Percutaneous trans-tracheal jet ventilation for paediatric endoscopic laser treatment of laryngeal and subglottic lesions

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Percutaneous transtracheal high frequency jet ventilation (TTJV) in adults is frequently used during anaesthesia for laryngeal microsurgery. It provides excellent surgical operating conditions and safety for the patient. The technique has not been evaluated in infants and children. Accordingly, we studied 16 infants and children (mean age 5.5 ± 3.8 yr, range 6 wk–12 yr) who underwent 28 consecutive endoscopic procedures with laser microsurgery of the glottic or subglottic space under general anaesthesia using a TTJV technique. All patients had a severe obstructive lesion of the larynx and/or upper trachea. The mean duration of the procedure was 70 ± 27 min (range 30–140 min). Indications for TTJV were: subglottic stenosis: 5, haemangioma: 4, laryngeal papillomatosis: 5, pharyngeal cyst: 1, laryngomalacia: 1. Adequate control of the airway and satisfactory gas exchange were obtained in all cases. Surgery was performed without being impeded by anaesthetic equipment. Three complications occurred: one extensive surgical emphysema; one bilateral pneumothorax; one severe vagus-induced cardiovascular depression. Prompt and complete recovery without sequelae followed appropriate treatment. In 32% of the cases, the children were outpatients and in about half of the procedures (13/28) they left the hospital between the

first and the third day. We conclude that percutaneous trans-tracheal jet ventilation is effective in paediatric endoscopic surgery. Procedures that might otherwise require a tracheostomy can be performed safely with this minimally invasive technique. Adequate indications and appropriate understanding of the technique and its potential problems are required for its correct application and successful use.

Les avantages et inconvénients de la ventilation transtrachéale pour la chirurgie endoscopique au laser des voies aériennes supérieures sont bien connus chez l'adulte. Par contre l'intérêt de cette technique dans le traitement chirurgical au laser des pathologies glottiques ou sous-glottiques de l'enfant n'a pas encore été évalué. Dans ce but, nous avons étudié 16 patients âgés de 6 semaines à 12 ans ($5,5 \pm 3,8$ ans), ayant nécessité 28 interventions endoscopiques pour le traitement d'une lésion obstructive sévère du larynx et/ou de la trachée supérieure, et chez qui une ventilation transtrachéale a été utilisée. La durée moyenne de l'intervention a été de 70 ± 27 min (30–140 min). Les indications de cette technique ont été: sténose sous-glottique: 5, hémangiome sous-glottique: 4, papillomatose laryngée: 5, kyste pharyngé: 1, laryngomalacie: 1. Les principaux avantages de cette technique sont: un accès chirurgical libre de tout tube ou sonde endotrachéale, une visibilité optimisée de l'endolarynx, un bon contrôle des voies aériennes, le maintien d'échanges gazeux satisfaisants, ainsi que l'élimination des dangers d'ignition du tube endotrachéal. Nous avons rencontré trois complications majeures: un emphysème sous-cutané important consécutif à la perforation accidentelle d'un cathéter par une aiguille chirurgicale; un barotraumatisme avec pneumothorax bilatéral lié à l'obstruction complète de la voie aérienne par une manipulation instrumentale; enfin, une bradycardie extrême avec arrêt circulatoire d'origine vagale au cours du positionnement d'une spatule de micro-laryngoscopie. Dans chacun de ces cas, l'instauration immédiate d'un traitement adéquat a permis une récupération rapide, complète et sans séquelles. Dans 32% des cas, les patients étaient am-

Key words

ANAESTHESIA: paediatric;

LARYNX: obstruction;

VENTILATION: jet, high frequency jet, transtracheal;

EQUIPMENT: catheters, transtracheal; ventilators, high frequency jet.

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bulatoires, et dans presque la moitié des cas (13/28), ils ont quitté l'hôpital entre le 1^{er} et le 3^{ème} jour. A notre sens, la ventilation transtrachéale est une alternative valable et utile en chirurgie endoscopique pédiatrique; elle assure des conditions opératoires optimales et, dans certaines situations, permet d'éviter une trachéostomie avec ses risques de morbidité et de mortalité chez le nourrisson et le petit enfant. Néanmoins cette technique est plus invasive que l'intubation trachéale et ne doit pas être utilisée de routine. Le respect des indications et la connaissance appropriée de cette technique et de ses complications potentielles sont indispensables pour une utilisation efficace et sûre.

