MANAGEMENT OF NON MALIGNANT AIRWAY OBSTRUCTION

Dr. Kajal Arora

16/10/2020

BASICS OF CAO

CAO – Central airway obstruction - Defined as obstruction of airflow in trachea and mainstem bronchi

UAO – Upper airway obstruction – obstruction of flow in portion of airway extending from mouth through length of trachea including nasopharynx and larynx

BASICS OF CAO

Two systems widely used for grading laryngotracheal stenosis

a. The McCaffrey system: Based on site and extent of airway stenosis

- Stage I – Lesions confined to subglottis or trachea that are less than 1cm in length
- Stage 2 – Subglottis stenosis longer than 1 cm within cricoid and not extending to glottis or trachea
- Stage 3 – Subglottic stenosis that extend into upper trachea but do not involve glottis
- Stage 4 – Lesions involving glottis

McCaffrey et.al. Laryngoscope. 1992;102:1335-1340

b. The Myer-Cotton System – Based on degree of narrowing

- GRADE I – lesions narrowed to maximum 50% obstruction
- GRADE II – From 51% to 70% obstruction
- GRADE III – From 71% to 99% obstruction
- GRADE IV – 100% obstruction (no lumen detected)

Myer et.al. Ann Otol Rhinol Larngol. 1994;103:319-323

CLINICAL ANATOMY

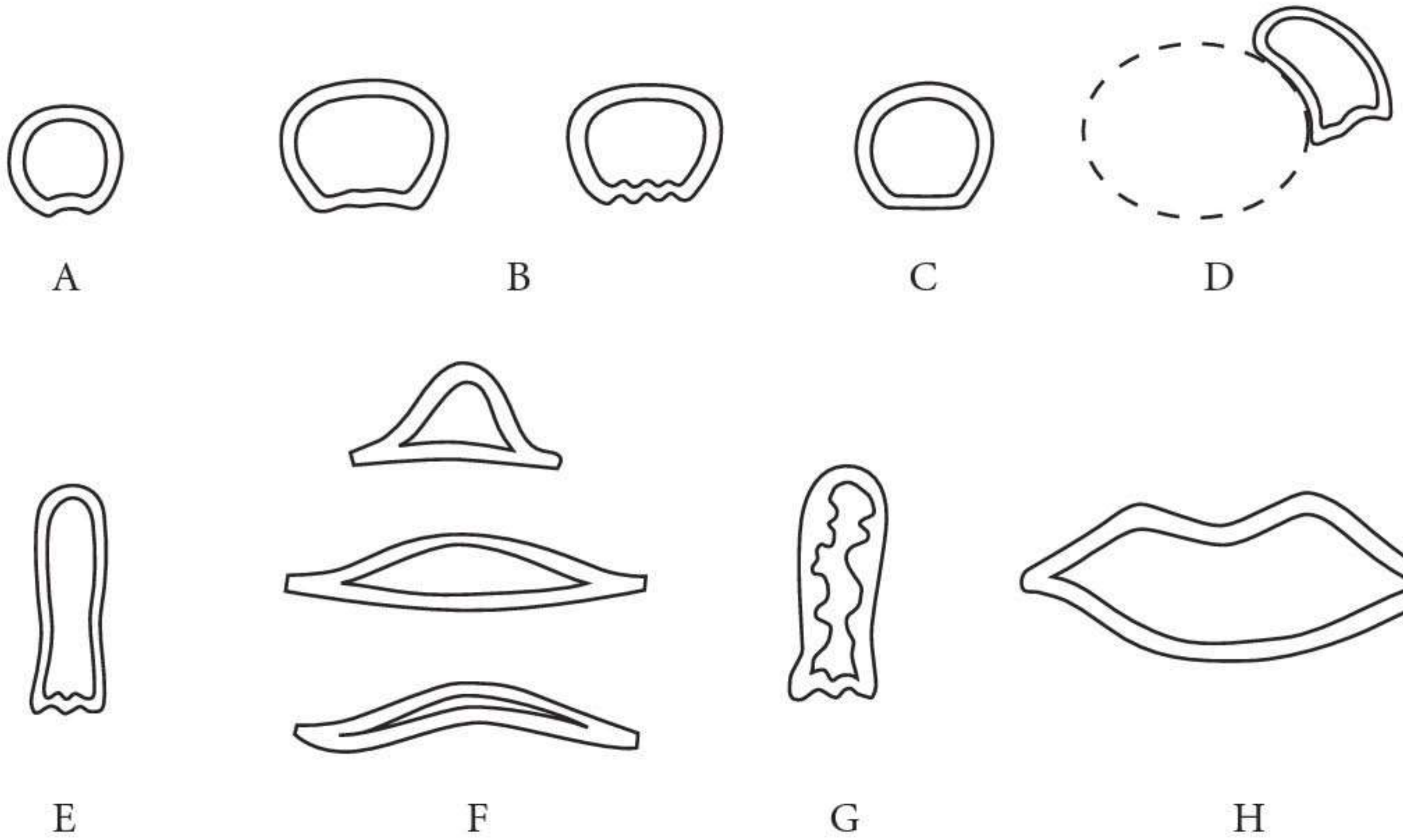
- About 3/5 of juvenile trachea reside above sternal notch. About ½ in young adults and 1/3 or less in older adults
- In adult, tracheal lumen is roughly ovoid, flattened anteroposteriorly
- In adult male external diameters measure about 2.3 cms coronally and 1.8 cms sagitally. In females 2.0 and 1.4 cms

Textbook Surgery of the trachea and bronchi by GRILLO, 2004

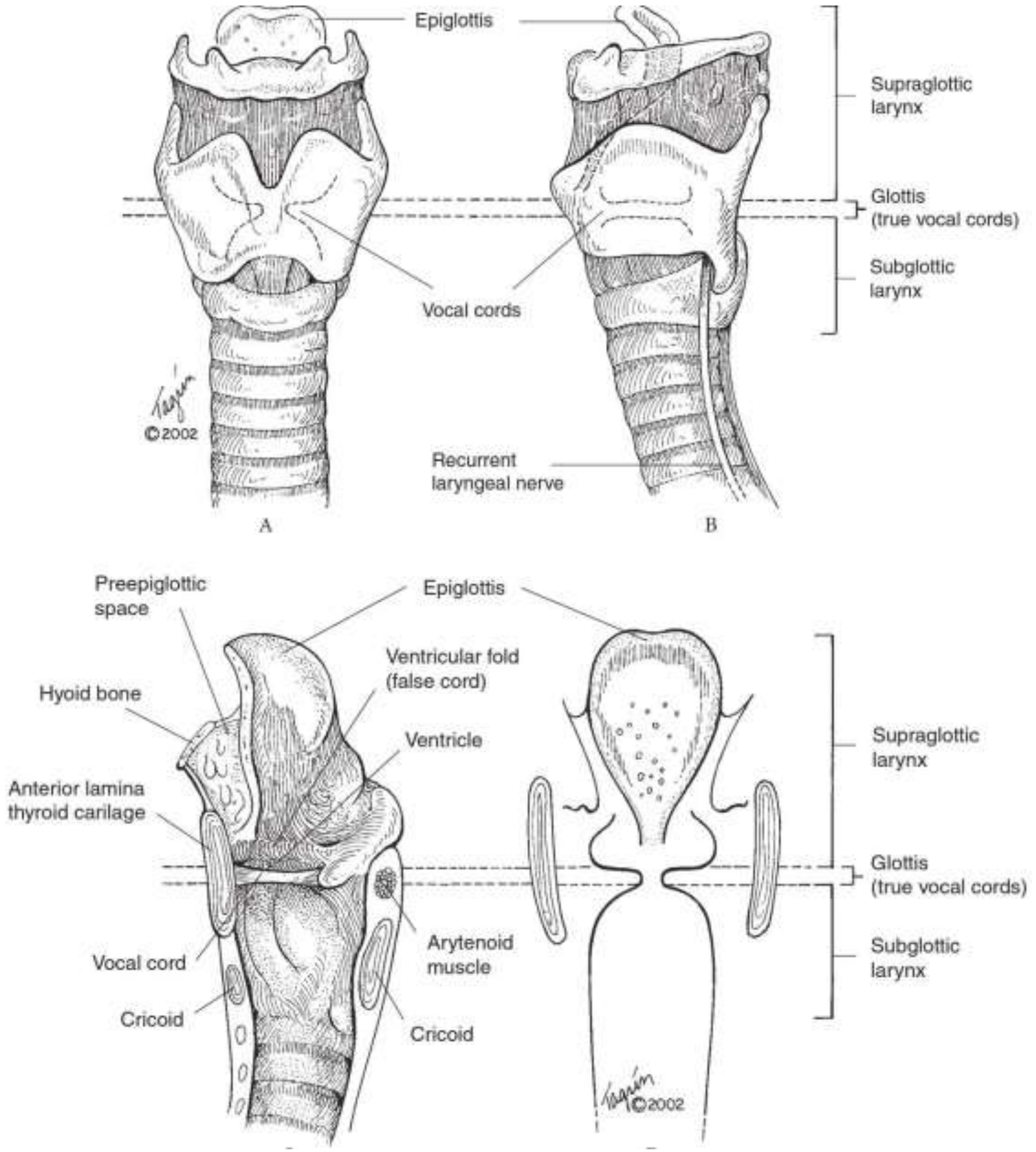
CLINICAL ANATOMY

- Tracheal wall is about 3mm thick
- Trachea narrows progressing distally to carina, more notably in children
- Small man or woman even if obese have trachea of shorter length and narrower diameter, excessively wide tube can produce subglottic erosion and stenosis

