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Review article

Iatrogenic damage to the pediatric airway Mechanisms and scar development

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Summary

Iatrogenic damage to the pediatric airway occurs rather often. Most injuries will heal without any sequelae because larynx and trachea of children tolerate considerable trauma. However, sometimes the injury is penetrating the mucosa and scar formation can lead to an obstruction of the airway which is followed by a tracheostomy and long term surgery. A great problem is the early detection of trauma since noisy breathing develops often late when scar formation has occluded more than 50% of the airway. A selection of photo documents of airway endoscopy out of more than 5000 photos from the years 1987–2007 were used to explain the development of injuries from minor lesions to large areas of necrosis of the mucosa of larynx and trachea of infants and children. The visualization of airway lesions might help to prevent iatrogenic damage.

Keywords: damage; pediatric airway; iatrogenic; pediatric intubation

Introduction

Injuries by the use of tracheal tubes of larynx and trachea, including carina and main stem bronchi are as old as the intubation procedure itself. Routine intubation of small children for elective surgery was introduced rather late in pediatric anesthesia compared with the first intubations in adults around 1895. In the 1930s intubation of small children was considered to be too dangerous because of frequently observed injuries, but with the specialization of anesthesiology (G. Jackson Rees, M. Digby Leigh) in the 1940s tracheal intubation became more and more accepted by pediatric surgeons (1).

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In consequence of wider application of tracheal tubes in all age groups, early warnings about injuries (mostly subglottic stenosis) appeared in the ENT-literature (2,3). The most frequent finding in adolescents and adults was subglottic stenosis by overinflation of a cuff, in children because of too large tubes, an injury which is still seen today.

Besides the avoidable use of too large tubes inadequate material (red rubber tubes), inappropriate sterilization of tubes or sterilization with toxic substances (ethylene dioxide) reacting with the mucosa, contributed to adverse outcomes after tracheal intubation. Only with the advent of disposable tubes toxic reactions and infection by tubes could be terminated.

Because of the ongoing discussion about the advantages and disadvantages of different modes

of intubation, more than 5000 photos and videoclips were screened retrospectively to present visually airway lesions from small scratches of the mucosa to very invasive lesions and the stepwise development of scar formation. Such an extensive, picture supported demonstration of airway injury might urge the community of anesthetists to greatest care when intubating children.

Knowledge of the anatomy of the pediatric airway is a prerequisite for avoiding 'A' airway damage

In 1951 an epoch making article was published by Eckenhoff (4), explaining in detail the particularities of the anatomy of the pediatric upper airway, giving evidence of the cricoid ring being the narrowest part of the larynx till about the 8th year of age before approaching the anatomy of an adult larynx where the level of the vocal cords present the narrowest part. The lumen of the larynx is funnel shaped, the posterior part of the cricoid ring being tilted back, giving the funnel a solid structure (Figure 1).

It is astounding what Eckenhoff could describe in such an exact way despite limited endoscopic instruments! His findings influenced pediatric anesthetists to use mainly uncuffed tracheal tubes before the 8th year of age with a rather low incidence of intubation trauma in the following decades.

More refined descriptions of the larynx followed with the advent of better optical instruments and specialization in pediatric airway surgery (5,6), demonstrating the unique structure of the pediatric airway in greater detail (Figure 2, 3). The most critical area of the upper airway being endangered by intubation is the cephaled facing cricothyroid membrane and the cricoid ring itself, showing a form like a sealing ring upside down. The anterior part is the 'arch' and the posterior part 'lamina' (Figure 2–5). The mucosa within the cricoid ring lacks practically the submucosa, exposing mucosa and perichondrium of the cricoid cartilage even by moderate trauma to laceration, infection and to the production of copious granulation tissue, followed by airway obstruction (Figure 13, 14).

Intubation injury persists till the present time, being mostly due to inadequate selection and placement of tubes, dislocation of correctly placed tubes or by inappropriate intubation techniques, documented regularly by airway endoscopy (Figure 6, 8, 10–12). The recommendation of cuffed tubes even in infants since 1997 (7) has introduced new types of injuries (see Figure 19, 22). Analysing the causes of airway trauma shows almost always an iatrogenic origin. The selection of the correct size of a tube poses real problem because the pediatric airway shows many variations from the normal anatomy (Figure 4, 6–8).

The entrance to the cricoid ring may present itself as a horizontally lying oval (Figure 6), a circle (Figure 7), or simply as a small entrance to the cricoid being accompanied by a very pronounced cricothyroid membrane (Figure 8a). These abnormalities allow

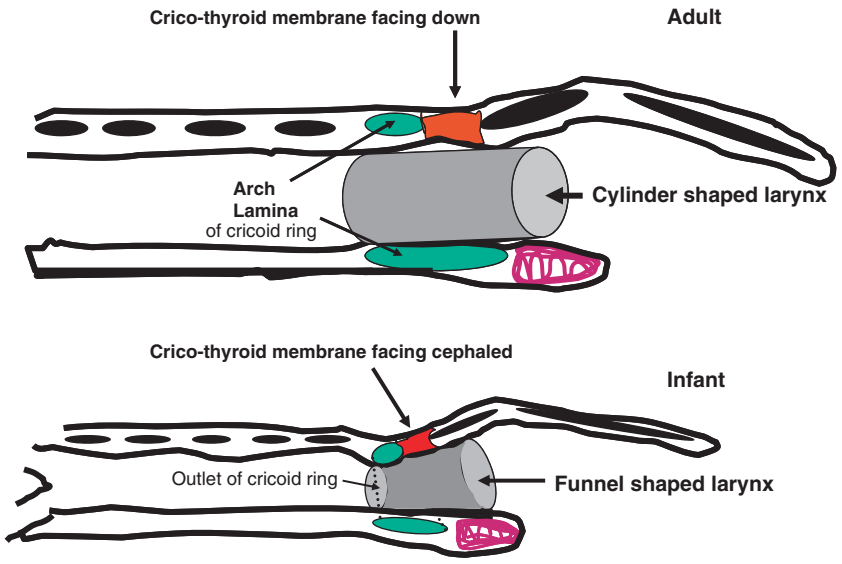

Figure 1
Different internal structure of adult and infant larynx. The outlet of the cricoid ring is the narrowest part of the infants airway, circularly shaped, permitting an adequate seal with adequately sized uncuffed tracheal tubes for ventilation and against aspiration of gastric contents. The cricothyroid membrane is forced into a cephaled facing position and is particularly exposed to injury, even perforation by intubation.

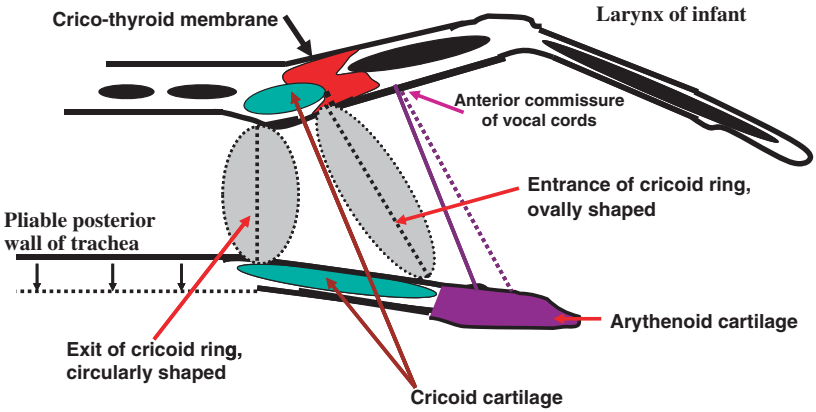

Figure 2
Important characteristics of the larynx of the infant compared with the adult in relation to intubation injury: The cricothyroid membrane is facing cephaled, the entrance of the cricoid ring is ovally shaped, the exit practically circular, permitting an adequate seal with an uncuffed tube (see Figure 6). The anterior commissure of the vocal cords inserts more caudally than after the 8th year of age.