Severe obstructive lesions of the upper airway remain a challenging problem for anaesthetists and ENT surgeons. The development of surgery with CO₂ laser and fiberoptic instrumentation has made it possible to treat some laryngeal or subglottic lesions by endoscopic laser microsurgery.^{1,2} However, a wide unobstructed endoscopic access and a motionless operative field are essential requirements for the safety and effectiveness of such a surgical technique. In infants and small children, a stenotic lesion at the level of their narrow glottic or subglottic space adds further constraints.³ The use of a transglottic endotracheal tube secures the airway but has major potential disadvantages including limited surgical access, direct laryngeal trauma or ignition of flammable material.^{4,5} Few alternative techniques ensure both a free endoscopic operative field and a secure airway with adequate ventilation and oxygenation, while eliminating potential hazards from accidental tube ignition.

Transtracheal oxygenation was first reported by Jacoby *et al.*⁶ in 1951. Later, in 1967, intermittent high-flow oxygen at high pressure (jet ventilation) was used to ventilate the lungs either via a bronchoscope^{7,8} or through a small catheter.⁹ Lung ventilators using a fluidic design were developed to provide high frequency jet ventilation (HFJV).¹⁰ The continuous monitoring of intratracheal pressure associated with automatic cut-off at any preset level increased the safety of this technique. Klain *et al.* first combined HFJV with transtracheal ventilation in 1977.¹¹

High frequency transtracheal jet ventilation (TTJV) for microlaryngoscopic laser surgery offers many advantages: the absence of an endotracheal tube allows excellent visibility of the operative field, profound muscular relaxation is possible whenever required, adequate gas exchange is maintained, the potential danger of endotracheal tube fire and airway trauma that a tracheal tube might cause are eliminated, and the risk of aspiration of blood and debris although present is prevented by the continuous expir-

FIGURE 1 Subglottic haemangioma obstructing the tracheal lumen by approximately 80% in a three-month-old infant weighing 5.3 kg.

atory flux.¹² Transtracheal jet ventilation in adults is used routinely by several authors,^{9,11-14} whereas in infants and children its use is still anecdotal¹⁵ and controversial.¹⁶ Accordingly, we prospectively studied 16 infants and young children with severe obstructive lesions of the larynx and/or upper trachea, who underwent 28 consecutive procedures using a TTJV technique for endoscopic CO₂ laser microsurgery.

Methods

Following approval of the departmental ethics committee we concluded a prospective study of infants and children aged up to 12 yr scheduled for endoscopic CO₂ laser microsurgery under general anaesthesia with TTJV. All patients scheduled for endoscopic airway laser microsurgery were identified. Indications for the use of a TTJV technique were: extensive laryngeal surgery involving the vocal cords and/or the subglottis with an obstruction of the lumen size of more than 70% of normal (Figure 1), or procedures requiring wide exposure of the operative field. Exclusion criteria for this technique were: infection at the puncture site and massive deformation of the anterior cervical area. Informed consent was obtained from the parents.

After preanaesthetic assessment, all patients were premedicated with atropine 0.04 mg · kg⁻¹ *po*. To diminish stress-induced dyspnoea, a benzodiazepine (midazolam 0.2 mg · kg⁻¹ or flunitrazepam 0.04 mg · kg⁻¹) was ad-

ministered orally as required under strict supervision 45 min before the child was brought to the operating room. Routine monitoring devices (ECG, precordial stethoscope, automated blood pressure cuff, pulse oximeter, peripheral nerve stimulator and temperature probe) were applied prior to the induction of anaesthesia. Anaesthesia was induced by mask with halothane in oxygen or by thiopentone ($3\text{--}5\text{ mg}\cdot\text{kg}^{-1}$) (or, since 1991, propofol $1.5\text{--}3\text{ mg}\cdot\text{kg}^{-1}$) *iv*, depending on the preference, age and physical status of the child. Once manual positive-pressure ventilation by bag and mask was possible, a paralyzing dose of vecuronium ($0.08\text{ mg}\cdot\text{kg}^{-1}$) was injected. Anaesthesia and muscle relaxation were maintained with alfentanil ($0.005\text{--}0.045\text{ mg}\cdot\text{kg}^{-1}$), vecuronium as needed and small doses of thiopentone or propofol to prevent awareness. At the end of the procedure, vecuronium was antagonised with neostigmine ($0.04\text{--}0.06\text{ mg}\cdot\text{kg}^{-1}$) and atropine ($0.02\text{--}0.03\text{ mg}\cdot\text{kg}^{-1}$).