Textbook Surgery of the trachea and bronchi by GRILLO, 2004

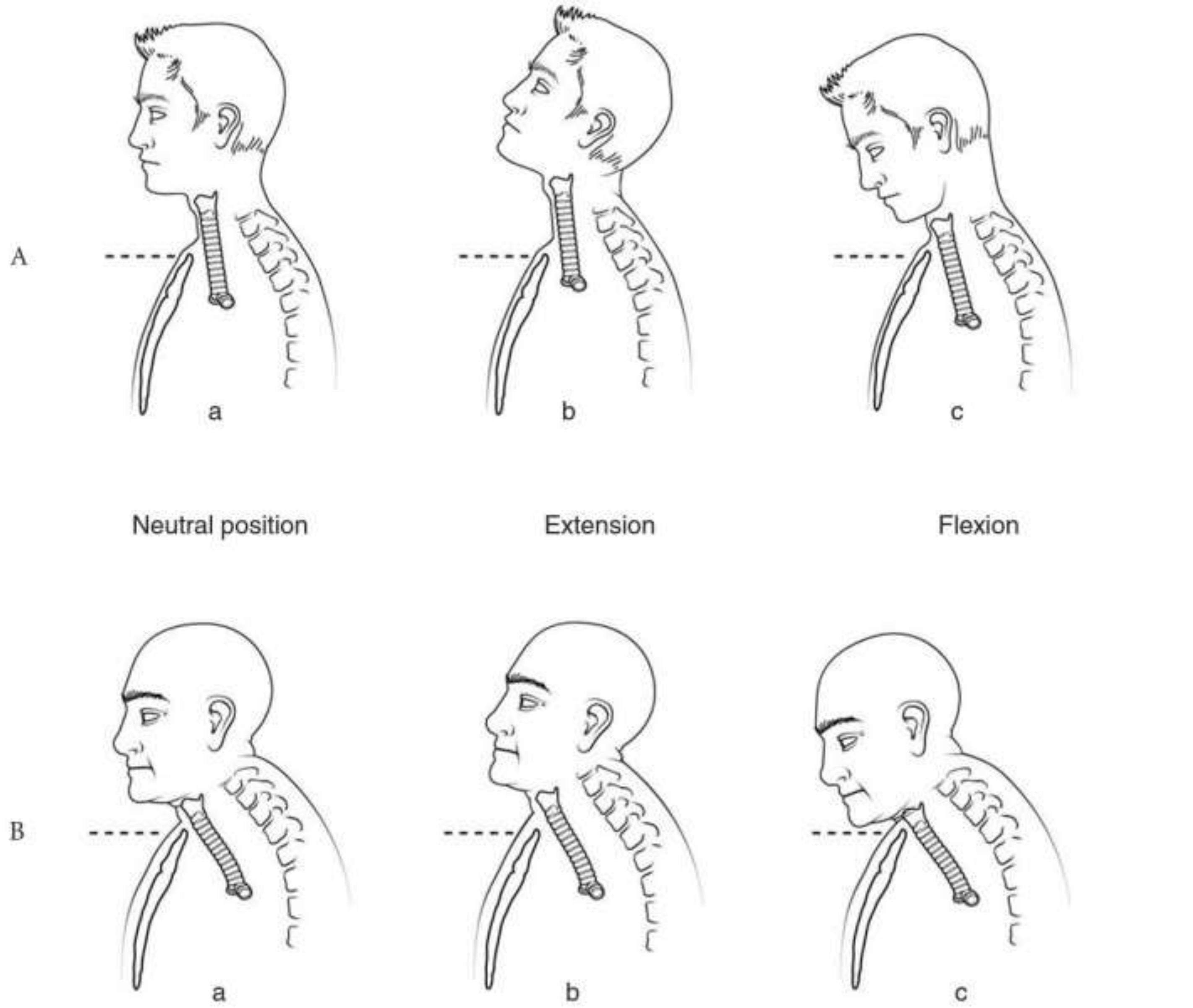


A. Juvenile trachea appear circular
B. Adult male trachea at rest, with cough membranous wall accordions pulling together cartilage
C. Adult female smaller in diameter
D. Common deformity related to proximity to aorta just above left main bronchus
E. Saber sheath. Walls are not malacic
F. Triangular deformation which occurs in COPD
G. Saber sheath configuration with characteristic submucosal osseocartilaginous nodules
H. Deformity occurring in tracheomegaly, Mounier- Kuhn disease



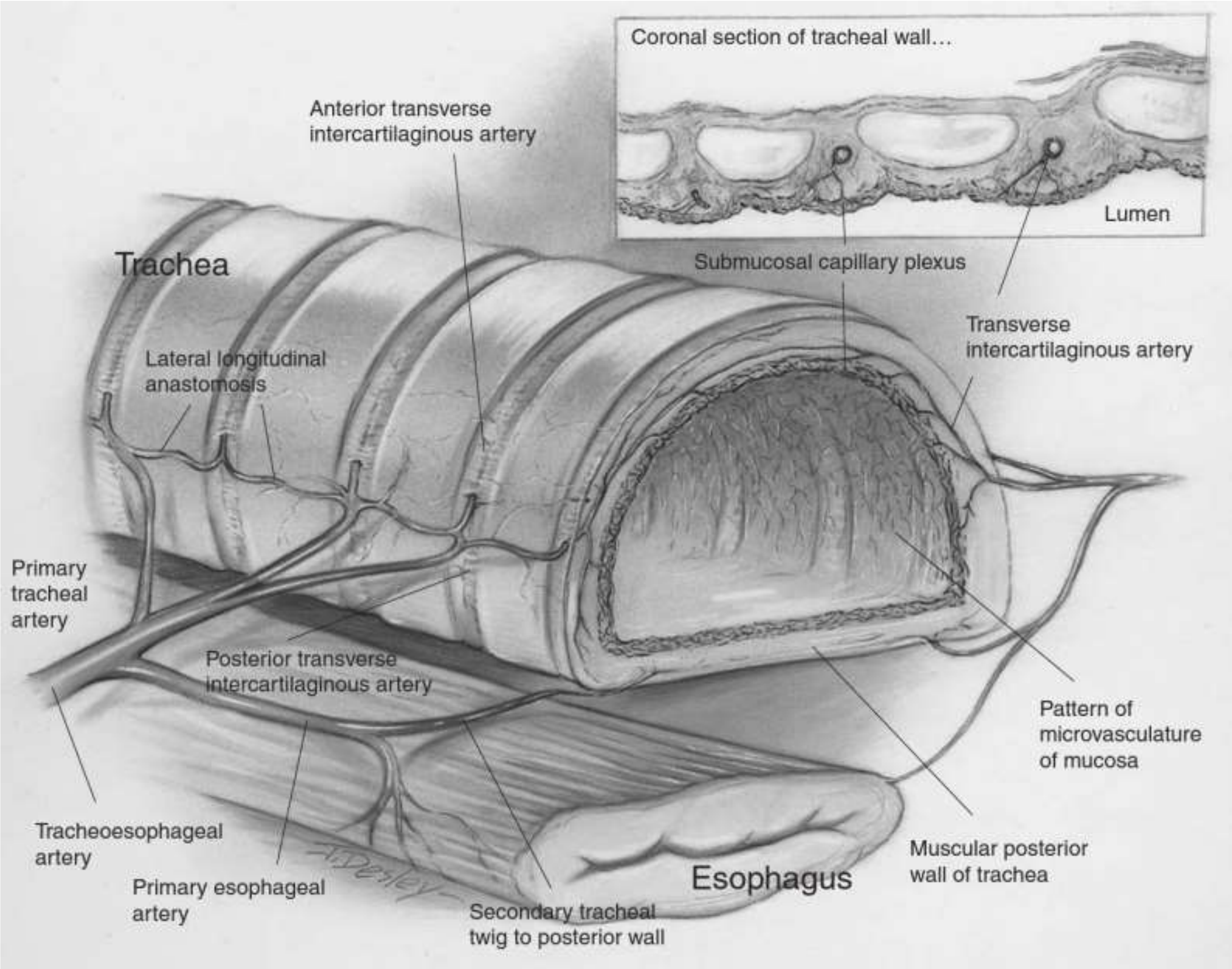
POSITION OF VOCAL CORDS IN THE LARYNX

Textbook Surgery of the trachea and bronchi by GRILLO, 2004



TRACHEAL POSITION IN YOUTH AND OLD AGE WITH CERVICAL EXTENSION AND FLEXION

Textbook Surgery of the trachea and bronchi by GRILLO, 2004



Likely pathogenesis of post intubation stenosis

Ischemic mucosal damage when cuff to tracheal wall tension exceeds mucosal capillary perfusion pressure, usually 20 to 30 mm Hg

Compression of submucosa by cuff of tube cause regional ischemia of cartilaginous rings – receive their blood supply from submucosal plexus

The mismatch in shape of cannula and trachea especially when tubes are oversized leads to critically high localized pressures on tracheal mucosa

Textbook Surgery of the trachea and bronchi by GRILLO, 2004

BENIGN CAUSES OF CAO

- Post-tuberculosis or post-infectious tracheobronchial stenosis
- Post-intubation stenosis
- Post-traumatic stenosis
- Pseudotumor: papillomatosis, amyloid, hemartomas, broncholiths
- Tracheobronchomalacia
- Excessive dynamic airway collapse
- Tracheobronchial stenosis: Idiopathic, Granulomatosis with polyangiitis, relapsing polychondritis
- Benign tracheoesophageal fistula
- Post-transplant bronchial stenosis

IMAGING OF CENTRAL AIRWAYS

- Contiguous high resolution images with corresponding contiguous coronal and saggital images – help visualize relationships between airways and adjacent mediastinal and hilar structures
- Minimum intensity projection (MINip) images – enhance visualization of airway lumens
- Expiratory scans –

- Static expiratory CT - During suspended respiration after forced exhalation

- Dynamic expiratory scan – During forced exhalation

- Administration of intravenous contrast material enchance visualization of airways in relation to mediastinal or hilar structures especially in atelectasis – facilitate differentiation between central tumor and peripheral consolidation, atelectasis and pleural fluid
- Limitations –
- Inability to differentiate mucosal from submucosal or extrinsic disease in absence of well-defined intraluminal abnormality
- Unreliable identification of lesions smaller than 2 to 3mm
- Inability to visualize flat mucosal lesions

Shiau et. al. Clinics in chest medicine,2015

- CT for diagnosis of TM accuracy of 97%
- Adequate dynamic expiratory image should include

- Posterior tracheal wall – flat or bowed forward
- Smaller anteroposterior airway diameter
- Increase in lung attenuation
- Calculation of degree of airway collapse or collapsibility index (CI)