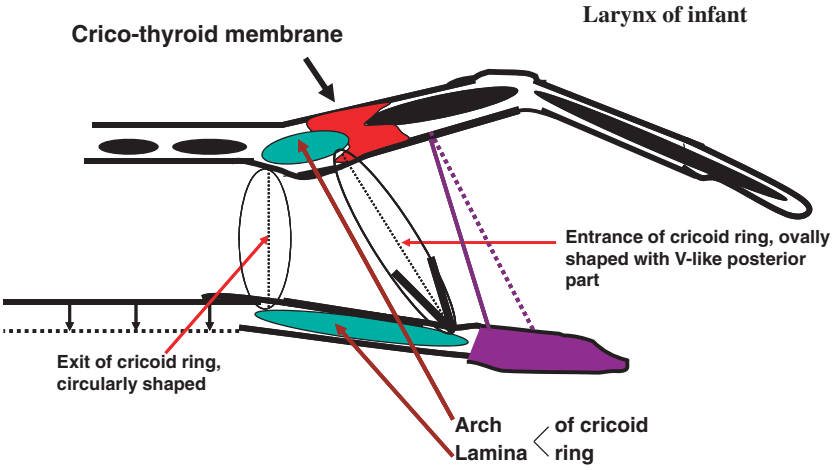

Figure 3
The cricoid ring shows a complicated structure faking an ovally shaped cricoid ring (see Figure 6, 7). The ovally shaped entrance has a posterior V-like narrowing, making this area particularly sensitive to trauma by too large tubes. These drawings are taken from autopsy specimens, *in vivo* the layers of mucosa create many variations of the lumen of the larynx.

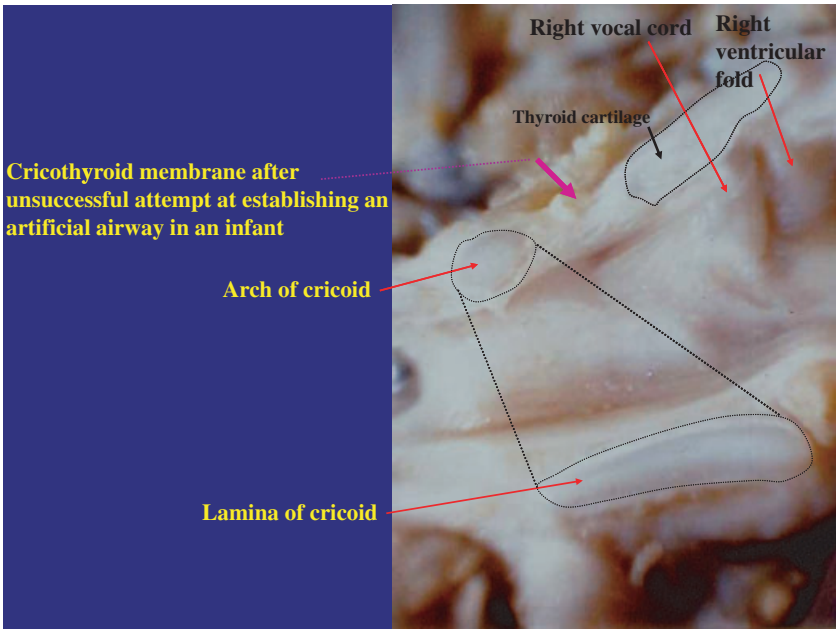

Figure 4
Autopsy specimen of a larynx of a 9-month-old infant after an attempt at establishing a surgical airway through the cricothyroid membrane with fatal outcome. Penetrating the cricothyroid membrane with an instrument in an infant will lead into the glottic area, not into the trachea.

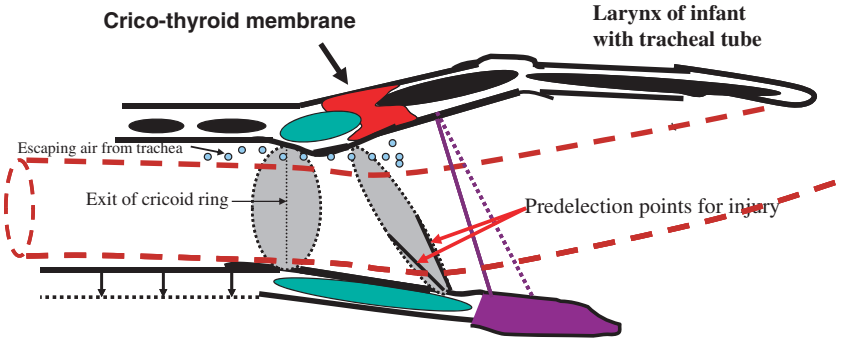

Figure 5
Uncuffed tube in trachea of an infant, sealing the cricoid ring adequately at the exit. The tracheal tube is being bent forward like always, not permitting a 'leak around the tube', occluding the posterior part of the larynx. An endoscopic view ventrally of the tube will show the cricothyroid membrane facing the endoscopist and exposing a crescent like slit, from which some air bubbles may escape (see Figure 9). Aspiration is not possible, particularly not when a small amount of PEEP is applied.

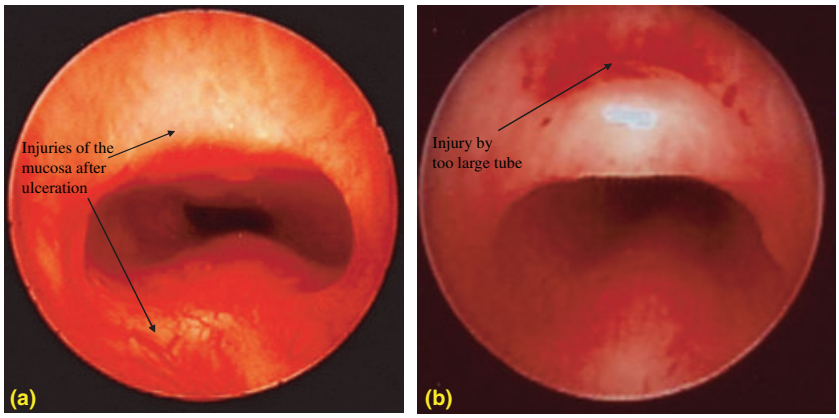

Figure 6
Injured larynges at the ovally shaped entrance to the cricoid ring by too large tubes. The oval presents in a horizontal way, a common finding in children <8th year of age. (a) Older injury with scarring of the mucosa. (b) Recent injury with submucosal hematoma in a horizontal ovally shaped entrance to the cricoid after attempt at intubation with a too large tube. The bevel of the tracheal tube has hit the cricothyroid membrane.

often only the passage of very small tubes. Not knowing about these numerous variations of the anatomy of the larynx of the infant might be the reason why inappropriate tube sizes are chosen so often.

Taken the standard of uncuffed intubation before the 8th year of age for routine intubation, it is the single most important consideration to avoid airway trauma by not introducing a too large tube! Unfortunately, with the popularization of cuffed tubes for infants and children in recent years, the use of too large tubes has not decreased, on the contrary, too large tubes are regularly used together with the then entirely unnecessary but dangerous cuffs (Figure 19, 22). Injuries because of too small tubes probably do not exist but they would interfere with adequate ventilation and need to be replaced by larger tubes, possibly with the same internal diameter (Figure 17). The rule, to have three consecutive tube sizes at hand when intubating a child, is well substantiated!

The key to avoiding intubation trauma is the correct placement of correctly sized tubes! To do this, occasional reintubations for 'titrating' the correct tube size, is necessary and should not be a problem at all in experienced hands. With adequate knowledge of the anatomy, a too large tube can always be avoided and permitting a small leak between the anterior wall of the tube and the cricoid

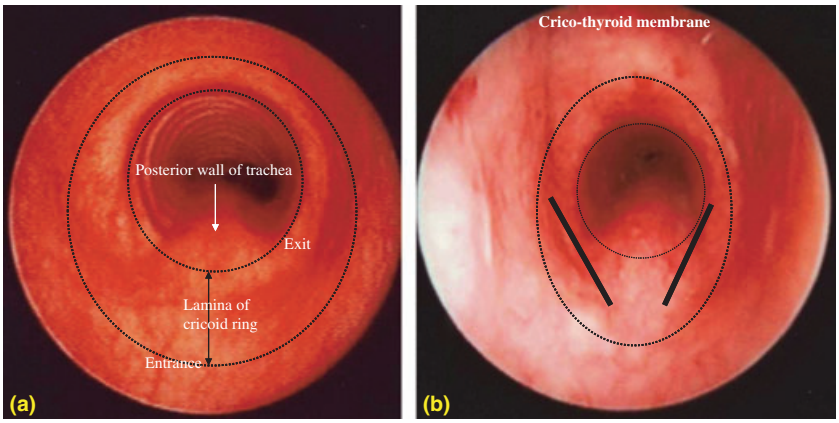

Figure 7
Endoscopic view of the pediatric larynx showing typical variables: (a) Entrance of the cricoid ring in an almost circular form (mucosa considerably inflamed). At the exit of the cricoid the pliable posterior wall of the trachea is visible. (b) An oval entrance of cricoid. The cricothyroid membrane is very pronounced, demonstrating again the impossibility to enter the trachea via this membrane. The solid bars indicate the predelection areas for ulcer development if the tubes are too large (see Figure 11–14). Mucosa shows signs of chronic inflammation.

