Bronhoskopija in krikotirotomija: primerjava Thielove fiksirne metode z ostalimi metodami fiksacije in pri živih

Bronchoscopy and cricothyrotomy: results from cadavers embalmed with Thiel's method compared to other embalming methods and living subjects

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Izvleček

Namen: *Krikotirotomija in bronhoskopija sta bili opravljeni in ovrednoteni na truplih fiksiranih s Thielovo metodo. Namen raziskave je bil ugotoviti ali je Thielova metoda primerna za praktične vaje in raziskave za oba postopka.*

Metode: *Slepa krikotirotomija je bila narejena na 40 truplih z uporabo dveh različnih setov – Cook in Portex setom, vsaka na 20 truplih. Bronhoskopija je bila narejena na 22 truplih. Vsi postopki so bili posneti. Opravljene postopke so opravili anatomi in anestezisti in jih primerjali s posegi pri živih ljudeh. Ocenili so obnašanje tkiva, odpor ligamentov, tipnost anatomskih struktur, barvo sluznic, otrplost trupla, še posebej pomik čeljusti in dvig jezika za vstavitev bronhoskopa. Prikazani so do-*

Abstract

Purpose: *Cricothyrotomy and bronchoscopy were performed on cadavers embalmed according to Thiel's method, and the results compared with findings from other types of cadavers and living subjects, to assess the suitability of such specimens for medical teaching and research.*

Methods: *Blind cricothyrotomy was performed in 40 cadavers using two different devices (Cook and Portex sets) on each of 20 cadavers and the procedures were recorded by a monitoring fibreoptic bronchoscope placed in the larynx. Bronchoscopy was performed on another 22 cadavers. All procedures were videotaped and evaluated by board certified anatomists and anaesthetists. Tissue behaviour, ligament resistance, palpability of anatomical*

bljeni rezultati s kvalitativno primerjavo pri živih in truplih, ki so bila fiksirana s klasično formalinsko metodo.

Rezultati: *Portex in Cook postopki so bili izvedeni pri vseh primerih. Lezije mukoze so bile ocenjene makroskopsko. Trupla so odgovarjala za vrednotenje vseh kriterijev za prikaz življenske situacije. Bronhoskopija je bila izvedljiva pri vseh truplih brez težav. Pomik čeljusti in dvig jezika niso bili omejeni in vedno je bil možen dostop do lobarnih bronhijev. Bronhoskopija je bila omejena s premerom dihalnih poti na nivoju malih bronhijev ali manjše količine tekočine v polovici primerov.*

Zaključek: *Trupla fiksirana po Thielovi metodi so izjemno dobro uporabna za raziskave pri krikotirotomiji in bronhoskopiji. Pozitiven učinek tega pristopa je ta, da so podatki primerljivi s podatki pri živih. Tako fiksirana trupla so uporabna za praktične vaje, saj nam zagotavljajo podobno situacijo kot pri živih.* •

structures, mucosal colour and cadaver flexibility, especially during jaw thrust and tongue lift, were evaluated and qualitatively compared to conditions found in the living and to reports of studies using specimens embalmed with the classic formalin method. Where the procedures caused mucosal lesions, the damaged was assessed during subsequent dissection.

Results: *The cadavers were life-like in all criteria evaluated. Portex and Cook cricothyrotomy was feasible in all cases. Bronchoscopy was feasible in all cadavers without difficulty. Jaw thrust and tongue lift was never limited and lobar bronchi were always reached. Further advancement was limited in half of the cases by either the preservation liquid or the diameter of the segmental bronchi; in the remaining half, advancement into the smaller airways was limited only by their diameter.*

Conclusion: *Cadavers fixed according to Thiel's method are highly useable, life-like specimens for teaching and researching cricothyrotomy and bronchoscopy. The data obtained are transferable to the living, so research findings should be valid and teaching effective.* •

Introduction

Cricothyrotomy and bronchoscopy require a good deal of skill for accurate performance. Both are performed by doctors from a variety of specialist backgrounds, such as surgeons, anaesthetists and, for cricothyrotomy, emergency physicians. Cricothyrotomy – also known as coniotomy [3] or laryngotomy [4] – is one of the safest and quickest ways to obtain an emergent airway in "can't intubate, can't ventilate" patients, with efficacy confirmed by several authors [1,2,5,6]. Unlike cricothyrotomy, bronchoscopy is conducted regularly, in well supervised and prepared conditions, in operating theatres. Clinicians performing either procedure require considerable experience to avoid failure or complications. [6] Careful technique must be combined with sound knowledge of anatomy, precise orientation and palpation and appropriate equipment [6].