CI = (AEI-DEA/AEI) x 100

AEI – Area at end inspiration

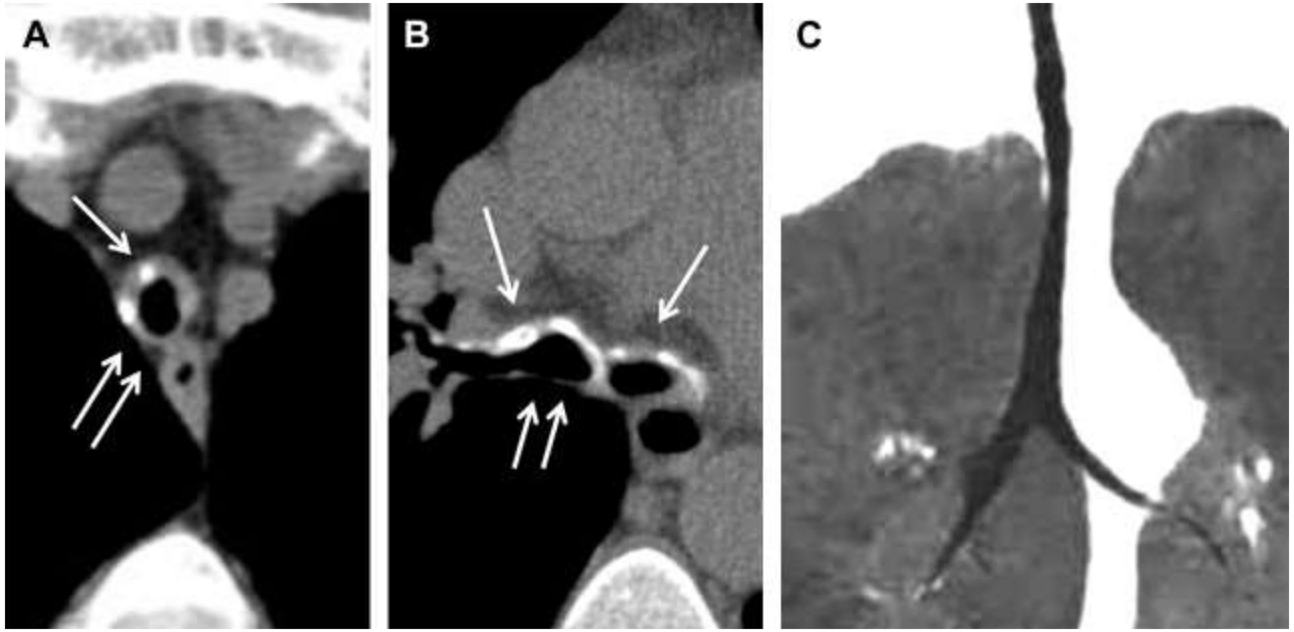
DEA – Dynamic expiratory area

Karen et al CHEST 2007; 131:758-764

CHARACTERISTIC CT INVOLVEMENT

- RELAPSING POLYCHONDRITIS

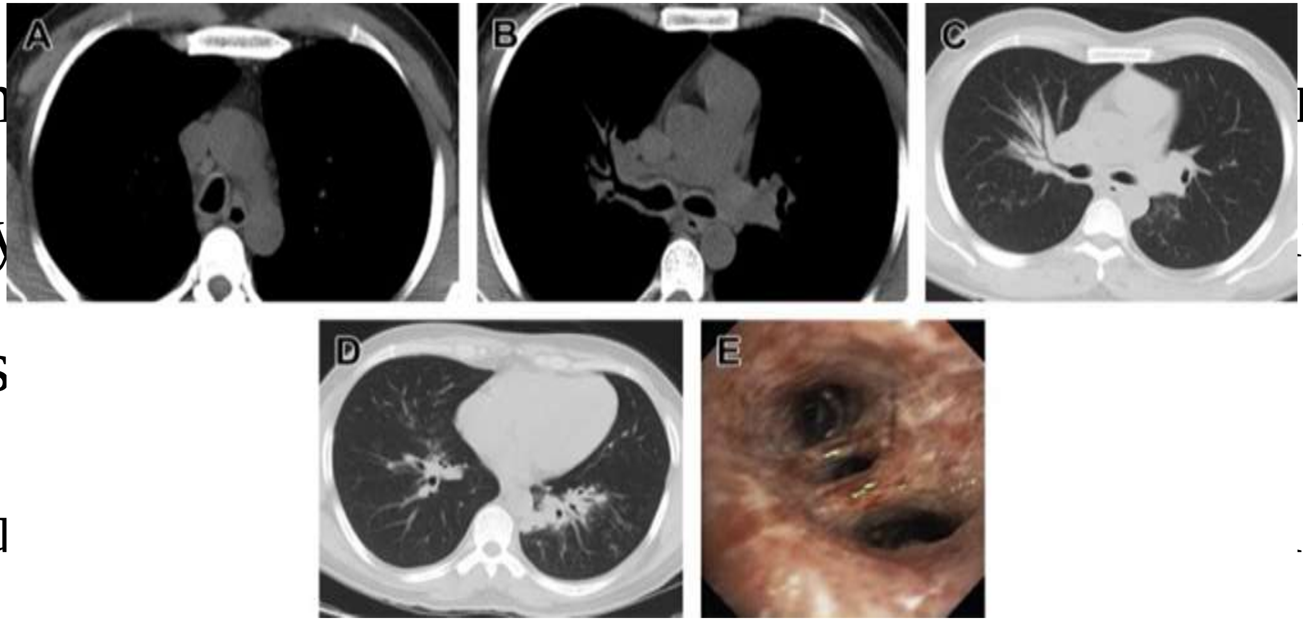
- Smooth diffuse airway thickening, sparing of posterior membrane with progressive cartilage calcifications and frequently associated tracheobronchomalacia



Shiau et. al. Clinics in chest medicine,2015

CHARACTERISTIC CT INVOLVEMENT

- GRANULOMATOSIS WITH POLYANGIITIS



- Abnormalities in n 50% of patients by bronchoscopy tions and subglottic stenos

- CT – Focal nodu ickening with luminal narrowing and calcification of cartilaginous rings

- Tracheal wall involvement circumferential opposite to RP

Shiau et. al. Clinics in chest medicine,2015

CHARACTERISTIC CT INVOLVEMENT

AMYLOIDOSIS

- Either as solitary n or diffuse circumferential s wing caused by submucosal plaq

- Mural calcificati
- Involvement of posterior bronchial wall differentiate from tracheobronchopathia osteochondroplastica (TO) and RP

Shiau et. al. Clinics in chest medicine,2015

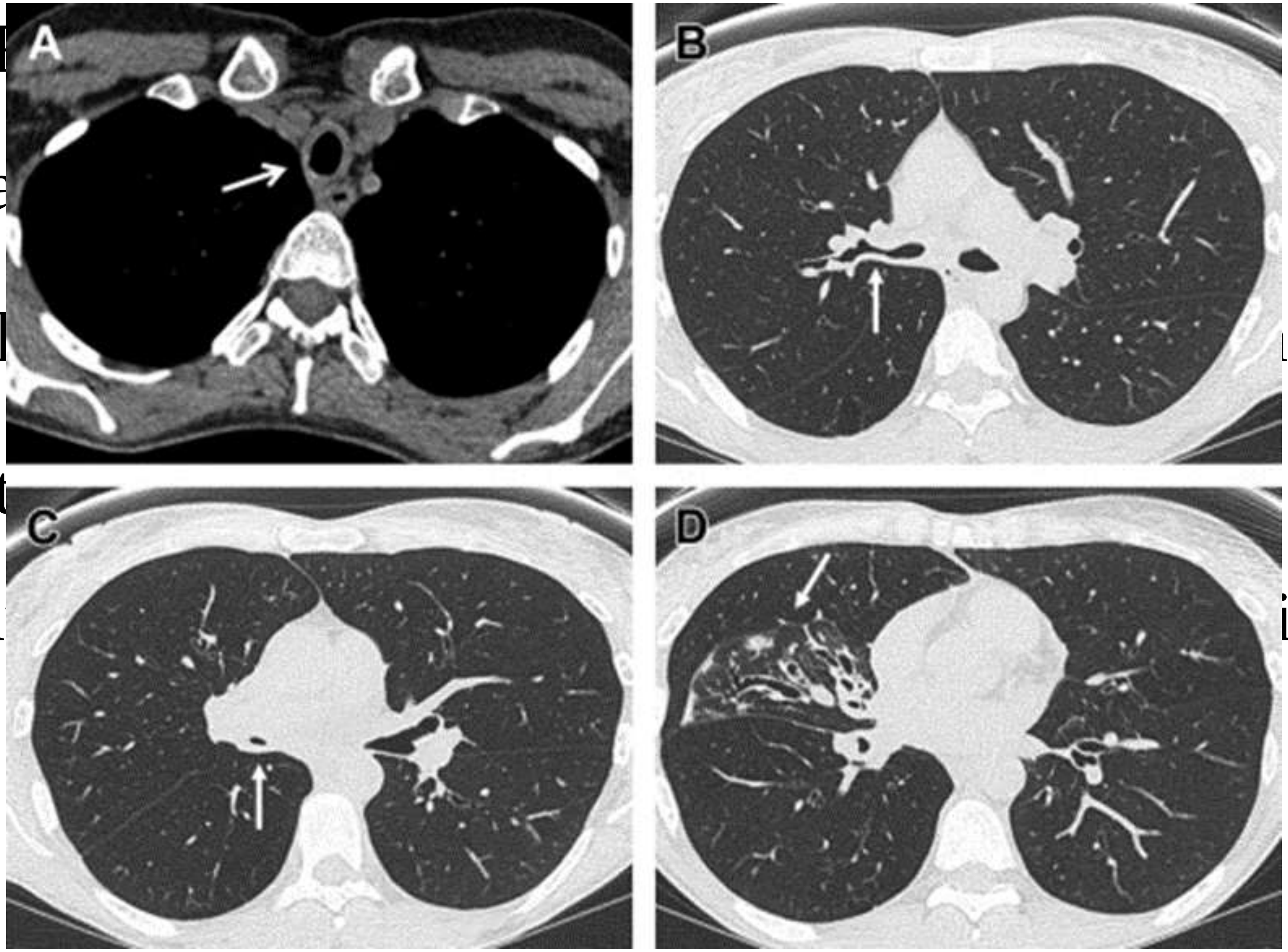
CHARACTERISTIC CT INVOLVEMENT

- INFLAMMATO

- Wall thickening a

- Airways mucosal ial narrowing

- Frequent associat proximal bronchiectasis ca irway involvement with constrictive