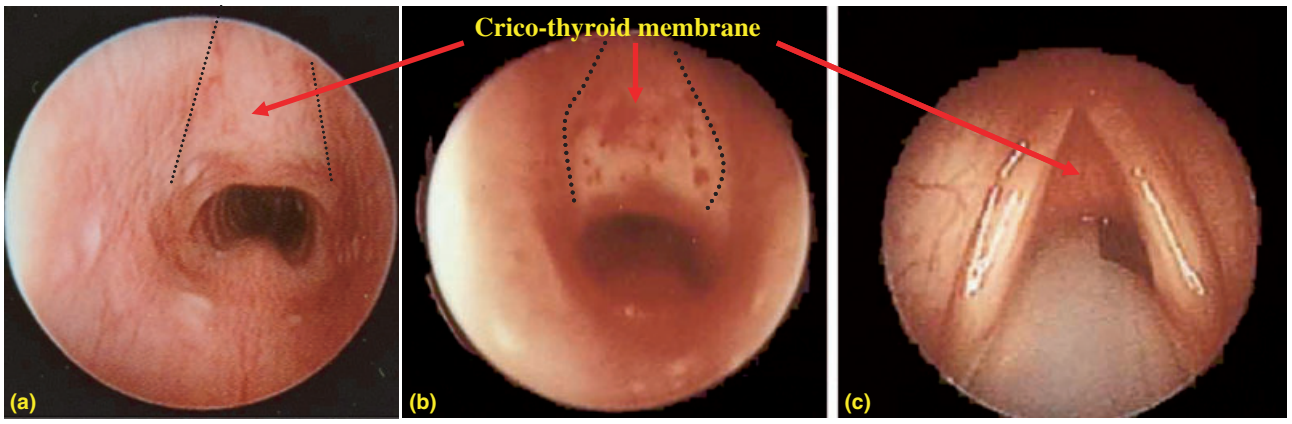

Figure 8
Variations of the appearance of the cricothyroid membrane and the entrance of the cricoid rings in infants and small children. (a) Very pronounced cricothyroid membranes with a vertical aspect. The entrance of the cricoid ring is ovally shaped in a horizontal dimension and considerably smaller than normal. (b) Cricothyroid membrane like before after an attempt at intubation. Danger of perforation. Subglottic tumour was diagnosed. (c) Too large tube in larynx, pushing the cricothyroid membrane up and occluding the larynx tightly. This will inevitably lead to intubation trauma (see Figure 11–13).

arch makes uncuffed intubation a very safe procedure (Figure 5, 9) till the 8th year of life.

Exceptions might be surgical interventions in the trachea or at a tracheostoma, malformations of the airway, previous injury to the larynx or intubation of children being considerably too small for their age because the airway is comparatively large in relation to the body of underweight children, indicating a very small tube with a cuff instead of a large uncuffed tube.

Documentation of airway injury might be important for avoiding further damage!

Airway injury will probably always occur to a certain extent by mal-calculation of tube sizes, unqualified intubation techniques or inadequate tube material. Therefore it is of great importance to document mechanisms of airway injury by photos. Making typical injuries widely known, might be a stimulus to avoid trauma and treat it early.

A moderately oversized tube, fitting too tightly in the cricoid ring for a short time, will cause swelling of the mucosa, disappearing soon without treatment or with nebulization of adrenaline. Small ulcers, though not desirable, will heal quickly (Figure 10).

More invasive injury may have a great number of causes, including combinations of causes (Figure 11). This particular injury, acquired during open heart surgery might be due to a too large tube, a curettage-like effect of a too stiff tube or to the

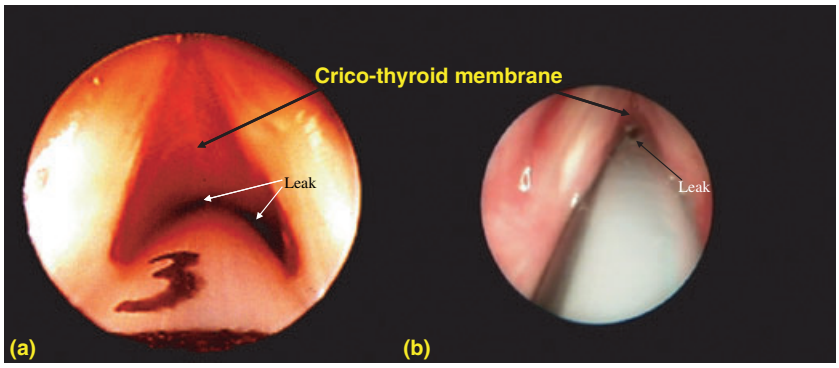

Figure 9
Adequately sized tracheal tubes in normal larynges. (a) The tube is lying on the V-shaped, posterior wall of the cricoid ring, sealing this area adequately. Permitting a minute slit anterior of the tube enables air to leak out in small bubbles, presenting the so called 'leak around the tube' which in practice does not exist. Aspiration is not possible under small amounts of PEEP. (b) A tube in place shows some air escaping from the trachea during mechanical ventilation, signifying an adequately sized tube. Et-CO2reading remains correct with such small amounts of gas escaping.

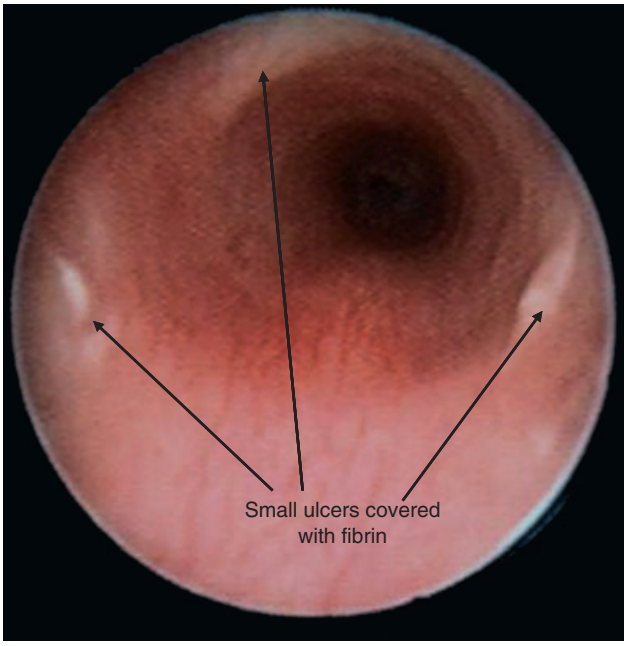

Figure 10
Entrance of the cricoid ring with superficial necrosis of the mucosa at typical places, namely the V-shaped part of the lamina and the anterior part of the cricoid arch (4, 8 and 12 o'clock). This injury will heal without sequelae if no infection occurs. No stridor noticable at any time. Cause: intubation with a slightly too large tube.

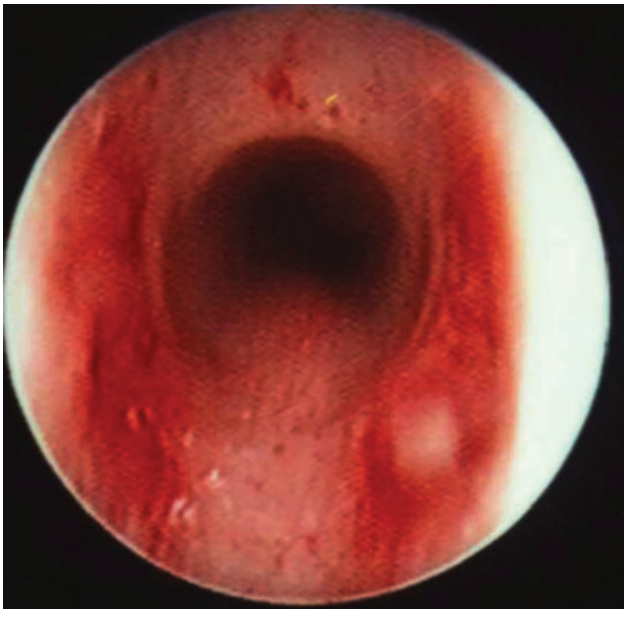

Figure 11
Large superficial abrasion of the mucosa at the entrance of the cricoid ring. The arch is practically free of damage. Possible causes: use of a too stiff, slightly too large tube, twisting movements during intubation, several attempts at intubation of unexperienced performer, temporarily inadequate perfusion of the mucosa. Finding after open heart surgery. Wound will heal with conservative treatment. No stridor at any time.