After induction of anaesthesia, a rigid paediatric bronchoscope was brought to the level of the vocal cords and connected to a Mapleson D breathing system using 100% oxygen. Under direct endoscopic vision (by the surgeon through a rigid telescope and by the anaesthetist on a monitoring screen coupled to an endoscopic videocamera) a transtracheal catheter was inserted percutaneously through the cricothyroid membrane and its correct position in the trachea confirmed (Figure 2). The catheter used was an 18G, ID 0.8 mm, length 37 mm, radio-opaque Teflon catheter, mounted on a stainless steel needle (VBM laboratories, D-72172 Sulz-am-Neckar, Germany). It is angulated 15° in the coronal plane to facilitate its insertion and alignment in the trachea. Two lateral attachments allow a tight and secure fixation around the neck using a Velcro band (Figure 3). In the postoperative period the catheter was left in place for 2–12 hr in all patients except the three with a severe complication (see below) for the administration of oxygen and/or for ventilatory management, if required, in the presence of laryngeal oedema or spasm.¹⁵

Once the catheter was correctly placed and secured, it was then attached via its Luer-Lock connector to an actuated solenoid valve jet ventilator (Acutronic MK 800 and, since 1990, Acutronic AMS 1000, Acutronic Medical System, CH-8645 Rapperswil, Switzerland). The jet flow was at first controlled manually until the suspension laryngoscope was satisfactorily positioned and adequate outflow was observed. Thereafter the driving pressure was set at 30 kPa (4.35 psi), at a T_i/T_{tot} ratio of 0.25 to 0.33 and at a rate of 100 to 125 min^{-1} , and gradually increased according to chest expansion, airway pressure (indicated by the AMS 1000) and SpO_2 , until an adequate minute volume was delivered. Adequate chest excursion and absence of escape of air at the end of expiration

FIGURE 2 Endoscopic view through a rigid bronchoscope of the introduction of the transtracheal 18G catheter, in a one-year-old boy. This patient had a glottic and subglottic posterior synechiae following tracheal intubation of four days' duration, five months previously.

FIGURE 3 Intraoperative position of the patient described in Figure 2. In such small children, the hand on the thorax may be a better monitoring for chest exsufflation than end-expiratory pressure (Cros *et al.* *Anesthesiology* 1993; 79, A555, ref 34).

were carefully checked throughout the procedure (Figure 3); CO_2 was not monitored routinely. The blender was set to deliver a mixture of 30% oxygen in nitrogen while the laser was in use. At the end of the procedure the jet ventilator was turned off and the lungs were gently ventilated with 100% oxygen via a face mask, until spontaneous ventilation resumed. The patients were then transferred to the paediatric intensive care unit or the recovery suite and observed and monitored for at least five hours.

Complications, i.e., airway obstruction, hypoventilation, hypoxaemia, high airway pressure, emphysema, barotrauma, aspiration of resected material or liquid as well

as haemodynamic or cardiac disturbances, were carefully noted.

Results

During the period 1987–93, 16 children (5 boys, 11 girls), aged from 6 wk to 12 yr (mean 5.5 ± 3.8 yr), weighing 2.8 to 46 kg (mean 18.1 ± 10.9 kg) underwent 28 endoscopic CO₂ laser microsurgical procedures using a TTJV technique (Figure 4) for various obstructive lesions (Table). The mean duration of the procedure was 70 ± 27 min (range 30–140 min). Four patients required more than one procedure because of recurrence of the disease, especially in juvenile laryngeal papillomatosis, one child needing nine sessions. All patients had inspiratory or inspiratory and expiratory stridor, epigastric retraction with or without tracheal tug, dyspnoea and/or tachypnoea on slight exertion or at rest; three patients had a history of recurrent episodes of cyanosis, which in two cases required repeated tracheal intubation; one infant had apnoeic spells and another's trachea had already been intubated for one month. Congenital abnormalities – a Pierre Robin and a Pallister-Hall syndrome – were present in two patients.

