hat” that covers the tracheo-esophageal (TE) fistula on the esophageal side.

It was expected that the shaft length of the Nijdam VP would influence tension between the hat and the esophageal mucous membrane. The trans-device pressure loss during speech would therefore be influenced by ad-
justment of the shaft length of the VP to TEW thickness. In this study we have examined the influence of TEW thickness on the trans-device pressure loss at physiological air flow. In vitro measurements were performed with a measuring set-up and a dummy TEW that permitted simulated changes in mucosal wall thickness and different air flow rates.

**Materials and methods**

The Nijdam VP

The Nijdam VP is shown schematically in Fig. 1. The VP consists of a tracheal flange and a smaller esophageal flange that are connected by a shaft. On top, a hat is connected to the esophageal flange by three small columns. The prosthesis is made from medical-grade silicone rubber and is molded in one piece. Five shaft lengths are available, varying from 4 to 8 mm, while shaft diameters are either 7 mm or 8 mm. These differences allow the VP to be used under conditions of different TEW thicknesses and fistula diameters. The barrier mechanism of the prosthesis results from increased tracheal pressure on attempted phonation causing deformation of both the hat and esophageal tissue, so that expired air can flow from the trachea through the shaft into the esophagus (Fig. 2).

**Experimental studies**

The experimental set-up used is illustrated in Fig. 3 and consisted of a housing in which a Nijdam VP was placed. To reproduce the interaction of the hat of the VP with the esophageal tissue, a part of the esophagus of a pig was used that consisted of both mucosal and muscular layers. Experiments were performed within 2 h after sacrificing the pig to maintain tissue freshness as much as possible. Plastic disks were also used to increase the thickness of the TEW to simulate a relatively small VP inserted in the TEW. The housing was equipped with a pressure and flow transducer (Aerophone II system, model 6800, KAY Elemetrics Corp, Pine Brook, N.J., USA) which was connected to a computer. All data were stored on disk. A 4 cm² piece of porcine esophagus was pierced with a scalpel. A Nijdam VP with a shaft length exceeding TEW thickness was inserted in the perforation. Both parts were placed into the test housing and a water level of 2 cm was placed above the VP hat to check for possible leakage. If necessary, leakage was controlled by assembling the two halves of one or more plastic disks underneath the esophageal specimen (Fig. 3). The corresponding artificial TEW thickness was used as reference thickness (TEW ref).

Measurements were carried out for increasing TEW thicknesses using plastic disks of 0.5 mm thickness until a maximal increase of 2.5 mm was reached. Human expiratory air was blown through the device at various flow rates, increasing from about 0.05 l/s to 0.5 l/s. Each flow rate was kept constant for a few seconds. The trans-device pressure loss was then measured for each

---

**Fig. 1** A, B Schematic representation of the Nijdam voice prosthesis (VP). A Cross section, B top view, with the dotted lines marking the prosthesis columns (1 tracheal flange, 2 esophageal flange, 3 umbrella-like "hat", 4 column, s.l. shaft length)

**Fig. 2** Nijdam VP in situ. At rest the umbrella-like hat deforms the esophageal mucosa. During phonation deformation of the hat and the mucosa is shown by the dotted lines. Arrows indicate the direction of air flow during phonation