'screwing' down of a tube in the ovally shaped entrance of the cricoid. A low perfusion state during pump time probably added to this injury. However, generally this type of injury is caused by a too large tube. It needs great skill and experience to find out whether the injury was avoidable or not. This injury needs treatment by an experienced pediatric ENT-surgeon, not just a dose of intravenous corticosteroids.

When the circumference of the larynx is affected, an even larger tube has been inserted (Figure 12, Video 1). Large areas of the mucosa appear in whitish colour, meaning mucosa without perfusion, being followed later by ulceration.

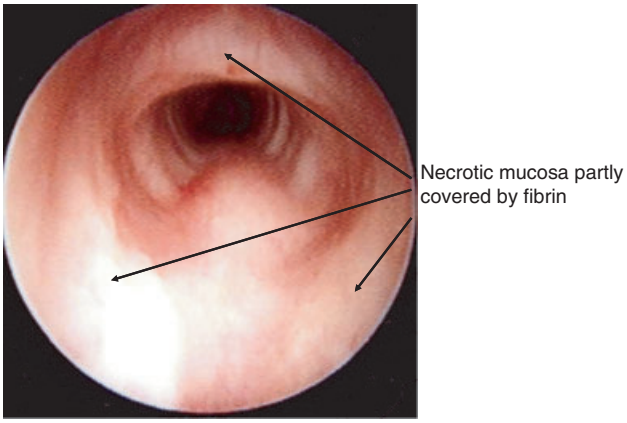

Figure 12
Necrosis of the mucosa at the entrance of the cricoid ring. Developing ulcers at typical locations, partly covered by fibrin. No stridor recorded. Cause: too large tube.

Lack of knowledge of the anatomy of the pediatric airway facilitates intubation damage

Pushing down a tube into a larynx, not knowing what structures are below the vocal cords, can lead to extraordinarily invasive trauma. After using a cuffed tube, being too large, incidentally placed into larynx and overinflated, the glottis is often hardly recognizable (Figure 13a). The severity of trauma needs immediate treatment on two levels to avoid tracheostomy. First the damage of the glottis has to be taken care of because this space consuming tissue together with oedema does not permit spontaneous respiration, second the pronounced circular necrosis of the mucosa within the cricoid cartilage (Figure 13b). The first step of treatment is always aiming at establishing spontaneous respiration without a tube, a most important prerequisite for rehabilitation of the larynx.

When asking the admitting physicians why this could have happened after elective intubation, the answers always point in the direction that large tubes are generally considered to be an advantage and to be supported by the literature! This shows in the end a surprising lack of knowledge of the anatomy of the pediatric airway and how to approach it.

Intubation with a grossly over-dimensioned tube, regardless whether cuffed or not, destroying the mucosa, laying wide open the cricoid cartilage,

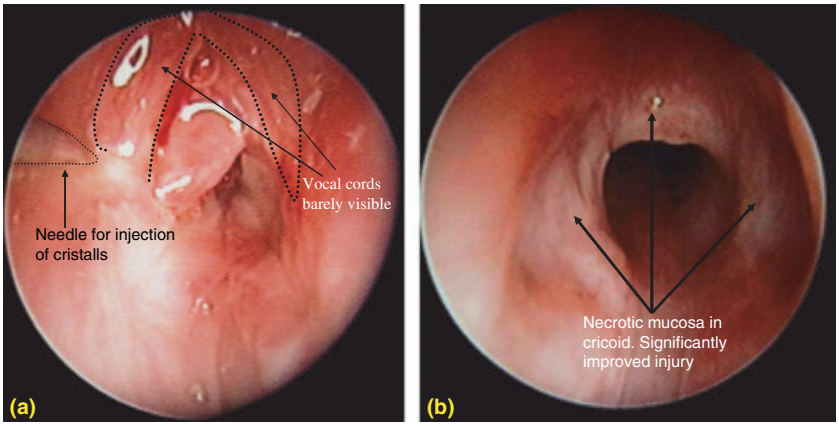

Figure 13
Severe, combined injury of the larynx at the level of glottis and subglottis by inadequate attempts at intubation and using a cuffed, too large tube. This trauma could have been prevented by adequate training and early call for assistance. (a) Invasive treatment by endoscopy-guided injection of cristalloid corticoids into base of granulation tissue, improving injury significantly. (b) Same patient 1 week later with circular necrotic mucosa in cricoid. Further treatment prevented tracheostomy.

belongs to injuries where the tube must have been squeezed into the glottis with considerable force (Figure 14). Such an injury is difficult to understand, it shows clearly that this particular child was intubated in a nonqualified surrounding.

However, frequently endoscopists encounter regularly occurring, typical injuries which show less invasive damage but cause also a potentially dangerous development of scars. The mechanism of this type of trauma is related to too large tubes (Figure 15a) or to cuffed tubes wrongly placed and inflated in the larynx (Figure 15b,c), resulting both in an over-distension of glottis and subglottis and lesions of the mucosa, being followed by scar formation.

The difference to earlier demonstrated extensive injuries might be a short exposure time of a too large tube which subsequently was changed to a smaller one. A very stiff tube, stylet use or just a too large tube could have caused the same trauma. These injuries are the precondition of the generation of tissue bridges which are regularly encountered in endoscopy. Tissue bridges between vocal cords may become a very unpleasant surprise for anesthetists when intubating an apparently healthy child! Normally they can not be detected clinically, they remain silent. It is astonishing that not even alterations of the voice are noticed by caretakers or nurses. These children can easily be bag-ventilated during induction of anesthesia but a tube can not pass. The same pathology is seen also in formerly premature infants after long term ventilation, showing no clinical signs of airway obstruction (Figure 16).

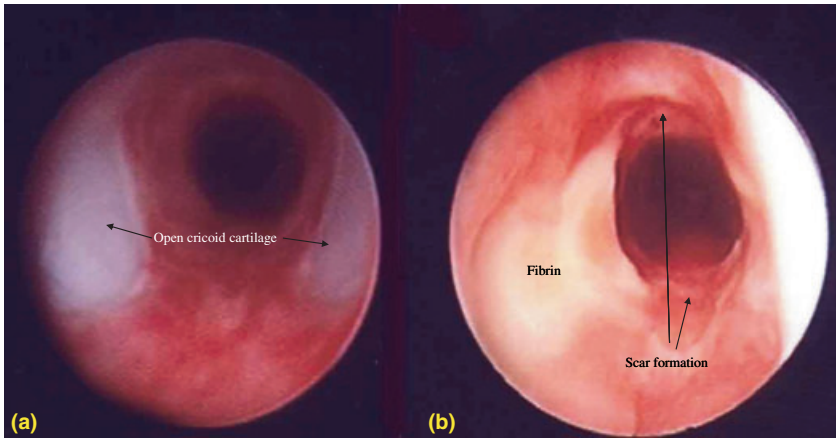

Figure 14
Circular necrosis of mucosa after extubation of a too large tracheal tube. (a) The cartilage of the cricoid ring is laid bare, granulation tissue covers lamina and anterior part of cricoid arch. (b) Same larynx, 1 week later. Shrinking process of the scar has begun despite treatment. No stridor for weeks! Tracheostomy and long term invasive treatment had to follow.

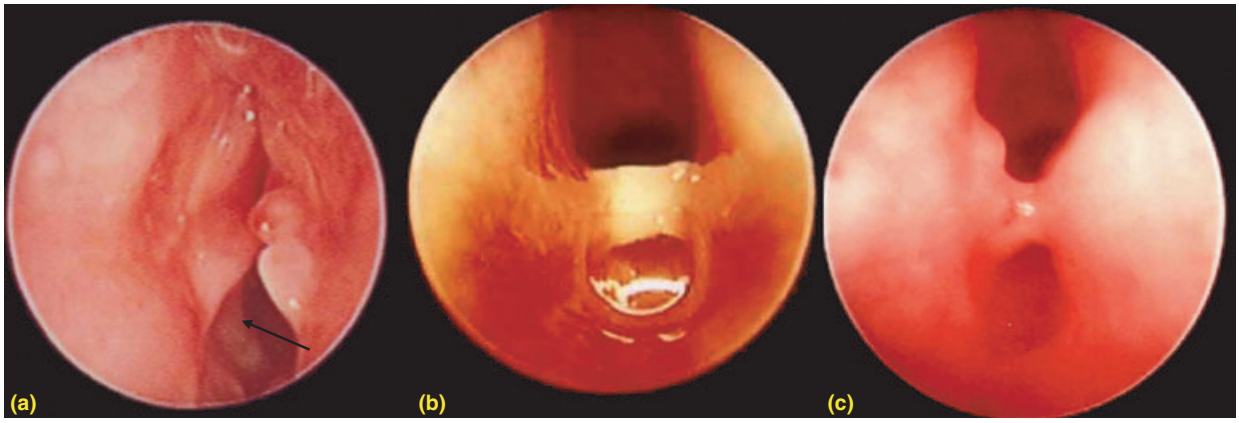

Figure 15
Three stages of scar development after laryngeal injury by too large or cuffed tubes placed in larynx. (a) Acute injury after 3 days of intubation. Granulation tissue at vocal cords, ulcers in subglottic region (arrow). This child had stridor but minor damage! (b) Cuffed intubation for 3 h. Patient had no stridor at any time, not even alterations of the voice. Damage detected 3 weeks after injury. (c) Incidental finding of a scar bridge about 2 months after cuffed intubation. No stridor at any time. Scar detected at induction of elective anesthesia.