On 26 occasions the transtracheal catheter was correctly placed on the first attempt. One catheter was seen to enter the oesophageal lumen and another followed a submucosal tracheal path, causing slight bleeding. In both cases, the cannula was withdrawn immediately and repositioned successfully on the second attempt without further incident. Exposure of the larynx and subglottic area was optimal in all but one case: microlaryngoscopy could not be achieved in the three-month-old boy with laryngomalacia and the Pierre-Robin syndrome; resection of the epiglottis required the use of a special bronchoscope coupled to the CO₂ laser. Oxygenation was adequate ($SpO_2 > 95\%$) in all patients but one in whom the lowest peripheral oxygen saturation reading recorded was 92%. No patient required immediate reoperation or tracheotomy and no airway fire occurred.

Outpatient endoscopic surgery was achieved in 32% (9/28) of the procedures, mainly in older children with laryngeal papillomatosis. In about half of the procedures (13/28) the patient was discharged between the first and the third postoperative day. A delayed discharge (between the sixth and the ninth postoperative day) occurred in four cases. Two patients, each having had one session of TTJV, required a prolonged hospital stay due to medical problems unrelated to the procedure. On two occasions, withdrawal of the transtracheal catheter was followed by benign subcutaneous cervical emphysema, which resolved spontaneously within a few hours.

Three severe complications (10.7%) occurred:

1 Cervical emphysema with pneumomediastinum and

FIGURE 4 Division of the 28 cases according to age.

TABLE Indications for endoscopic surgery

Type	No. of patients	No. of sessions
Subglottic stenosis	5	6
Subglottic haemangioma	4	5
Laryngeal papillomatosis	5	15
Pharyngeal cyst	1	1
Laryngomalacia	1	1
Total	16	28

pneumoperitoneum occurred within minutes following accidental puncture of the transtracheal catheter with a surgical needle used to fix a strip of silicone at the level of the anterior commissure. The HFJV was stopped immediately and the trachea was intubated. Surgery could be completed. The subcutaneous emphysema was treated by needle aspiration, but pleural drainage was considered unnecessary. Complete regression of the emphysema and pneumothorax occurred rapidly and the trachea was extubated 12 hr later without sequelae.

- 2 Pulmonary barotrauma occurred in a six-week-old girl as a result of three associated factors: (a) total outflow obstruction by surgical instrumentation, (b) absence of an airway pressure monitor coupled to automatic interruption of gas delivery following activation of the alarm device, and (c) delay in switching off the jet ventilator. A chest x-ray showed bilateral pneumothoraces and subcutaneous emphysema extending to the mediastinum and the peritoneum. Bilateral chest tubes were inserted and the trachea intubated without difficulty using a 2.5 mm diameter nasal endotracheal tube. Three days later, the operation was carried out uneventfully using TTJV. The child was discharged six days later.

3 Bradycardia and hypotension occurred in a five-year-old child during manipulation of the larynx while the surgical laryngoscope was being positioned. Administration of atropine in incremental doses up to 1 mg had no effect. Clinical examination revealed normal chest motion with normal symmetrical auscultation and adequate gas escape. At this time the peripheral oxygen saturation was 100% and no twitches were visible during supramaximal train-of-four stimulation. No signs of subcutaneous emphysema were noted. Despite the administration of atropine the bradycardia was followed by AV dissociation. One minute of external chest compression restored normal sinus rhythm and blood pressure. The chest x-ray was normal and blood gas analysis indicated a mild respiratory acidosis ($\text{PaO}_2 = 274$ mmHg, $\text{PaCO}_2 = 59$ mmHg and $\text{pH} = 7.30$). It was decided to complete the procedure and the trachea was intubated at the end of the procedure for postoperative respiratory assistance. The trachea was extubated uneventfully 18 hr later and the patient was discharged on the third postoperative day without further problems. Vagal stimulation during positioning of the microlaryngoscopy blade and not the TTJV technique itself was probably the cause of this complication.