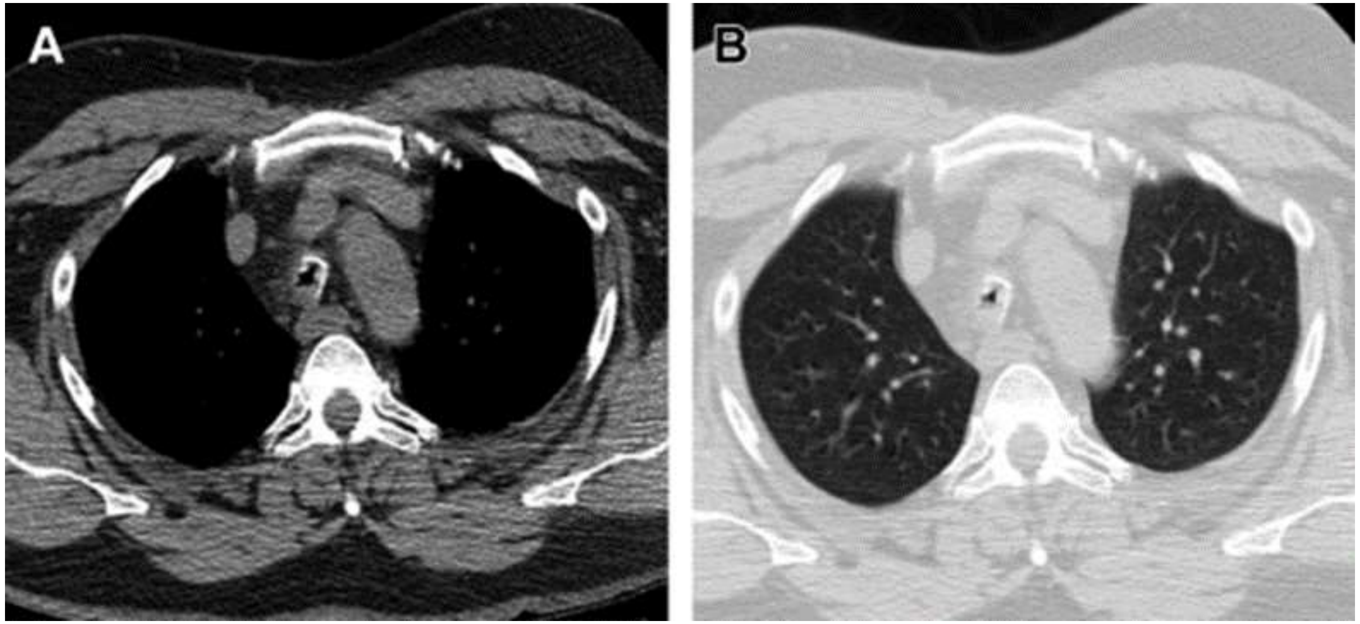


Shiau et. al. Clinics in chest medicine,2015

CHARACTERISTIC CT INVOLVEMENT

- SARCOIDOSIS

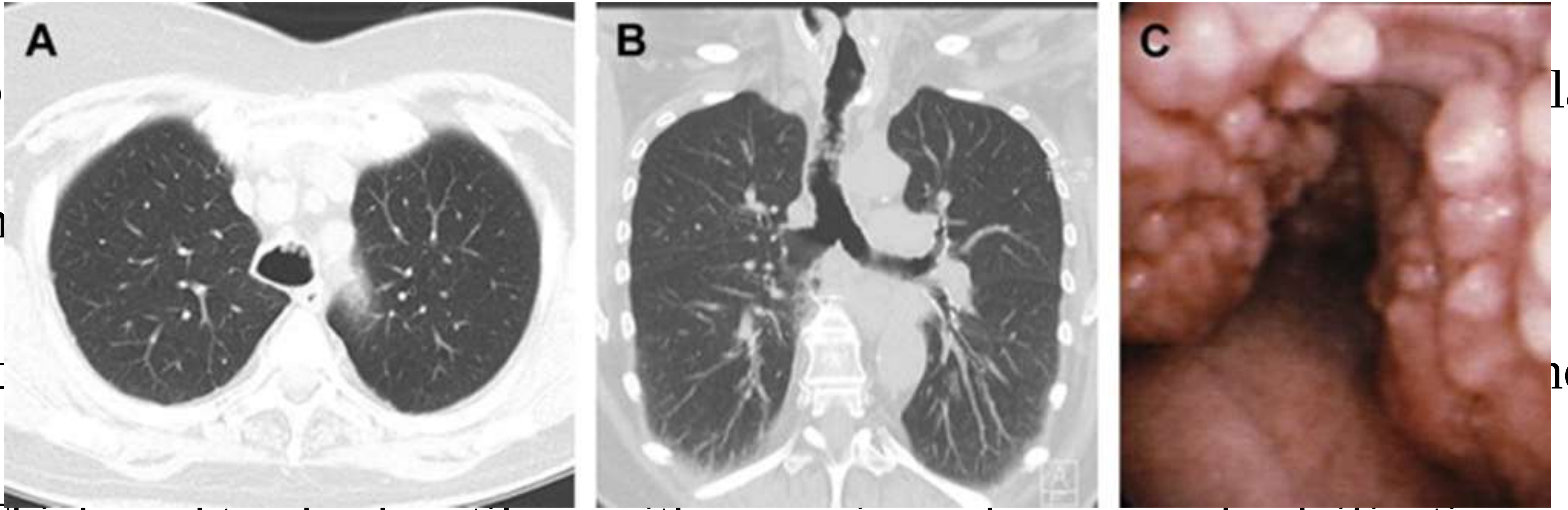
- Tracheal involvement result in nodular stenosis or less commonly smooth or irregular concentric tracheobronchial wall thickening
- On bronchoscopy raised cobblestone appearance is characteristic



Shiau et. al. Clinics in chest medicine,2015

CHARACTERISTIC CT INVOLVEMENT

- TRACHEOBRONCHOPATHIA OSTEOCHONDROPLASTICA



- Multip ... lar
  protein
- Classic ... nchi
- CT – Thickened tracheal cartilage with wavy, irregular mucosal calcifications with characteristic sparing of posterior wall

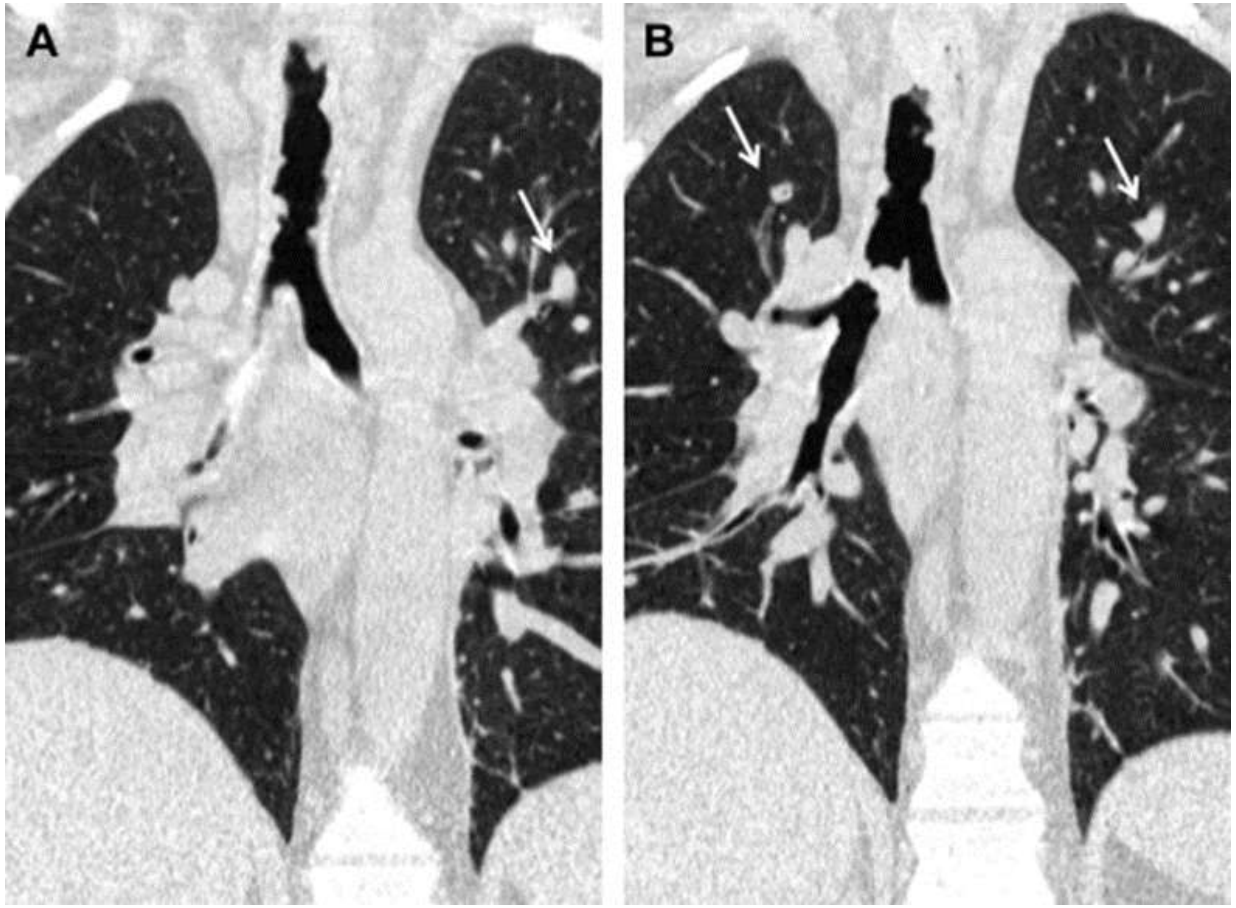
Shiau et. al. Clinics in chest medicine,2015

CHARACTERISTIC CT INVOLVEMENT

- Laryngotracheobronchial papillomatosis

- Tracheal and bronchial involvement occurs in 5% of cases, whereas pulmonary parenchymal 1%

- Evidence of cavitation strongly suggests carcinomatous transformation



COMPLEX STENOSIS

- Involvement of cartilaginous rings and stenosis length longer than 1cm

- Circumferential hourglass like contraction scarring

- Prescence of associated malacia

- For management of complex stenosis, 2 different opinions:

- Favoring surgery as first line

Rationale – Stent might lengthen tracheal segment to be resected

Some national societies such as the Interventional Pulmonology Study Group of the Italian Association of Pulmonologists (AIPO) recommends involvement of one or more cartilaginous rings as contraindication to endoscopic procedure (Level of Recommendation B)

Patelli M et.al. Monaldi Arch Chest Dis. 2007;67:71-72

Management of post-intubation tracheal stenoses using the endoscopic approach

Cavaliere et.al.

- Retrospective study between 1998 and 2001
- Sixty patients with complex stenosis
- RESULTS: Laser assisted mechanical dilation sufficient to treat 13 patients (22%), whereas 47 patients (78%) required stent placement
- Twenty two had removal of stent after 1 year and did not require further therapy
- Thirteen inoperable cases required permanent stents
- Twelve referred to surgery after failure of multiple endoscopic treatments

Cavaliere et.al. Monaldi Arch Chest Dis 2007

Management of post-intubation tracheal stenoses using the endoscopic approach

Cavaliere et.al.

- CONCLUSION: Forty eight patients (66%) had stable results after endoscopic procedure, 13 patients (18%) required permanent stents while 12 (16%) referred to surgery
- Endoscopic treatment can be first line therapy leaving some selected cases and relapsing stenosis for surgical resection

Cavaliere et.al. Monaldi Arch Chest Dis 2007

Interventional endoscopy in the management of benign tracheal stenoses: definitive treatment at long-term follow-up

Galluccio et.al.