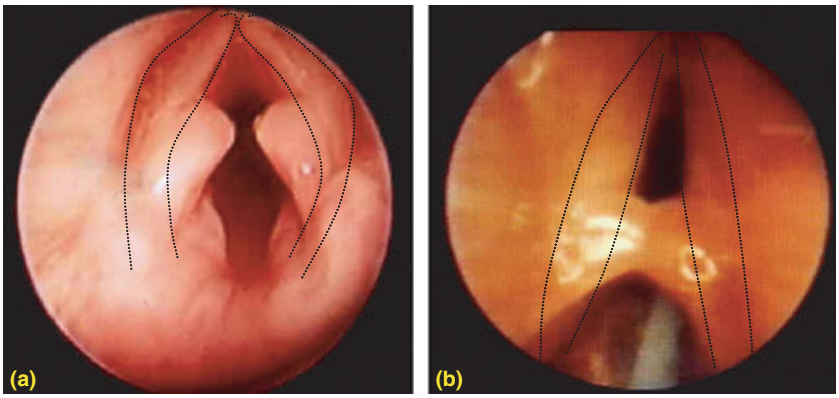

Figure 16
Development of tissue bridges in premature infants after application of adequate tubes for long times (>2 months) and airway infection. (a) Copious granulation tissue after long time intubation in a premature. Vocal cords indicated by dotted lines, partly hidden under old, retracting granulation tissue. (b) Bridge of tissue in a premature when granulation tissue was not treated nor removed in time. Vocal cords indicated by dotted lines.

Probably the continuous movements of the prematures in the incubator have caused some rubbing of the tube against the mucosa, being followed by the formation of granulation tissue creating a sort of 'key hole' scar. This injury is mostly not avoidable in ventilator dependent patients but earlier endoscopy would have always been helpful to begin early treatment or to change to a softer tube material or choosing a tube with a smaller outer diameter, maintaining the same internal diameter (Figure 17).

Stridor in PICU graduates, having been mechanically ventilated, persisting for weeks and months should always be endoscopically investigated for airway injury even if stridor disappeared after some time (Figure 15b,c Figure 16b)! Leaving the tissue bridges without treatment, they will prevent intubation in an emergency situation and might endanger the life of the child as long as this scar is not removed. Particularly dangerous is the clinical silence of these impressive scars, giving no warning to the caretakers or anesthetists.

Of greatest help in such situations is a quick look with a rigid endoscope at the larynx (Figure 18) to establish a diagnosis which will stop all surmises of why a tube could not pass and prevent possibly risky intubation manoeuvres. One of the rather economical Hopkins rod lenses[1], easy at handling, ought to be present in every pediatric anesthesia department for differentiation of obstructions.

[1]Karl Storz GmbH & CO.KG Tuttlingen, Germany

Figure 17
Tracheal tubes for infants and preschool children consist of different material which result in different outer diameters with the same internal diameter. Some tubes are softer, others are stiffer, all have special indications. 'Titrating' the size of tubes is possible!

It can be life saving and prevent additional airway injuries. The small Bonfils instrument (Figure 18)[1] is particulary useful to intubate many truly difficult airways. Fiberoptic instruments are as useful as rigid lenses but need far more experience and time to apply them in an emergency situation.

Scar brigdes are found also in the trachea after cuffed intubation (11) and cause the same problems when trying to intubate a child. A laryngeal mask

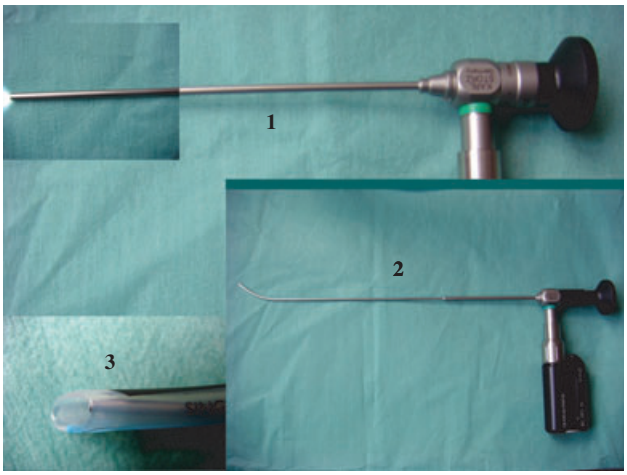

Figure 18
Different rigid endoscopes for diagnosis of airway injury and difficult intubation. (a) Straight, rigid, battery powered Hopkins rod-lens with a wide angle lens. This instrument can be used for quick emergency diagnoses when intubation difficulties arise. (b) Small, semiflexible, battery powered Bonfils lens for emergency diagnosis and difficult intubation in infants. (c) Tube over rigid lens for difficult intubation under view.

airway is safe in all these situations were ventilation is possible and no urgent indication for intubation is given – but endoscopy should always be performed during or immediately after the procedure to find out about the full pathology of scar formation and about a possible threat of complete airway obstruction. If an immediate intubation is needed, cutting through the bridge becomes necessary.

Does routine use of cuffed tracheal tubes in children <8 years reduce the incidence of intubation trauma?

The use of cuffed tubes in children bears always the risk of applying too large specimens of tubes like in uncuffed intubation, increasing the risk of trauma by the addition of a cuff and the possibility to over-inflate it. The folds of the cuff, even when not inflated or the attachment area of the cuff to the tube shaft add to the risk of trauma (Figure 19, Video 2).

Again, a quick view through a rigid lens (see Figure 18) when suspecting a malformation, a scar, a cyst or other impediments for passing a tracheal tube, can demonstrate the danger of injury immediately. Relying on stridor as sign of injury and postponing endoscopy would miss a great number of significant injuries as well as any stenosis which does not occlude the airway by more than 50% (Figure 11,12,22, Video 3), delaying the chance of early treatment.

The development of scar production in dimensions of quantity is unpredictable. Recently developed granulation tissue shows a rapid regression when treated conservatively (e.g. local injection of corticoid crystals, Figure 20a), weeks and months old narrowing within the cricoid ring pose a greater problem for therapy and need surgical interventions (e.g. cricoid split, Figure 20b, Video 4), whereas treatment of solid scars, the development of which takes about 9–12 months, need always time consuming

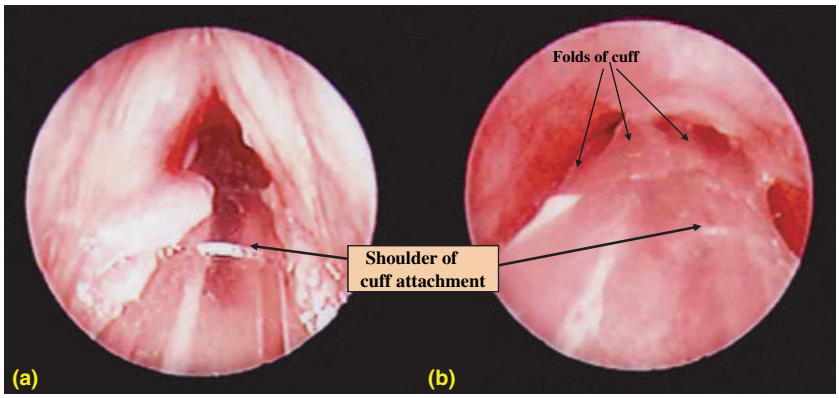

Figure 19
Too large cuffed tubes in larynx and trachea of 2 and 3 years old children. (a) Trauma at vocal cords by sharp shoulder of cuff attachment at the tube shaft, scratching over glottic and subglottic area with every head movement. (b) Trauma by folds of noninflated cuff in distal trachea. Shoulder of cuff-attachment at tube shaft is causing additional injury. No good indication for the use of cuffs discernible in both patients! All injuries in this article detected by use of Hopkins rod lenses.

surgical interventions like stenting or tracheo-laryngeal resection (Figure 20c, Figure 25, Video 5).