Discussion

Various techniques for ventilation during anaesthesia for micro-laryngeal laser surgery have been described. Spontaneous breathing techniques using nasotracheal insufflation of an oxygen-enriched gas mixture including a volatile agent can be useful if functional abnormalities of the larynx or trachea are to be diagnosed.¹⁶ However, spontaneous ventilation is less suitable for endoscopic laser surgery because aspiration of blood or debris may occur at any time and immobility of the laryngeal field, which is essential for accurate laser application, cannot be guaranteed. Moreover, the depth of anaesthesia required to obtund the strong laryngeal and upper airway reflexes is associated with a substantial risk of respiratory depression, and laryngospasm may occur if the patient is lightly anaesthetized. Contamination with volatile agents is another disadvantage.⁵ Thus it seems more advisable and safer to use muscle relaxation and controlled ventilation.

Tracheal intubation for microlaryngeal surgery is probably the most widely used technique. It ensures protection of the airway, and adequacy of ventilation can be assessed by spirometry and capnography. The drawbacks and complications of this technique have been well documented^{4,5,17} and include: limited surgical access to certain lesions, impeded view of the endolarynx, decreased space for surgical manipulations, distortion of tissues and structures and the presence of potentially ignitable material

close to the laser beam. Intubation can also cause the spread of neoplastic cells and tissue¹⁸ and is known to cause mucosal trauma and oedema that may lead to prolonged postoperative intubation or even to tracheostomy.¹⁹ Reintubation should be avoided whenever possible as it may compromise many of the advantages of laser surgery, which essentially allows a wound to heal with limited retractions due to minimal tissue trauma, absence of oedema and a bloodless field.²

Since, in these cases, the goal of surgery is to relieve airway obstruction, we try to avoid elective tracheostomy. Tracheostomy in infants and children is associated with severe morbidity and even mortality^{19,20} and should be reserved for immediately life-threatening situations when other methods have failed.²⁰

Jet ventilation allows the use of small ID tubes or catheters. Supraglottic jet ventilation produces vibrations of the vocal cord-false cord region and incurs the risk of blowing tissue particles down the tracheobronchial tree. Hence it is contra-indicated in children with juvenile papillomatosis because of the risk of tracheal or pulmonary implantation.²¹ Furthermore, when jet ventilation is performed proximal to a stenosis, adequate ventilation and oxygenation cannot be reliably achieved and regurgitation, gastric distension, and even gastric rupture have been reported.^{5,22}

The HFJV technique through a nasal or oral 16G transglottic catheter inserted into the upper trachea is used routinely at our institution for endoscopic paediatric surgery. However, with severe stenotic lesions, the laryngeal diameter may be decreased by more than 70%, so that even a small catheter (e.g., 1 mm ID) placed through the orifice will severely impair expiration resulting in the risk of barotrauma. Furthermore, a translaryngeal catheter may cause drawbacks similar to those encountered with an endotracheal tube. Before using TTJV, we used this technique with periods of apnoea during laser resection in infants and small children with severe glottic or subglottic stenosis. The complications were two pneumothoraces and three severe laryngospasms in 15 patients between 1982 and 1987.

Percutaneous TTJV is a well-established technique in adult micro-laryngeal surgery²³ and may be a life-saving procedure in acute laryngeal obstruction of the larynx. The advantages and complications of TTJV have been described during both elective surgery and emergency airway management.^{9,13,14,24-26} In endoscopic surgery, TTJV avoids trauma to the diseased tissues and preserves the initial laryngeal state which, along with the quality of endoscopic exposure, may offer a decisive therapeutic advantage. Immobility of the operative field ensures optimal precision of the laser beam and inhalation of particles, saliva and/or tumour debris is prevented by the contin-

uous expiratory flow. The most serious complication associated with the use of an endoscopic laser is an endotracheal fire.²⁷ The high energy density of the laser beam striking a flammable tube can convert it into a "blow torch," thereby inflicting extensive damage to the airway. The absence of an endotracheal tube to act as a source of combustion is a major advantage of TTJV. Moreover, a recent evaluation of the Teflon catheter used in this study showed that a high laser power setting under continuous mode and 100% oxygen generates only a small intermittent candle-like ignition after several seconds.²⁸