- Retrospective study From Jan 1996 to June 2006
- Cases with benign tracheal stenosis (n = 209). Etiology included 167 post intubation and 34 cases of posttracheostomy stenosis, 8 cases of other diseases
- Simple stenosis were treated by 346 endoscopic procedures. Overall success rate 96%

Galluccio et.al. Eur J Cardiothorac Surg. 2009 Mar

- Forty two cases of complex stenosis – nine immediately treated by surgical resection and remaining 33 lesions underwent 123 endoscopic procedures (3.27 procedures) with 34 stents and 1 end to end anastomosis. Overall group success – 69%

CONCLUSION: Endoscopy should be considered as first choice for simple stenosis whereas complex stenosis need multidisciplinary approach and often require surgery

Galluccio et.al. Eur J Cardiothorac Surg. 2009 Mar

TRACHEOMALACIA

- Defined as diffuse or segmental tracheal weakness

- Two distinct anatomical forms :

- Cartilaginous malacia – Characterised by softening of cartilage

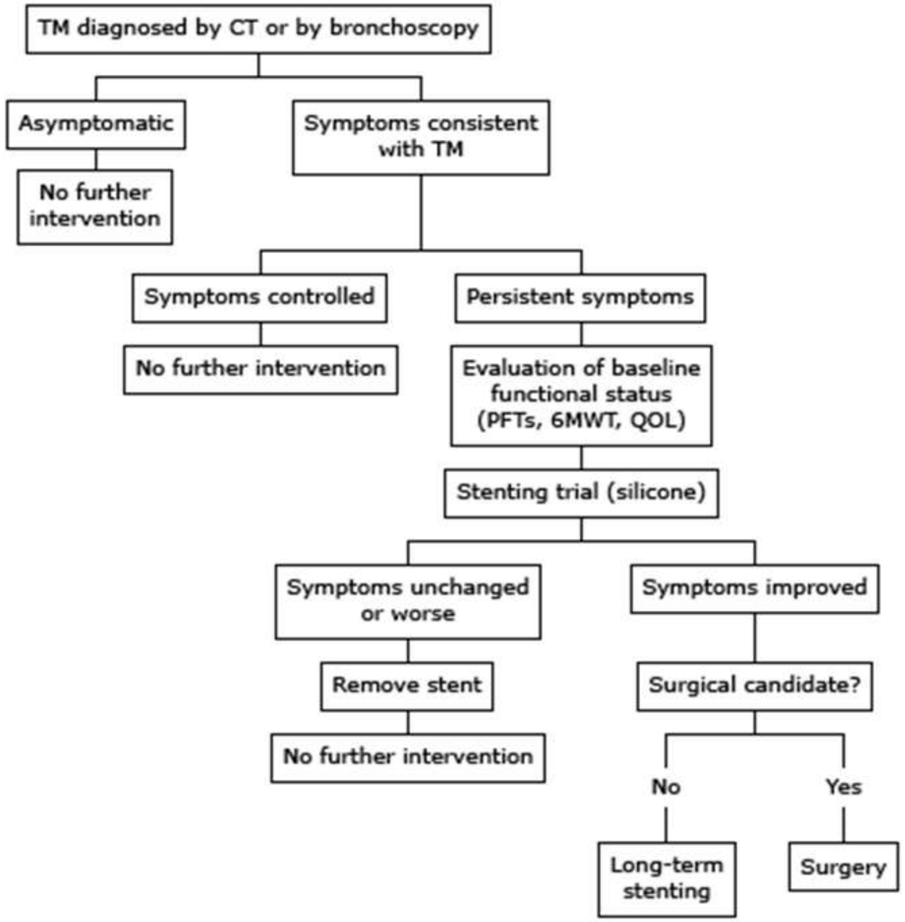
- Membranous malacia – Along with excessive anterior displacement of membranous wall (excessive dynamic airway collapse)

Classification of adult tracheomalacia

Primary or Congenital
Genetic, such as polychondritis (See also Pediatric table)
Idiopathic "Giant Trachea" or Mounier-Kuhn
Secondary or Acquired
Post-traumatic
Post intubation
Post tracheostomy
External chest trauma
Post lung transplantation
Emphysema
Chronic Infection/Bronchitis
Chronic Inflammation
Relapsing Polychondritis
Chronic External Compression of the Trachea
Malignancy
Benign Tumors
Cysts
Abscesses
Aortic aneurysm
Vascular Rings, previously undiagnosed in childhood

- Optimize medical therapy of underlying condition
- Along with treatment of GERD

Treatment algorithm for tracheomalacia



Treatment algorithm for adult tracheomalacia.

TM: tracheomalacia; CT: computed tomography; PFTs: pulmonary function tests; 6MWT: six-minute walk test; QOL: quality of life.

Adapted with permission from: Carden KA, Boiselle PM, Waltz D, Ernst A. Tracheomalacia and tracheobronchomalacia in children and adults: An in-depth review. Chest 2005; 127:984. Copyright © 2005 American College of Chest Physicians.

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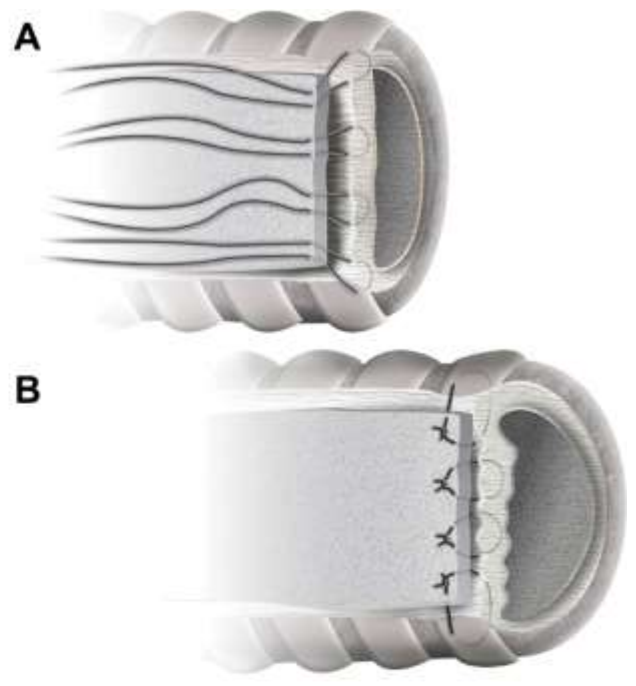
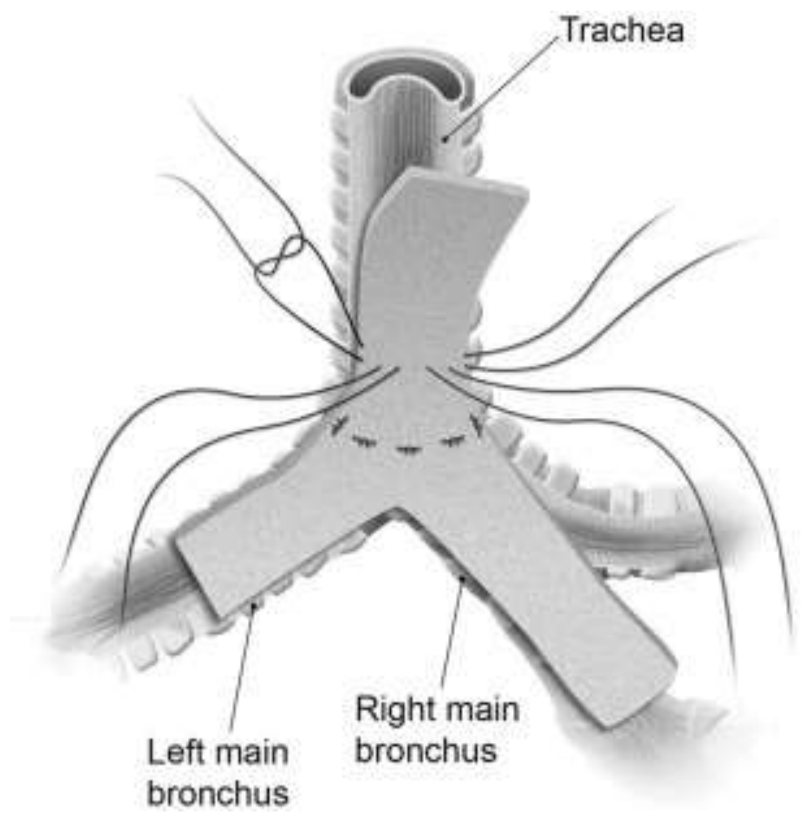
TRACHEOBROCHOPLASTY





Principle of membranous wall splinting is to stabilize and add rigidity in case of membranous malacia and to reconfigure normal shape of trachea in case of cartilaginous malacia

Material used are polypropylene mesh or extra-thick acellular dermis

Wright Thorac Surg Clin 28 (2018) 163-166

ENDOBRONCHIAL CARCINOID

- Symptoms depend on tumor size, site and growth pattern
- Diffuse wheeze rare in patient with carcinoids, regardless of tumor location as only 1-5% of patients exhibit hormone related symptoms

- WHO diagnostic criteria for typical carcinoid

- Include tumor with carcinoid morphology and <2 mitosis/2mm² (10 HPFs)
- Lacking necrosis and tumor size 0.5 cm or larger

- Atypical carcinoid – Tumor with carcinoid morphology with 2-10 mitosis/2 mm² and/or necrosis (punctate)

- Typical carcinoids – good prognosis, with 5 year survival 87-89%

- Distant metastasis – approx. 10% patients even many years after radical resection
- Prolonged 10 year follow up is recommended
- Atypical carcinoids associated with 5 year survival of 44% to 78%

BRONCHOSCOPIC PROCEDURE

- INDICATIONS:

- To palliate central airway obstruction in patients who are poor surgical candidates
- To guide open surgical procedures after laser bronchoscopic removal of obstructing lesion
- Reasonable alternative to Immediate surgical resection in patients who present with exophytic intraluminal tumor, good visualization of distal tumor margin and no evidence of bronchial wall involvement or suspicious lymphadenopathy at HRCT

Brokx et.al. J Thorac Cardiovasc Surg. 2007;133:973-978
Rea et.al. Eur J Cardiothorac Surg. 2007;31:186-192

BRONCHOSCOPIC INTERVENTION

- Radical endoscopic treatment in patients with entirely endobronchial, polypoidal lesion with small (less than 1cm) base of implantation, small dimension (< 3-4 cm), no extraluminal growth and no lymph node involvement