New devices have been introduced to simplify the procedures and minimize risks. Before being used on the living, they were tested on embalmed cadavers [7,8] or otherwise [9,10]. Training in these techniques may also involve the use of cadavers [8, 28]. To support such research and teaching, anatomists have been developing embalming methods with the aim of producing models with near life-like characteristics. Among these embalming techniques, cadavers "**P**reserved **A**ccording to **T**hiel's **E**mbalming **M**ethod" [11] (PATEM) are widely used for surgical and anaesthetic training [12, 13, 14, 15, 16] and for research [17]. For example, studies of nerve block models show that the distribution of embalming solutions injected into cadavers is comparable to the distribution of injected anaesthetic agents in the living. [17,18,19].

Fig.1: *Outside and inside view of a cricothyroidotomy with the use of a Melker set: Insertion and arrival of the needle are clearly shown.*

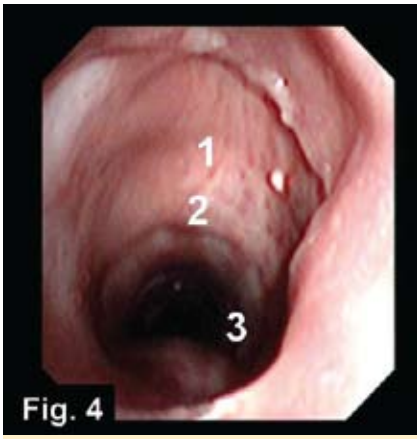

Fig. 4: *View for the anaesthetist performing the fibreoptic bronchoscopy: the location of the cricothyroid ligament (1), the arch of cricoid cartilage (2) and the trachea are marked.*

Fig. 2: *Outside and inside view of a cricothyroidotomy with the use of a Melker set.*

The aim of this study is to report on our experience of performing cricothyrotomy and bronchoscopy on cadavers PATEM and compare it to conditions in the living human and to the results of studies of these techniques performed on cadavers embalmed with other methods. In particular, we looked at whether cadavers PATEM are suitable for research on and training in these procedures.

Table 1: *Characteristics of the cricothyrotomy cadavers*

	Cook Group (n=20)	Portex Group (n=20)
Men	12 (60%)	12 (60%)
Women	8 (40%)	8 (40%)
Age (years).	81±15	77±12
Body Mass Index (kg.cm^{-2})	21.8±2.7	23.2±3.1
Cervical circumference (cm)	42.0±4.9	42.5±5.2
Tracheal anteroposterior diameter (mm)	17.8±2.4	7.0±0.8
Thyromental distance (cm)	7.0±0.9	7.0±0.8
Cormack and Lehane score: 1 2	 18 (90%) 2 (10%)	 19 (95%) 1 (5%)

Data are expressed as means ± SD or number (percentages). There were no significant differences between the groups.

Table 2: *Characteristics of the bronchoscopy cadavers (n=22)*

Men	11 (50%)
Women	11 (50%)
Age (years).	75,3±11,4
Body Mass Index (kg.cm^{2})	21,4±2,8
Cervical circumference (cm)	35,3±4,6
Tracheal anteroposterior diameter (mm)	17,2±3,6
Thyromental distance (cm)	not mesaured
Cormack and Lehane score: 1 2	 not mesaured not mesaured

Data are expressed as means ± SD or number (percentages).

Matherial & Methods

The study was conducted in the anatomical laboratory of the Institute of Anatomy, Medical University Graz, Austria. The human cadavers were supplied by people who in their wills donated their bodies to the Institute for scientific purposes. 62 cadavers were used. Cricothyrotomy was performed on 40 cadavers (Tab. 1) and bronchoscopy on 22 cadavers (Tab. 2). All cadavers were randomly selected by taking the cadavers in the row as they arrived at the department of Anatomy during a certain time of period.