Under direct endoscopic vision, percutaneous positioning of the catheter is a safe and easy technique even in infants and small children. The catheter was placed on the first attempt without bleeding or trauma to the posterior tracheal wall in more than 90% (26/28) of the cases. Correct positioning of the tip of the catheter must be checked before starting jet ventilation. The two misplacements that occurred during introduction of the cannula were without complication because they were immediately detected endoscopically. Thanks to adequate attachment around the neck, no catheter kinked or was displaced during the procedure or the postoperative period. The benign cervical subcutaneous emphysema, which occurred in two patients after removal of the transtracheal cannula, is a common feature of many reports.^{11,25,26,29,30} It is a minor but disturbing complication because it is difficult to avoid. Slight pressure at the puncture site after removal of the catheter as advocated by many authors^{9,26,29,30} is not always feasible in uncooperative and agitated babies. The accidental perforation of the catheter by a surgical needle (complication #1) is the only serious and unusual complication related directly to the use of a transtracheal catheter. The risk that this will occur again is obviously very small.

It has been shown in a model using a standard setting of jet ventilation that narrowing of the airway proximal to the jet produces a higher peak inspiratory pressure, a longer expiratory time for total deflation of the lung (Tdef) and an increased end-expiratory pressure (EEP), resulting in an increased functional residual capacity, while the tidal volume remains largely unchanged.^{31,32} The level of EEP depends on the one hand on the ventilator setting and on the other hand on the expiratory time constant, thus Tdef.^{31,32} So, in the presence of severe glottic stenosis with prolonged Tdef, pulmonary overdistension may occur together with increased EEP, and subsequent risk of barotrauma, unless the driving pressure is decreased and the expiratory time is increased by lowering T_i/T_{tot} ($\leq 25\%$) and/or the frequency ($\leq 100 \text{ min}^{-1}$).^{31,32} It is also the responsibility of the surgeon to ensure permanent patency of the airway which is grad-

ually improved by laser resection of the obstructive lesion. Therefore the driving pressure can be progressively increased until an optimal setting is achieved. If, for technical reasons such as laryngoscope insertion, or lateral vaporisation of a tumour, a temporary total obstruction of the airway is needed, short periods of apnoea may be required. Thus, close cooperation between the surgeon and the anaesthetist, and careful observation of chest inflation and deflation (Figure 3) as well as breath sounds during each respiratory cycle are mandatory to prevent air trapping and barotrauma.

Finally, to prevent barotrauma, the ventilator must be equipped with an EEP alarm, which immediately stops the insufflation until EEP has reached its preset level. High frequency jet ventilators applying this principle require a second catheter in the airway for airway pressure monitoring. It may be inconvenient to pass a second cannula perorally into the trachea of infants with severe glottic or subglottic stenosis; for this reason measurement of airway pressure was not attempted in the patient who developed bilateral pneumothoraces (complication #2). This complication might have been avoided by the correct use of such monitoring, although airway pressure is not reliable for the evaluation of lung volume in infants.^{33,34} A new system for airway pressure monitoring has been developed and adjusted to the AMS 1000 ventilator; EEP is measured directly through the injector catheter at the end of each expiration and the next ventilatory cycle is inhibited whenever EEP does not decrease below a preselected limit. In infants, however, the correlation between pulmonary distension and EEP is not as accurate as in adults;^{33,34} for this reason, it is recommended that pulmonary distension be evaluated continuously with one's hand on the thorax of the infant (Figure 3) together with EEP monitoring.

Conclusions

We believe that percutaneous TTJV is a useful technique for therapeutic endoscopy of the narrow larynx and subglottic space in infants and small children. It provides excellent operative conditions by increasing the exposure of the surgical field,³⁵ provides adequate gas exchange and reduces ignition hazards, all conditions which greatly increase the safety of the procedure.²³ Postoperative tracheal intubation or even tracheostomy may thus be avoided.

The insertion of the catheter is a safe procedure provided that it is performed under direct endoscopic control. Adequate monitoring of the end-expiratory pressure together with constant clinical surveillance of chest movements and gas egress is of great importance to avoid pulmonary barotrauma.

As TTJV is more invasive than orotracheal intubation,

it should not be used as a routine technique in paediatric endoscopic surgery, despite its advantages. However, in selected cases such as those with upper airway stenosis, TTJV can avoid a difficult and complicated procedure or the need for a tracheostomy and should therefore be considered and performed by experienced practitioners in specialised centres.

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