STENTS

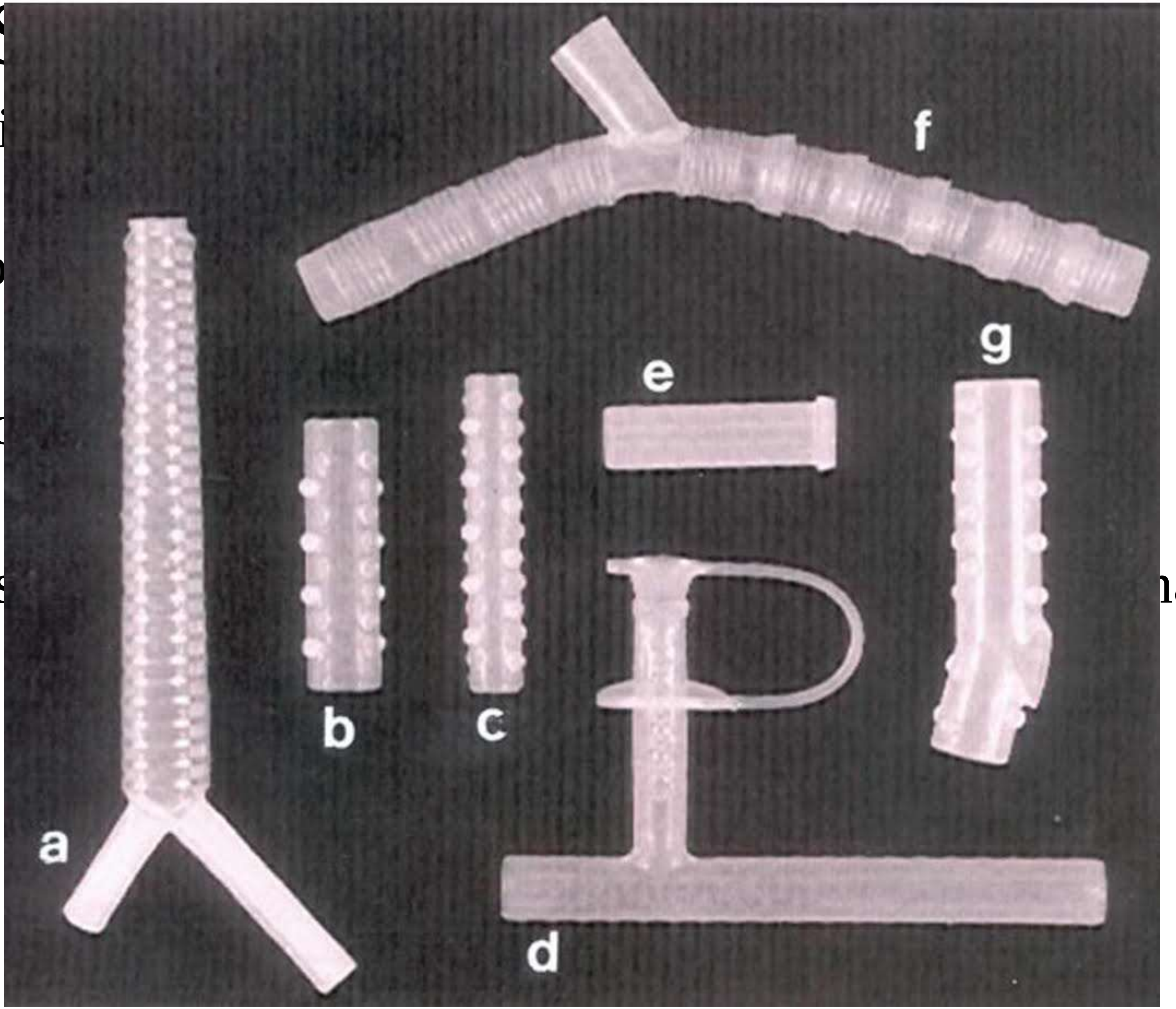
TYPES

• Divided i

- Tube (Po

- Metal (co

- Hybrid (s   namic



METALLIC STENTS

- Three generations:

- First generation- Uncovered balloon-expandable metallic stents (stainless steel)
- Second generation – Partially covered or uncovered self-expandable metallic stents made from nitinol
- Third generation – Hybrid fully covered SEMS (nitinol with polymer covering like silicone and polyurethane (PU)

METALLIC STENTS FOR BENIGN AIRWAY STENOSIS

- Use in benign airway disease cautioned by United States Food and Drug Association (FDA) in 2005 due to significant complications
- At time of this recommendation, available metallic stents were mostly uncovered and with limited biomechanical properties
- Currently, third generation metallic stents (Hybrid SEMS) such as bonastent (EndoChoice, USA) and Silmet stent (Novatech, France) available

Lund et.al. CHEST 2007;132:1107-8

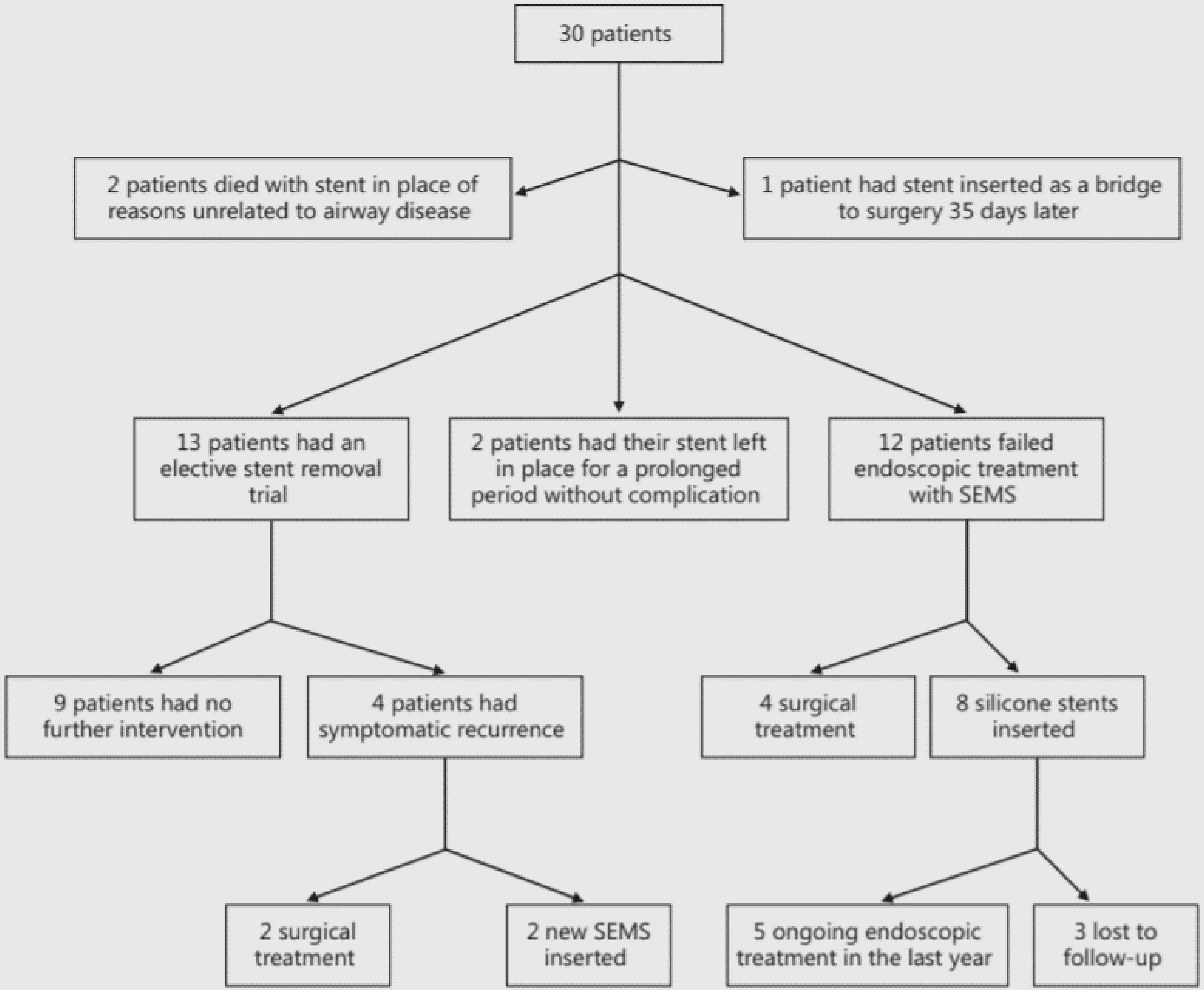
- Use metallic tracheal stents in patients with benign airway disorders only after thoroughly exploring all other treatment options (such as tracheal surgical procedures or placement of silicone stents)
- Using metallic tracheal stents as a bridge to other therapies is not recommended, because removal of the metallic stent can result in serious complications

Safety and Efficacy of a Fully Covered Self-Expandable Metallic Stent in Benign Airway Stenosis

Fortin et. al.

- Retrospective study
- Patients treated with for benign airway stenosis with third generation SEMS (SILMET)
- From January 2011 to December 2015, North Hospital of Marseilles, France
- Forty SEMS in 30 patients. Twenty (50%) stents removed because of stent related complications after median of 77 ± 96 days (migration 32.5%, granulation tissue formation 7.5%, subjective intolerance 5%, mucus plugging 2.5%, laryngeal edema 2.5%)
- Thirty six stents (90%) removed successfully after median of 122 ± 113.2 days without any complications
- Success rate of stent treatment was 40.7%
- **CONCLUSION**: Third-generation SEMS can be considered for complex benign airway stenosis bit complications requiring stent removal are frequent

Fortin et.al. Respiration 2017;93:430–435


30 patients
2 patients died with stent in place of reasons unrelated to airway disease
1 patient had stent inserted as a bridge to surgery 35 days later
13 patients had an elective stent removal trial
2 patients had their stent left in place for a prolonged period without complication
12 patients failed endoscopic treatment with SEMS
9 patients had no further intervention
4 patients had symptomatic recurrence
4 surgical treatment
8 silicone stents inserted
2 surgical treatment
2 new SEMS inserted
5 ongoing endoscopic treatment in the last year
3 lost to follow-up

Long-term follow-up of self-expandable metallic stents in benign tracheobronchial stenosis: a retrospective study Xiong et.al.