Cricothyrotomy

Blind cricothyrotomies were conducted by two board certified anaesthetists on 40 human PATEM cadavers [11] without fibreoptic assistance. Two different devices – the Cook, also known as the Melker, set (Fig. 1 and 2) and the Portex, also know as the PCK, set (Fig.3) – were employed on 20 cadavers

Fig. 3: *Outside and Inside view of a cricothyroidotomy with the use of the PCK set.*

each. These two sets were chosen because they represent the most commonly used devices in clinical practice; each requires a different technique, which must be practiced before use in an emergency. A newly developed device was used for each cadaver to record epidemiological data (age, sex) and morphometric data (such as body mass index, neck circumference, thyromental distance, the difficulty in manually identifying the cricothyroid ligament and the Cormack and Lehanne score).

Before each procedure began, a fibreoptic bronchoscope (Olympus LF type V; Visera tracheal intubation videoscope, Olympus® Medical Systems Corp. Vienna, Austria) was placed through the oral cavity and oropharynx into the larynx and maintained in this position in order to get a good of view of the infraglottic cavity, the trachea and the posterior wall of the larynx and trachea (Fig.1). All fibreoptic procedures were performed by a third anaesthetist. The cricothyrotomies were videorecorded in order to check the position of the airway catheter and to document possible laryngeal or tracheal lesions caused by the two procedural anaesthetists. All lesions identified by fibroscopy were anatomically confirmed by dissection, performed by an anatomist while the airway catheter was kept in place. Additionally, the lesions were photographed and compared to images recorded during bronchoscopies on living patients.

Bronchoscopy

Bronchoscopy was performed by one board certified anatomist and one board certified anaesthetist on 22 additional cadavers. All cadavers were placed in the supine position with the neck slightly elevated and extended. The fibreoptic bronchoscope (Olympus LF type V; Visera tracheal intubation videoscope, Olympus® Medical Systems Corp. Vienna, Austria) was inserted, transorally advanced and placed cephalad to the laryngeal inlet (Fig. 5). Particular attention was made to evaluate jaw thrust and tongue shift, which are necessary manoeuvres for the proper insertion of the bronchoscope. The bronchoscope was further advanced to the trachea to be positioned close to and cephalad to the tracheal bifurcation. Subsequently, it was pushed into the pulmonary airways as far as possible. The success of this procedure was determined by arrival at a lobar bronchus.

The procedures were video recorded on tape. When lesions occurred, they were investigated as a thorough dissection of the cadavers performed by the same anatomist during coursework for senior medical students. Additionally, the lesions were photographed and compared to images recorded during bronchoscopies on living patients.

Evaluation of Thiel's embalming method

We took keen interest in documenting flexibility, ability to palpate anatomical landmarks, and the ease with which the cadavers could be positioned, particularly extending the neck, throughout the procedures. The specialists, anaesthetists and anatomists, considered tissue behaviour, cartilage consistency, ligament resistance and mucosal colour. We also evaluated mucosal and other tissue lesions and made detailed records of any prob-

lems arising during the procedures, to help other researchers prepare for such incidents in future scientific investigations.

The data were compared by the anaesthetists to images taken during bronchoscopies on the living and on cadavers embalmed with other methods, as well as reports from other studies using other embalming methods. Qualitative evaluation of tissue properties was performed; the results of quantitative assessments will be published separately.

Results

Cricothyrotomy

The Portex and Cook groups were comparable in terms of age, sex, morphometric data (body mass index, neck circumference, thyromental distance, the difficulty in manually identifying the cricothyroid ligament) and Cormack and Lehane score. The anteroposterior diameters of the trachea were also comparable between the two groups (Tab. 1). Cricothyrotomies were easily performed in all cases except one. In the exceptional case, the cadaver was eventually positioned appropriately but the procedure lasted more than five minutes and was, therefore, classified as a failure. Even in this case, there were no problems with palpation or orientation of the cadaver. In all cases it was easy to locate the cricothyroid membrane because of the life-like consistency and resistance of the cadaver skin. The search for the cricothyroid membrane took more than 10 s in the Portex group in one case and more than 10 s in the Cook group in three cases. We could not identify a specific reason for the longer duration in the Cook group. All procedures were performed without being limited by inappropriate cadaver flexibility, orientation or palpability. There were no problems with concurrent fibreoptic observation.