Trying to make comparisons between the well established traditional approach to intubation, using adequately sized uncuffed tubes before the 8th year of age and the spreading fashion of using cuffed tubes in all age groups, proves to be very difficult. Endoscopists see regularly extensive injuries by cuffed tubes which were extremely seldom encountered before 1997 (see article A. Wolf in this volume).

All studies, recommending cuffed intubation even in infancy, are considerably flawed by not having endoscopic evidence to substantiate their recommendations (7–10,12,13), because they used stridor as their main outcome measure. With this outcome measure all injuries, depicted in Figure 6–8, 11–18, 21 would not have been detected including stenoses smaller than 50% of the lumen of the airway. This demonstrates that stridor is not a validated outcome measure in trying to screen for airway injury in studies with far reaching influence on intubation practice (7,9,12,13).

A critical review of this body of literature and endoscopic documentation from the point of view of endoscopists and ENT-surgeons would be of greatest importance for bringing the discussion of this controversial field to a fact related, objective level! However, dealing with this vast topic of iatrogenic trauma by cuffed tubes would break up this article and can only be touched upon to a certain extent in this paper.

Endoscopists are very concerned about seeing many extensive injuries caused by cuffs which might be avoided simply by using cuffed tubes only with important indications. The market is overflowing with different brands of cuffed tracheal tubes for children. Till now it is impossible to find out which of these tubes are adequate for children and if they are useful for small children at all! Comparing cuffed tubes on real-sized laryngo-tracheal models, show important disadvantages in all makes of tubes which were tested. Some do not fit into the trachea they are made for, in others the cuff is over-dimensioned or the attachment of the cuff to the tube shaft results in a sharp shoulder (14), irritating the mucosa of the airway or even the vocal cords (Figure 19, 22c).

The worst injury by a too large tube is a circular necrosis of the mucosa within the cricoid ring (Figure 21). When detected early by endoscopy (stridor might develop only after months and years and might be attributed to croup or congential malformation), early treatment (cricoid split or stenting) could prevent cricoid stenosis and tracheostomy.

The worst injury by cuffed intubation is first of all a combined necrosis of the mucosa, affecting glottis, cricoid and upper trachea because the cuff is frequently misplaced into larynx and trachea (Figure 19, 22, Video 6). Treatment of such injuries is very difficult and frequently accompanied by infections and other complications. This experience

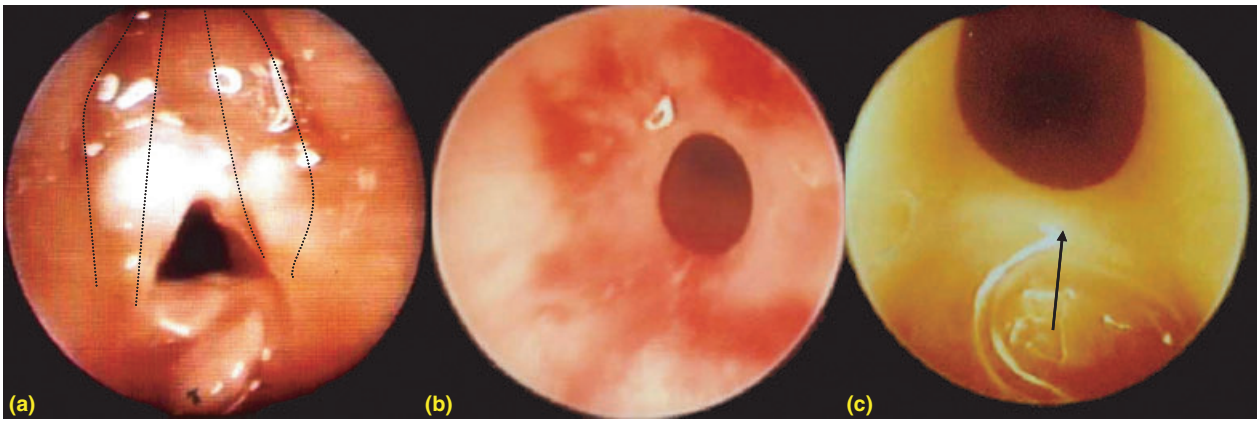

Figure 20
Endoscopic views of too late diagnosed and untreated significant laryngeal injuries by intubation. Patient 1 and 2 needing a tracheostomy. (a) Large amounts of granulation tissue cover glottis. Vocal cords (dotted lines) covered by granulation tissue of different stages of scar formation. Cause: repeated intubations because of severe obstruction after attempts at extubation. Diagnosis too late! (b) Central stenosis within cricoid ring caused by a too large tube. Scar formation in progress. (c) Late stage of scar formation within the posterior commissure of the vocal cords, impeding their movements (arrow). Normal sized tube could not be introduced. Surgical intervention needed.

shows that damages caused by cuffs are mostly very extensive.

Special attention is needed in children with severe burns accompanied by inhalation trauma. In particular after smoke inhalation the mucosa is severely inflamed, extremely sensitive to irritation and will swell rapidly (Figure 23). The mucosa of the upper airway will look similar like the skin of the face of this child. Because of rapid swelling of the mucosa, stepping down with the size of tubes during the first days after trauma till the oedema resolves might be indicated.

The recommendation of the use of cuffed tubes for intubation in children of all ages with severe burns, adapting the cuff pressure to ventilatory needs to avoid reintubations (15), appears to be dangerous according to the experience with folds of cuffs (Figure 19, 22). Releasing the pressure of a cuff will always lead to fold formation and damage the highly inflamed trachea (Figure 23). Testing the

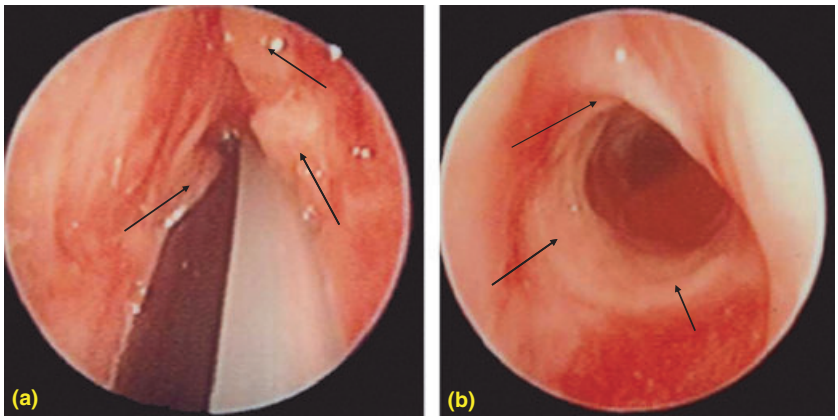

Figure 21
Circular necrosis of the mucosa within the cridoid ring, severest damage after the use of a too large tracheal tube for intubation. (a) A too large tube in the glottis, having injured the anterior commissure followed by formation of granulation tissue (arrows). This tube must have been in place for days. (b) Circular necrosis of cricoid mucosa of same patient. Fibrin covering the open perichondrium of cricoid (arrows). Early treatment might prevent formation of subglottic stenosis.