- Retrospective study
- Patients managed with SEMs from July 2003 to June 2016 for symptomatic response, complications and long term outcomes
- Total 131 stents deployed in 116 patients

- **RESULTS**: Ninety eight patients demonstrated clinical improvement after stent insertion (84.48%)
- Compared with uncovered stents, covered stents associated with higher incidences of major and minor granulation tissue formation and with recurrent stenosis ($p < 0.0001$ and 0.005 respectively)
- Each covered and uncovered stent developing hyperplasia required median of 2 (range 1-15) and 1 (range 1-7) fibrobronchoscope with electrocautery respectively

Xiong et al. BMC Pulmonary Medicine (2019) 19:33

- At follow up (median: 1276 days), 68 patients had complete resolution, 15 remained under interventional treatment, 8 had bronchial occlusions, 7 underwent surgery, 14 were lost to follow-up and 4 died of stent related causes
- **CONCLUSION:** SEMS placement achieved most clinical improvement among patients but required adequate endotracheal measures for addressing stent-related complications

TYPE OF STENT (material)	PROS	CONS	PLACEMENT
Tubular silicone	Less granulation Less tumor infiltration Long term placement Easily removable	Migration Mucus plugging	Rigid bronchoscopy
Y-stent silicone (silicone)	Less granulation Less tumor infiltration Long term placement Easily removable	Migration Mucus plugging	Rigid bronchoscopy
T-tube silicone (silicone)	Horizontal limb prevents migration	Granulation	Tracheostomy
AERO stent (laser cut nitinol structure with PU cover)	Antimigration Embedded into mucosa	Harder to remove	Rigid bronchoscopy
Ultraflex stent (nitinol structure partially with/without PU or silicone cover)	Easy placement	Epithelisation Migration	Rigid/Flexible bronchoscopy
Dynamic Y-stent (Stainless steel structure with silicon cover) Rigid stent	Maintains airway patency well due to rigid profile	Harder to remove	Requires laryngoscopy during initial stage of implantation

Type of stent (material)	Pros	Cons	Placement technique
Bonastent stent (nitinol structure with silicon cover), self expanding	Removable With ultra-thin delivery catheter Resist sever stricture	Migration Fracture Mucus plugging	Rigid bronchoscopy/ Flexible bronchoscopy, with delivery catheter
Silment stent (nitinol structure with polyester cover), self expanding	Multiple shapes	Migration Fracture	Rigid/Flexible bronchoscopy
Hanaro stent (nitinol structure with silicon cover), self expanding	Antimigration Flares at both ends	Migration Fracture	Rigid/Flexible bronchoscopy
Micro- Tech stent (nitinol structure with/without elastic cover), self expanding	Multiple selection	Migration	Rigid/Flexible bronchoscopy
Balloon- expanding stents (fully covered stainless steel in two layers of polytetrafluoroethylene)	For distal airways	Migration	Rigid/Flexible bronchoscopy With balloon

CHARACTERISTICS	DUMON STENT	ULTRAFLEX STENT
MECHANICAL CONSIDERATIONS		
Resistant to recompression when deployed	+	++
High internal to external diameter ratio	-	++++
Radial force exerted uniformly across stent	+	++
Absence of migration	-	++
Suitable for use in tortuous airways	-	+++
Removable	+++	-
Dynamic expansion	-	+++
Can be customized	+++	-
TISSUE-STENT INTERACTIONS		
Biologically inert	++	++
Devoid of granulation tissue	+	-
Tumor ingrowth	++	+

CHARACTERISTICS	DUMON STENT	ULTRAFLEX STENT
EASE OF USE		
Can be deployed with FB	-	+++
Deployed under local anesthesia with conscious sedation	-	++
Radiopaque for position evaluation	-	+++
Can be easily repositioned	++	-
Cost Inexpensive	+	-

Original Article of Interventional Pulmonology Corner

Airway stent complications: the role of follow-up bronchoscopy as a surveillance method

LEE et.al.

- Retrospective cohort study
- From April 2010 to December 2013 for malignant and benign airway diseases
- Stents included metallic, silicone (straight, Y stent, T tube) and hybrid
- Included 134 patients of which 147 stents placed, follow up bronchoscopy in 94 patients
- **RESULTS:** Symptomatic status at time of follow up bronchoscopy not associated with stent complications (p=0.15)
- Patient age, sex, indication for stent placement and location not associated (p > 0.05)
- Hybrid stents are more likely to migrate (p=0.001) or obstruct by secretions (p = 0.03)

CONCLUSION – Surveillance bronchoscopy within 4-6 weeks useful for early detection of stent complications

J Thorac Dis 2017;9(11):4651-4659

Practice patterns for maintaining airway stents deployed for malignant central airway obstruction

Hoag et.al.

- Surveyed 62 members of the American Association of Bronchology and Interventional Pulmonology (AABIP)
- At annual meeting during CHEST 2008
- **RESULT -** Less than 50% responders had protocol for post-stent management and significant variability in practice of post stent care
- Seventy-five percent of respondents used inhaled medications (bronchodilators (59.8%) followed by humidification (46.8%) or mucolytics (46.8%)
- **CONCLUSION** – No conclusive studies post-airway stenting to support use of inhaled steroids or antibiotics to prevent granuloma formation and infection respectively

Hoag et.al. J Bronchol Intervent Pulmonol 2010;17:131–135

WHEN TO REMOVE STENT??

Short-Term Use of Uncovered Self-Expanding Metallic Airway Stents for Severe Expiratory Central Airway Collapse

- Retrospective review
- Thirty three patients underwent USEMAS trial and measurements such as mMRC, CQLQ, spirometry testing and 6-minute walk test (6MWT)
- **RESULTS:** Dyspnea, cough and secretions clearance improved in 88, 70 and 57% respectively

Majid et. al. Respiration 2016;92:389–396

Short-Term Use of Uncovered Self-Expanding Metallic Airway Stents for Severe Expiratory Central Airway Collapse

- Significant improvement in mMRC (p <0.001), CQLQ (p=0.015) and 6MWT (p=0.015)
- Median duration of USEMAS – 7 days with all stents removed without any complications
- Minimal granulation tissue – 30.9% and no granulation tissue – 69%
- **CONCLUSION:** Short term USEMAS improves respiratory symptoms, quality of life and exercise capacity

Majid et. al. Respiration 2016;92:389–396

Metallic stent insertion and removal for post-tracheotomy and post-intubation tracheal stenosis

Yonghua Bi et.al.

- Retrospective study
- Thirty two patients undergoing fluoroscopic stenting
- Between September 2011 to March 2017

- **RESULTS**: Most common complications - Insufficient expansion and tissue hyperplasia

  Technical success rate of 92.1% in stent removal under fluoroscopy

  Routine removal performed after 2.9 ± 0.3 mths and restenosis after mean duration of 2.7 ± 0.3 mths

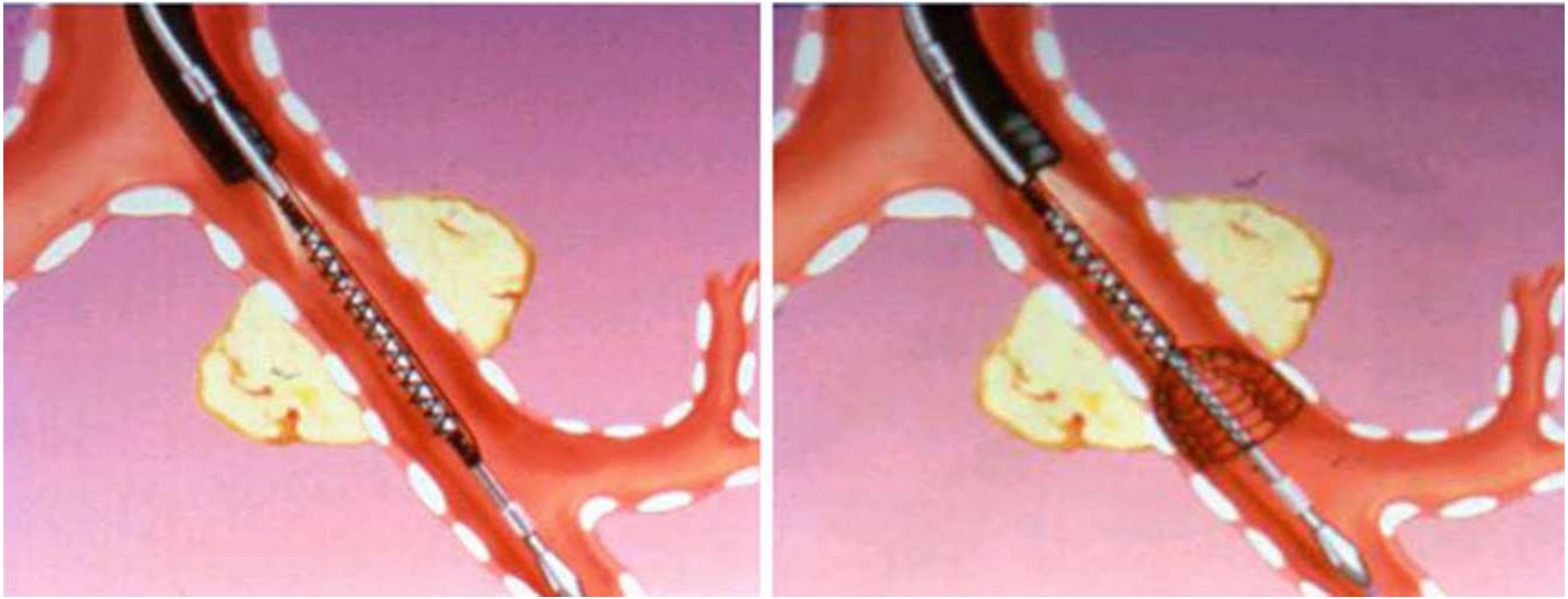
  Six complications of stent removal with no death