Bronchoscopy

Bronchoscopy was feasible on all 22 cadavers. The jaw thrust and tongue lift necessary for accurate insertion of the bronchoscope were never limited (Tab. 2). The missing tonus of the tongue made insertion of the bronchoscope more difficult in five cases. Before reaching the laryngeal

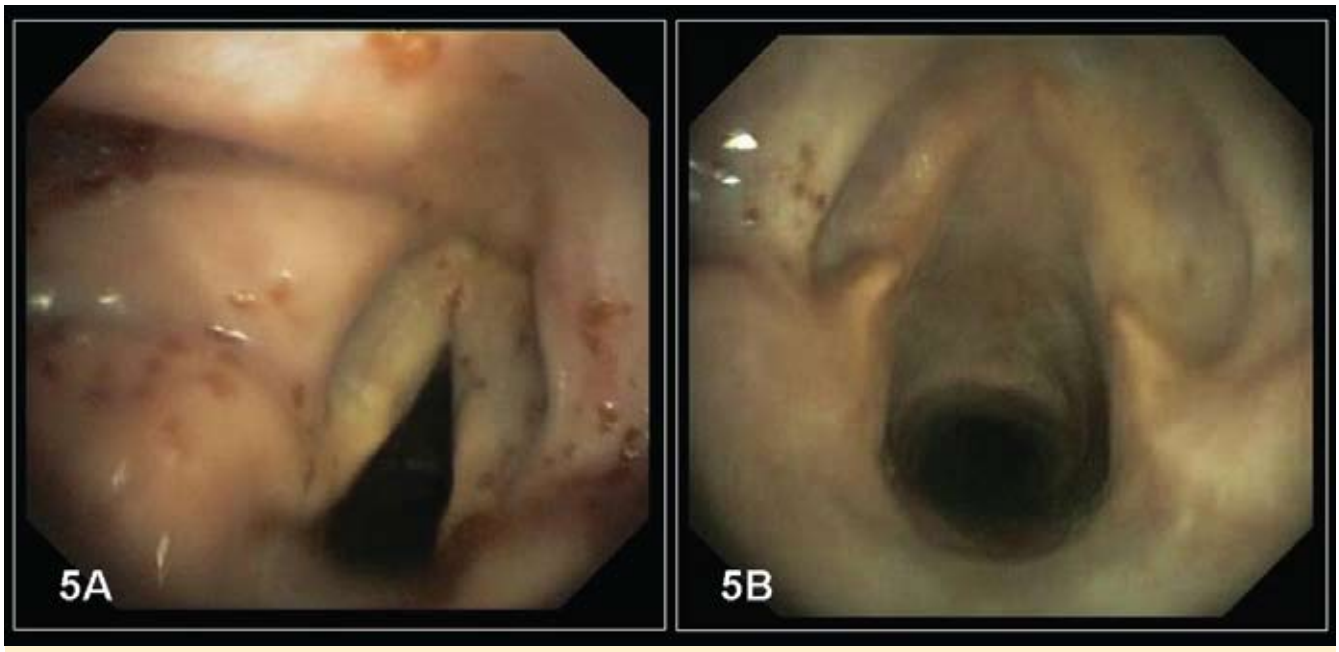

Fig. 5A and B: *Two fibreoptic views of the laryngeal inlets of cadavers PATEM.*

inlet, it was in most cases necessary to aspirate the embalming liquid but the presence of the liquid never made insertion impossible. The tracheal bifurcation was reached and clearly identifiable. The fibreoptic bronchoscope could be advanced via the two principal lobes into the lobar bronchi without difficulty in all cases. Further advancement was limited in half of the cases by either the preservation liquid or the diameter of the segmental bronchus. In the remaining half, the fibreoptic bronchoscope could be advanced into the segmental bronchi and advance into smaller airways was limited only by their diameter.

Evaluation of the effects of Thiel's embalming method on cricothyrotomy and bronchoscopy and comparison to procedures in the living (Tab. 3)

The flexibility of the cadavers enabled them to be positioned properly with ease. Extension of the neck was performed without difficulty and fibreoptic bronchoscopy was feasible in all cases. There were no problems palpating the cartilaginous structures of the larynx and connective tissue such as the thyrohyoid membrane or the cricothyroid ligament. Tissue behaviour during procedure was considered life-like and the ligaments had a resistance comparable to that of living tissue.

Prior to bronchoscopy it was necessary to aspirate the embalming liquid with the aid of a suction device. This was done without restricting the view of the anaesthetist performing the fibreoptic bronchoscopy, the evaluation of the procedure or the documentation of lesions (Fig. 4).

A low degree of mucosal calcification was evident but did not interfere with the procedures. In general, the mucosa was slightly pink in most of the areas of the larynx, trachea (Fig. 1, 2, 3, 4 and 5) and pulmonary airways (Fig. 6), similar to images found of living subjects (Fig. 7). However, some areas were pale or slightly less colourful.