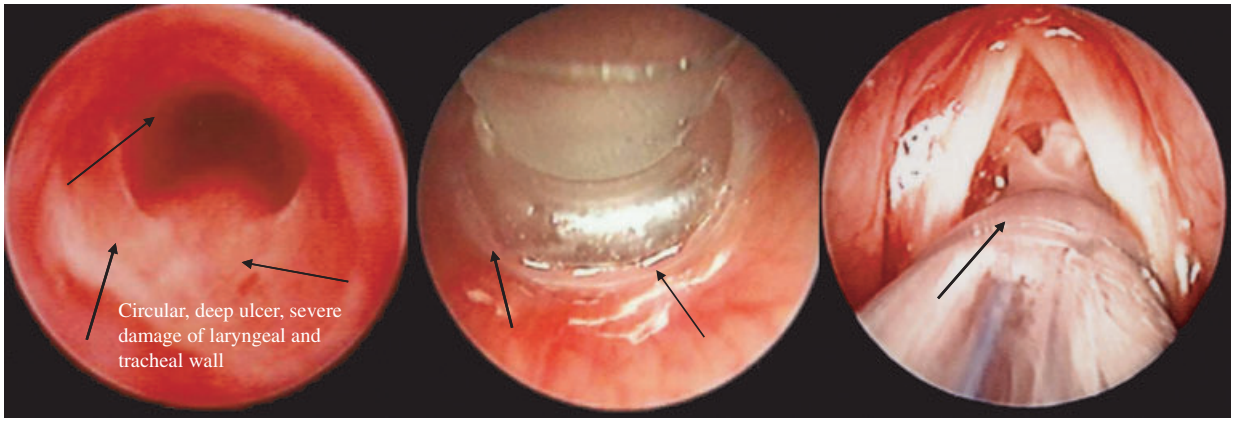

Figure 22
Severest damage of the upper trachea by overinflated cuffed tube, regular findings in cuffed intubation despite precautions. Mucosa and tracheal wall destroyed, sometimes combined with severe trauma when cuff mal-positioned in larynx (three different patients). (a) Circular necrosis of cricod ring and upper trachea after cuffed intubation destroying not only the mucosa but also cartilage! Laryngeal recurrent nerves can be included in scar formation. No stridor, but pain when swallowing. Stridor would have developed after weeks when not treated. (b) Overinflated cuff in trachea showing the compression of mucosa to the point of no perfusion (arrows). (c) Too large cuffed tube within glottis, cricoid ring and upper trachea. Cuff not inflated. Very sharp folds of cuff injuring mucosa. Sharply edged shoulder of cuff attachment in foreground (arrow).

Figure 23
Severe facial burns with inhalation trauma after inflammation of furniture. (a) Swollen mucosa of glottis covered with soot, vocal cords hardly recognizable. (b) Highly inflamed mucosa of subglottic region and trachea after removal of soot and debris by suctioning under vision. Folds of cuffs in this vulnerable mucosa would have an extremely traumatic effect.

Sheridan tube on a real size cartoon of a trachea of a 1-year-old infant demonstrates considerably sharp folds and sharp shoulders of the cuff attachment at the tube (Figure 24) and a clearly too long cuff, barely fitting into the trachea of the child the tube is made for [Figure 24, embedded picture (1)].

A change to smaller sized tubes during the process of oedema formation might still be the safest approach in such situations, well knowing that this procedure will be difficult and should be carried out only by experienced pediatric anesthetists or – intensivists. All patients with severe burns, being ventilated for weeks, should undergo endoscopy during one of the wound dressings to evaluate the always present airway injuries according to the experience not only of the authors of this article.

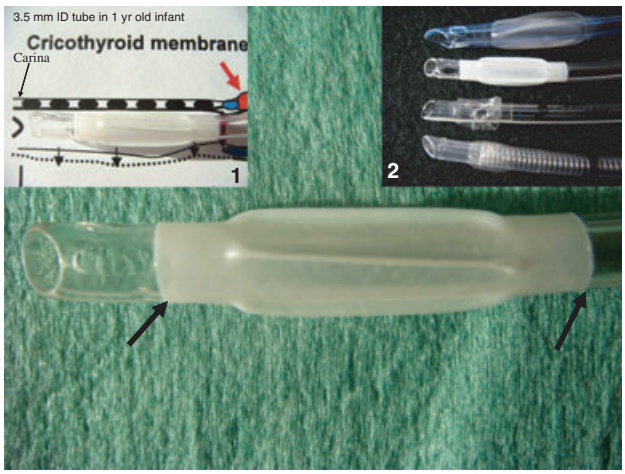

Figure 24
Deflated Sheridan cuffed tube recommended for intubation of children with severe burns of all ages. Sharp shoulders at cuff attachment (arrows). The cuff length of the 3.5 mm ID tube barely fits into the trachea of a 1-year-old child (embedded photo). This tube might cause considerable damage in a trachea like in Figure 23b as soon as the patient is moving or being passively moved.

Results

In the end all different types of severe airway injury end in a long distance scar stenosis which can only be treated surgically, subjecting the child to a tracheostomy and many operations and frequent hospital stays. But it makes a great difference for rehabilitation whether the child has an old, solid scar (Figure 25) or shows recent damage (Figure 11, 15a, Figure 21).

This demonstrates how important it is to make an early diagnosis by endoscopy, treat early, screen the injury for bacteria and start antibiotic treatment accordingly to avoid formation of scars and scar retraction.

Discussion

It has a tragic aspect that almost all injuries depicted in this article could have been prevented! Presenting pictures like above in meetings usually causes often an opposition against the presented data calling them anecdotal cases. That they are not just anecdotal cases can be refuted by the vast experience with hundreds of cases as documented in an active referral center treating airway damage (Figure 26).

With such a large experience through many years it appears very likely that we see only the tip of the iceberg of all airway damages (Figure 27). These incidental findings show how hidden and intricate intubation injuries can be, not showing the symptom of stridor. Again, only endoscopy can find out clinically silent injuries as documented in Figure 27!

How can intubation trauma be reduced or prevented? 'D'

Having presented a very small but typical series out of a large body of documented injuries, the question arises: how can we handle this problem and how can we reduce or even avoid these invasive injuries? It seems to be obvious that we can not simply go on with this and simply watch airway injury to occur! Airway damage is a very heavy burden to child, parents and medical personel which is obvious!

To clarify the problem whether cuffed tubes could be used in small children routinely or not, only endoscopy controlled studies with photo-documentation, being evaluated by blinded observers, would provide some progress in this question. All the risks of using cuffed tubes are on the side of children, not on the side of physicians, as long as we don't have evidence based studies. A controlled study with the possibility to interrupt the investigation as soon as significantly greater injury is accumulating in one branch of the study would be ethically mandatory as only the smallest risk possible ought to remain on the side of the children.

However, before starting a study it needed to be defined of what a cuffed tube ought to consist of! Attempts at dealing with this problem have been

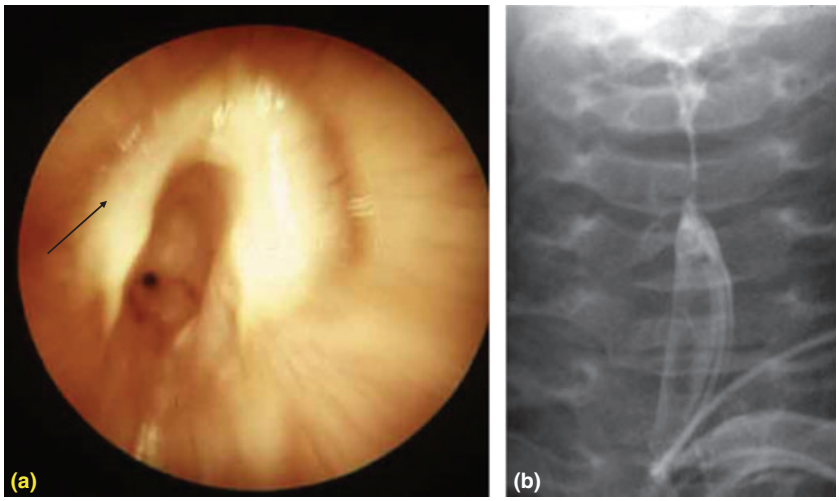

Figure 25
Final stage of all types of severe intubation trauma. Very narrow and long scar stenosis needing tracheostomy and long term surgery. (a) Subglottic and upper tracheal stenosis without infection before reconstructive surgery. The left vocal cord shows atrophy (arrow). (b) Laryngography of same stenosis, demonstrating a more than two vertebra long narrowing.

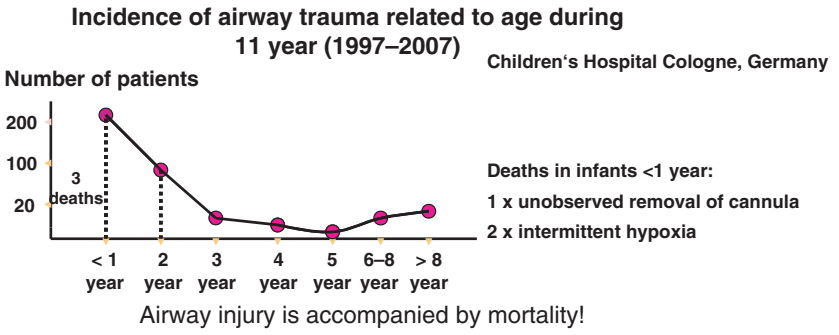

Figure 26
Number of patients investigated for airway injury during 11 years, acquired in the operating room or in the neonatal or pediatric ICU. The highest number airway injuries occurred in the first and second year of life.