Discussion

Manual skills are of paramount importance for doctors, who perform a variety of procedures with precision, care and responsibility. This is essential, for example, for bronchoscopy and cricothyrotomy. Their indications and frequency of use are

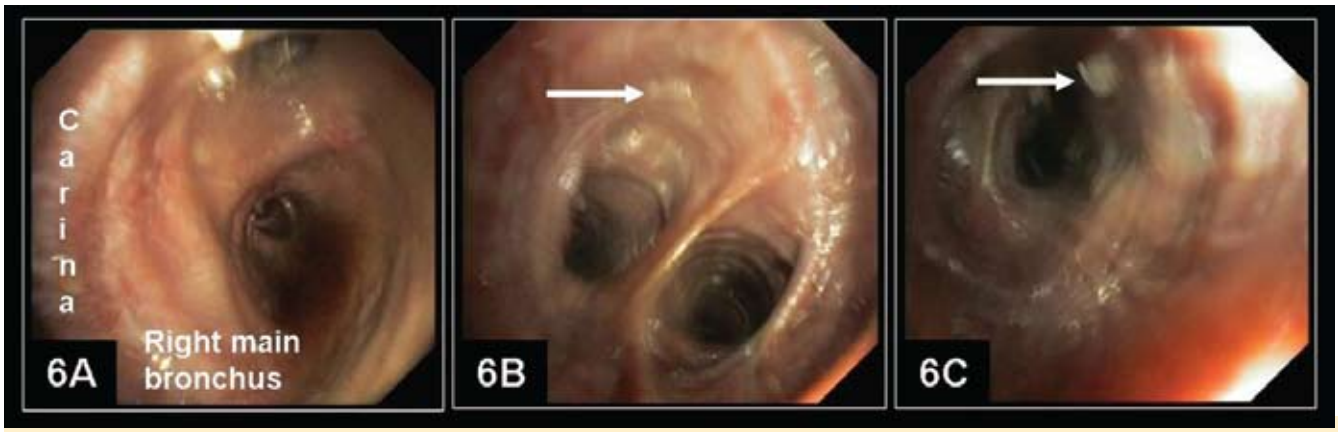

Figure 6A, B and C: *The images show bronchoscopic views of the lobar bronchus of the right lung (6A) and the segmental bronchus of the right inferior lobe (6B) and the smaller bronchus of one of a segmental lobe (6C) on a cadaver PATEM. There are no limitations caused by liquid and diameter of the airways. Colour is slightly pink. There are small calcifications (white arrow) which do not limit the procedure.*

Table 3: *Overview of the properties evaluated*

	Thiel's method	Living human	Classic formaldehyde fixation
Flexibility, positioning	No limitation	Physiologically no limitation	Strongly limited
Neck extension	No limitation	No limitation	Limited
Jaw thrust	No limitation	No limitation	Limited
Tongue lift	No imitation, because of softness sometimes difficult	No limitation	Limited
Mucosa colour and properties	Slightly pink, pale, sometimes small calcifications	Pink	Pale, white, grey
Palpation of cartilage	Easy, lifelike	-	Possible, sometimes very difficult
Consistency of cartilage	Lifelike	-	Hard, sometimes lifelike
Resistance of ligaments	Perceptible, lifelike	Perceptible	Perceptible, hard
Skin	Soft, lifelike resistance, wet		Hard, not flexible

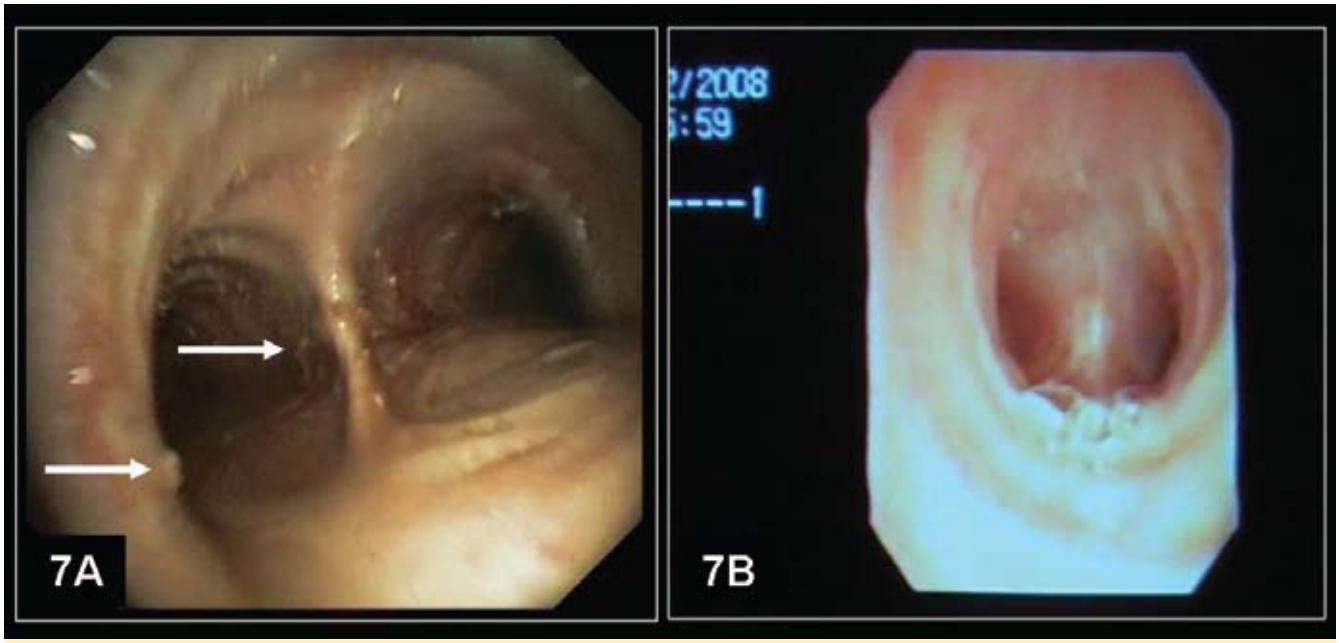

Figure 7: ***Comparison of two bronchoscopies: 7A shows the bronchoscopy on the cadaver with a view on the tracheal bifurcation whereas 7B represents a bronchoscopic view on the tracheal bifurcation on the living. Small calcifications marked with a white arrow can be identified.***

different but both call for a good deal of practice to reduce the risks complications or failure. It is thought these skills should be acquired through practice with models or cadavers before use on the living. [20 21 22]. Horlocker, for instance, places particular emphasis on the role of anatomical departments in providing training facilities and cadavers, with the objectives of building confidence and enhancing the effectiveness of doctors who perform regional anaesthesia [22]; Walls stresses the importance of familiarity with anatomy for successful cricothyrotomy [23]; and Wood goes as far as claiming that simulated practice should be a condition for subsequent clinical practice [24]. Recent developments include special plastic models for fibreoptic bronchoscopy, [25] 3D-animated computer models for anaesthetic blocks [26] and Goldmann and Steinfeldt's AccuTouch Bronchoscopy Simulator for managing the difficult airway [27]. These technologies have proved to be most useful in countries without access to anatomical teaching.

However, there is no denying that the training on cadavers is a common and excellent teaching tool. [27] There have been several studies on cricothyrotomy. Mutzbauer gave a detailed account of training anesthetic assistants and medical students using unembalmed cadavers [10] and Hatton investigated cricothyrotomy, retrograde intubation and fibreoptic bronchoscopy on embalmed cadavers [7] (see below). The risks of cricothyrotomy include oesophageal perforation, puncture of the thyroid vessels and fracture of the larynx. The risks are heightened by the circumstances in which the procedure is typically undertaken, namely, in the pre-hospital phase or emergency room. [6, 28] Studies of the types of complications and their risks have involved freshly frozen cadavers, [9, 29] unembalmed cadavers, formaldehyde-embalmed cadavers and plastic models which all fail to display the biomechanical properties observed in vivo. In one cadaver study, the risk with the Cook cricothyrotomy kit was exclusively of punctiform wounds of the posterior wall of the larynx, which occurred in up to 20% of procedures [8]. This study also showed that the data was valid and transferable to the living.