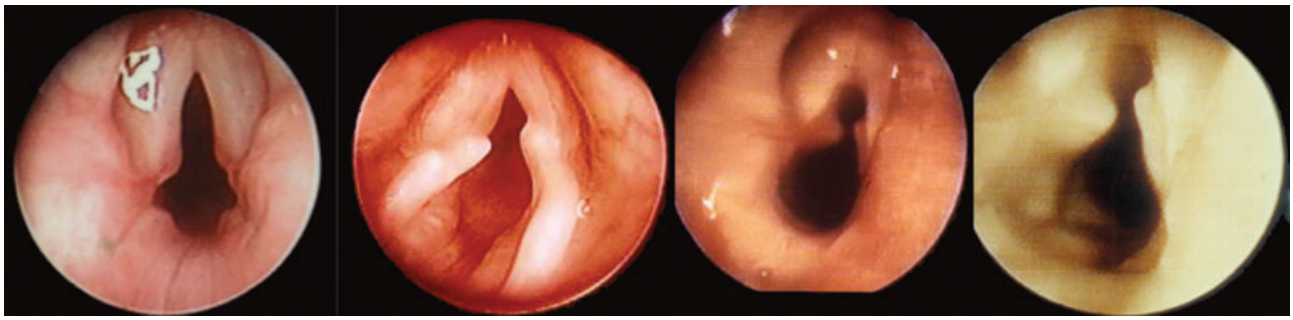

Figure 27
Preschool children with recent and old airway injuries without any clinical signs of airway injury at the time of endoscopy nor in the personal history. All patients underwent anesthesia one or more times. Incidental findings, probably showing that we see only the tip of the iceberg of airway injuries.

made (16), but no comparative description of cuffed tubes in all details is presently available. Figure 24 shows what details have to be considered when designing cuffed tubes for children.

Discussing intubation trauma at meetings and round tables, arguing occurs usually on two levels which impede understanding each other, leading to highly contrary opinions. One level deals with endoscopic data, the second with data from the literature, theoretical deductions thereof, material of cuffs (a very important aspect!) and measurements of dimensions of cuff and cuff pressures. Understanding between endoscopists is easy because all see the same anatomical structures with the same instruments and describe the injuries according to what they see. Understanding with the other group, using cuffed tubes without having endoscopic data of the effects of the cuffs on airway mucosa at their disposal, is very difficult. Arguments derived from studies with inadequate outcome measures, declaring them evidence based can not lead to solve any question in the field of intubation. These discussions on two levels should be brought to one by using only endoscopic follow-ups!

To our opinion the easiest way to accomplish this is a better training of far more anesthetists in endoscopic practice with simple instruments like Hopkins or Bonfils lenses (Figure 18) and its regular use in cooperation with pediatric ENT-surgeons. The involvement of pediatric ENT-surgeons in studies dealing with airway injury appears to be indispensable since many relevant lesions are detected only by experienced specialists. The sometimes devastating injuries caused by intubation which continue to occur should be a very strong incentive to do this! All manufacturers of cuffed tubes should present endoscopic evidence of the innocuousness of their respective products on larynx and trachea before releasing them on the market [Figure 24, embedded picture (b)]. In the future, using endoscopic instruments on a daily basis, diagnosing immediately clinically undetectable airway damage (Figure 10–12, 16, 27), wrong positions of tracheal tubes (Figure 19, 22c) and other types of injury to larynx and trachea (Figure 15, 16), will change the situation entirely. Having the opportunity to see airway damage with the own eyes will lead toward a more careful approach to the airway.

Conclusion

In all fields of medicine instruments providing direct view of hollow organs are used more and more often. Dealing with airway injury, only the use of endoscopes will provide comparable data and relate damage to causes and mechanisms of injury. The use endoscopic lenses on a daily basis ought to be one of the aims of training for pediatric anesthetists in the future to prevent iatrogenic airway trauma.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Video S1: Two year-old boy intubated for three days. Extubation after two days failed because of severe inspiratory stridor and obstruction of the upper airway. Endoscopy on the third day revealed combined injury of the larynx with deep ulceration and open cartilage on the posterior part of the the lamina of the cricoid ring and granulation tissue on the vocal cords.

Video S2: 15 year-old girl intubated because of pneumonia for two weeks. Endoscopy after three unsuccessful attemps to extubate revealed subglottic trauma with ulceras caused by the sharp folds of a non-inflated cuff placed in the subglottic area.

Video S3: Four year-old boy, three years after heart surgery at the age of one year. Short term post-extubation stridor. Scheduled for gastrostomy. No stridor present at the time of surgery. Central cicatricial stenosis at the level of the arch of the cricoid. Diameter is 4.5 millimeters.

Video S4: Girl, aged two months, four weeks after intubation-trauma with increasing stridor. Endoscopy revealed scar formation in progress at the level of the arch of the cricoid, diameter is 2 mm.

Video S5: Four year-old girl with a cicatricial stenosis at the level of the cricoid arch after intubation for cardiac surgery nine months ago. Diameter is 3 millimeters, tracheal cannula in the upper trachea.

Video S6: 11 year-old boy, two years after intubation for resection of adenoids. No post-extubation stridor. Increasing inspiratory stridor and decreasing physical ability appeared one year later. To the day of the endoscopy symptoms were treated as asthma. Endoscopy revealed a narrow eccentric stenosis at the level of the cricoids ring. The diameter is less than 3 millimeters.

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Conflict of interests

J.H. has received reimbursement from Karl Storz GmbH & Co. for attending several conferences. The other authors have declared no conflicts of interest.

References

1 Smith RM, Rockoff MA. History of pediatric anesthesia. In: Motoyama EK, Davis PJ eds. *Smith's Anesthesia for Infants and Children*, 7th edition. Mosby Elsevier, Philadelphia, 2006: 1178–1179.

2 Flag PJ. Endotracheal inhalation anesthesia: special reference to postoperative reaction and suggestions for their elimination. *Laryngoscope* 1951; **61:** 1.

3 Baron SH, Kohlmoos HW. Laryngeal sequelae of endotracheal anesthesia. *Ann Otol Rhinol Laryngol* 1951; **60:** 67.

4 Eckenhoff JE. Some anatomic considerations of the infant larynx. *Anesthesiology* 1951; **12:** 401–410.

5 Holinger LD, Green CG. Anatomy. In: Holinger LD, Lusk RP, Green CG, eds. *Pediatric Laryngology & Broncholog*. Philadelphia: Lippincott-Raven, 1997; 21–24.

6 Eckel HE, Sprinzl GM, Sittel C *et al*. Zur Anatomie von Glottis und Subglottis beim kindlichen Kehlkopf. *HNO* 2000; **48:** 501–508.

7 Khine HH, Corddry DH, Kettrik RG *et al*. Comparison of cuffed and uncuffed endotracheal tubes in young children during general anesthesia. *Anesthesiology* 1997; **86:** 627–631.

8 Murat I, Holzki J *Pro/*Contra Cession Cuffed vs Uncuffed Tracheal Tubes in Children <8 years. Dublin: APA annual scientific meeting, 2003.

9 Newth CJ, Rachman B, Patel N *et al*. The use of cuffed vs uncuffed endotracheal tubes in intensive care. *J Pediatr* 2004; **144:** 333–337.

10 The International Liaison Committee on Resuscitation (ILCOR) consensus on science with treatment recommendations for pediatric and neonatal patients: pediatric basic and advanced life support. *Pediatrics* 2006; **117:** e955–77.

11 Holzki J. Threat to the larynx in early childhood by intubation. *Dtsch Arztebl* 1993; **90B:** 1131–1134.

12 Fisher DM. Highlight: comparison of cuffed and uncuffed endotracheal tubes in young children during general anesthesia. *Anesthesiology* 1997; **V 86:** 27 A.

13 Deakers TW, Reynolds G, Stretton M *et al*. Cuffed endotracheal tubes in pediatric intensive care. *J Pediatr* 1994; **125:** 57–62.

14 Holzki J, Laschat M, Puder C *et al*. *The difficult airway in paediatric anaesthesia*. Presented at the HAI congress Berlin, September 2008, FEAPA conference Athens, September 2008, Airway days University, Heidelberg, November 2008. Unpublished experimental data.

15 Sheridan RL. Uncuffed endotracheal tubes should not be used in seriously burned children. *Pediatr Crit Care Med* 2006; **7:** 258–259.

16 Dullenkopf A, Schmitz A, Gerber AC *et al*. Tracheal sealing characteristics of pediatric cuffed tracheal tubes. *Pediatr Anesth* 2004; **14:** 825–830.

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