The experimental model used in the present study is similar to that described in the paper of Hatton[7]. The major difference is the comparison of the results of Thiel's embalming method to conditions found in the living. Regrettably, Hatton did not provide information about the embalming method or supply images of the quality of the cadavers, which would have been of great interest. The search for the optimal embalming method, one which provides life-like conditions, is ongoing. However, several publications have described Thiel's method as having exceptional benefits, particularly for surgical and anatomical investigations as well teaching purposes. [11, 12, 14, 16]. The technique was developed by Thiel at the Institute of Anatomy, Medical University Graz, Austria, in 1992[11]. It offers excellent cadaver conservation, spectacular flexibility, natural colours and limited respiratory and eye irritation for operators. More recently, Peuker successfully employed this technique to produce cadavers for the study of the cervical and facial regions; [14] Alberty used it in the field of otology [12]; Umfahrer utilized it for trials on the spread of local anaesthetics for mandibular nerve blocks, eventually concluding that the results of injections into PATEM cadavers were transferable to the living[18]; and Feigl confirmed this conclusion in several publications [17], [19]. In addition, Feigl favourably evaluated cadaver PATEM properties for workshops on regional anaesthesia, finding that the cadavers could be easily positioned for the different blocks, the bony landmarks could be readily palpated and the tissue quality was good. [16]

Ours is the first study to evaluate Thiel's embalming method for both the life-saving skill of cricothyrotomy and the more commonly performed procedure of fibreoptic bronchoscopy. Because all procedures were performed with continuous fibreoptic recording by an experience bronchoscopist, tissue behaviour could be assessed both by the proceduralist and independently. We – four anatomists and four anaesthetists– concluded that the colours, textures, structures, and consistencies of the different tissues were comparable to in vivo conditions. This has implications for training in cricothyrotomy, a

procedure that requires extension of the neck and, therefore, flexible specimens. [1] Our findings contradict those of Alberty[12] and Peuker[14] regarding mucosal colour and cartilage consistency. Peuker described a dark red coloration, possibly caused by the muscles underlying the mucosa, whereas Alberty observed a pale mucosa because of the missing blood supply. Alberty also found the cartilage much softer than living cartilage. This may be because Alberty assessed the auricula, which is composed of elastic cartilage. Both the thyroid and cricoid cartilages, however, are made out of hyaline cartilage, which we found to have a consistency fully comparable to that of living humans.

The main drawback of Thiel's embalming method is that excessive embalming fluid may limit bronchoscopy in some cases. Fortunately, the liquid is easily aspirated. Another potential visual problem may be calcification caused by the concentration of salt in the embalming fluid, although this is usually minor. We have not yet encountered any limitation of any procedure during research or training from this calcifying process.

The qualities of cadavers PATEM surpass that of unembalmed cadavers, which also carry a risk of infection. Moreover, time is limited to work on fresh cadavers owing to the rapidly advancing process of decay[30]. And even fresh cadavers can be difficult to use; Mutzbauer, for example, described difficulties with neck extension (however, in that study the bodies had a temperature of 4° Celsius, which is certainly low enough to limit flexibility and positioning). [10] The more commonly used "classic" formaldehyde fixation or phenol preservation of cadavers produces a far lower degree of flexibility than Thiel's method. Disadvantages include the inability to palpate landmarks and the impossibility of appropriate positioning, which makes it impractical to perform the special manoeuvres required for some procedures, such as such as jaw thrust or tongue lift for bronchoscopy. [7, 10, 16] This makes it impossible to perform concurrent bronchoscopy, which in turns hampers the immediate evaluation and precise documentation of the success or failure of cricothyrotomy. Moreover, the quality of research and training are adversely affected by the unnatural hardening of the tissue.

In real life, cricothyrotomy is usually performed in emergencies. Bronchoscopy is more frequently performed but is difficult to learn. Both are invasive procedures that cannot ethically be studied on volunteers. Practicing fibreoptic bronchoscopy on anaesthetized patients is also a balancing act between ethical laws and the undoubtedly need for educational training [31, 32]. Bartley, for instance, writes that "learning by doing" on the living is ethically not justifiable and warns against exposing living patients to additional risks. [33] Cadaver training has therefore been recommended to help build confidence, develop manual skills, broaden specialist knowledge and gain experience.

Our model may provide more suitable and realistic conditions than manikins, animal models, fresh cadavers or cadavers embalmed with other techniques, producing results that can reasonably be extrapolated to clinical conditions. It may provide near-perfect, safe and ethically appropriate training for emergency physicians, surgeons, anaesthetists and other doctors wanting to gain competence, experience and the manual skills needed for specific clinical procedures before performing procedures on the living. It suits the high ethical standards of clinicians and is solely for the good of the patients.

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