  Four stents showed strut fracture after removal

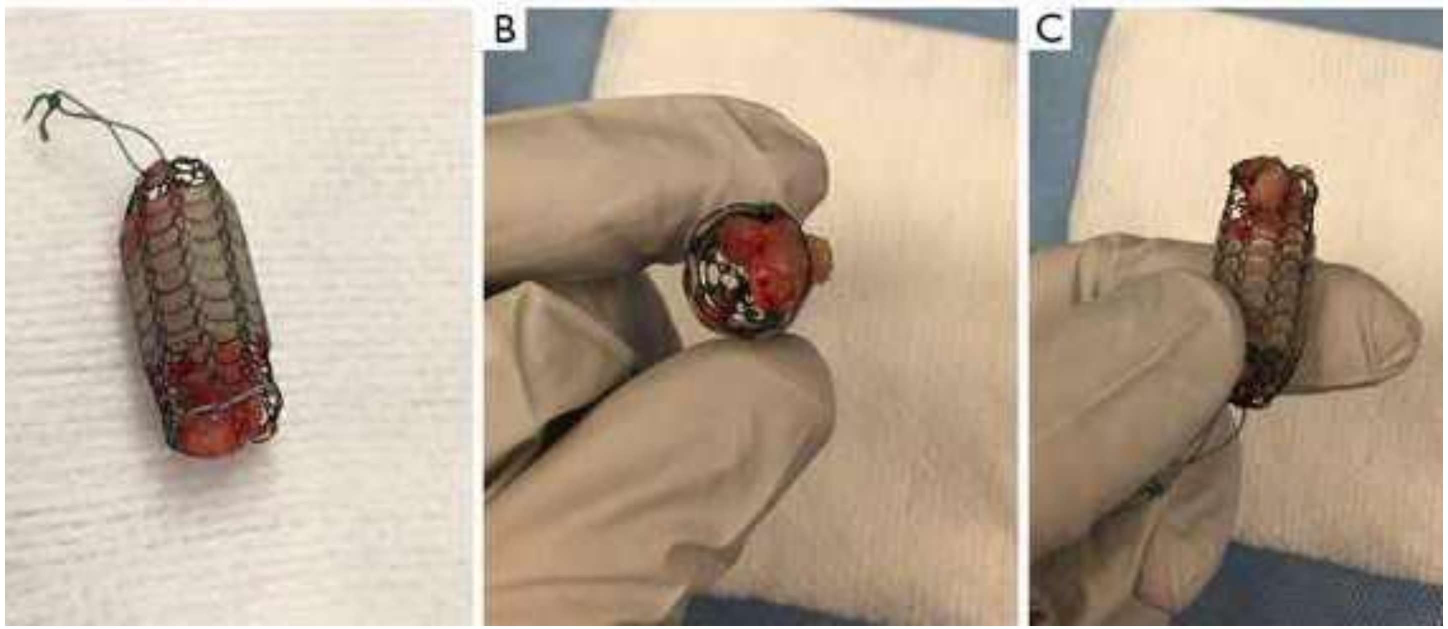
  One, three, five year patency rates were 87.1%, 76.2% and 70.8% respectively

- **CONCLUSION** – Fluoroscopic insertion and removal of stent is safe and effective for PITS and PTTS. Three months retention time reasonable for airway stents

Bi et. al. La radiologia medica (2019) 124:191–198



SELF-EXPANDING ULTRAFLEX STENT DEPLOYMENT SYSTEM: ULTRAFLEX STENT MOUNTED ON INTRODUCTION CATHETER WITH CROCHET KNOTS, PULLING THE THREAD RELEASES STENT



- Braided nitinol stent (i.e. ultraflex) should be freed from wall with Jackson and Fogarty balloons first
- Thereafter, identify proximal circumferential suture and pull from that point in order to purse-string proximal end of stent and facilitate removal
- Failure to do so leads to piecemeal removal of stent

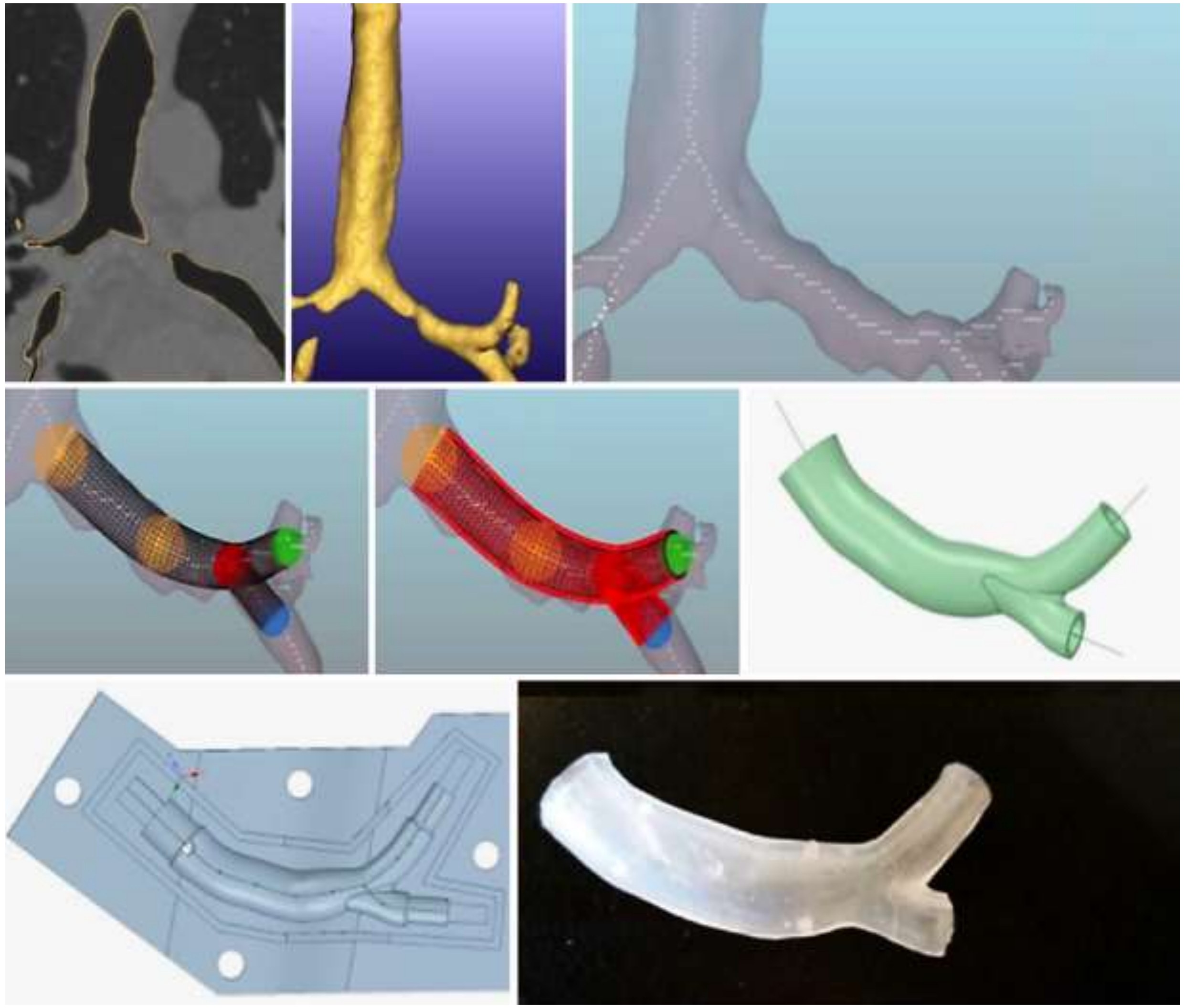
Folch et.al. Ann Cardiothorac Surg 2018

Application of 3D Printing for Patient-Specific Silicone Stents: 1-Year Follow-Up on 2 Patients

Gildea et.al.

- Reported 1 year outcome of 2 patients with airway disease caused by granulomatosis with polyangiitis affecting left main bronchus and secondary carina
- Non responsive to systemic therapy, standard bronchoscopic techniques, and had complications with commercially available stents
- Patients' chest computed tomography (CT) scan imported into a proprietary software originally developed for orthopedic surgery (COS Inc., Cleveland, OH, USA)
- Patients showed improved durability, a shorter procedure time, and improvement of patient-reported symptoms leading to a reduced need for stent changes and modifications.

Gildea et.al. Respiration 2018;96:488–494



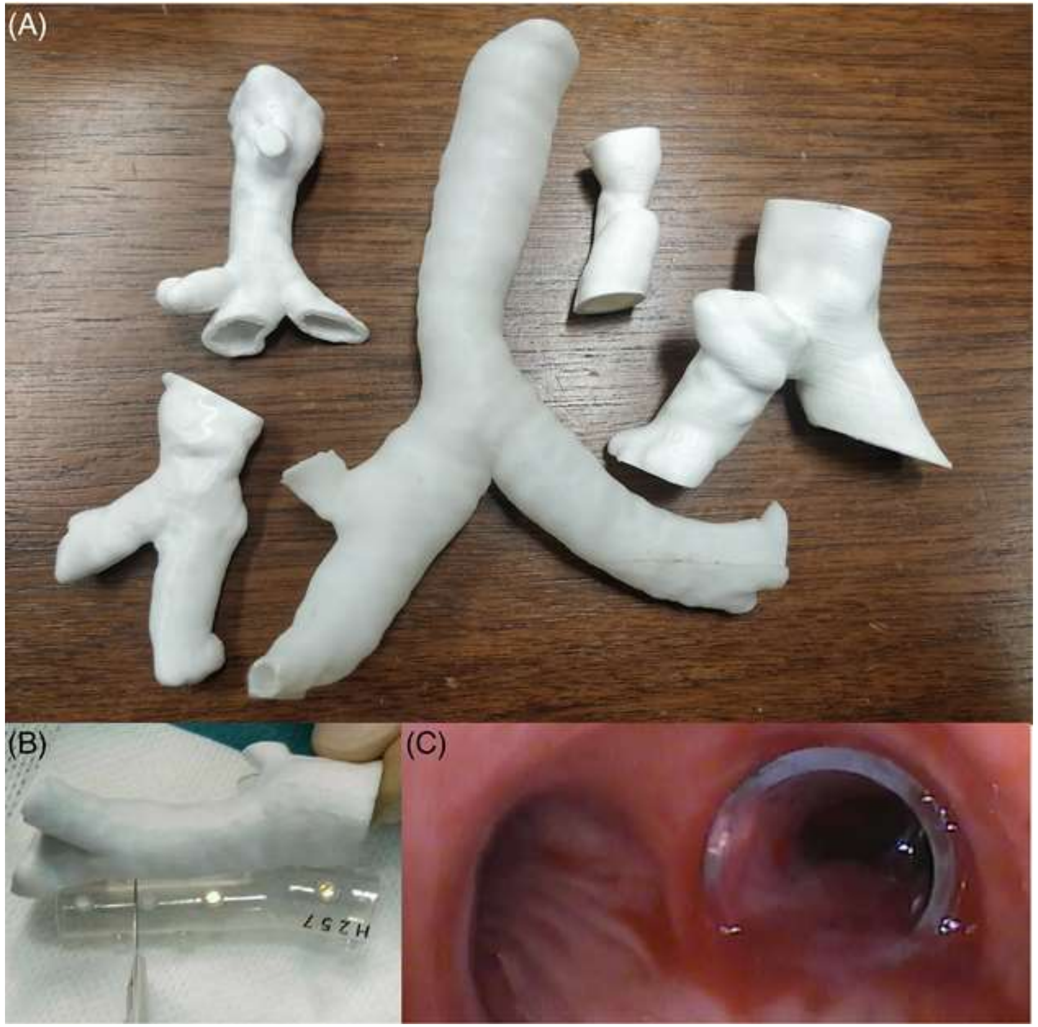
a. Coronal CT representation for segmentation
b. 3D airway reconstruction done by the manufacturer
c. Centerline plotting for stent alignment
d. The spheres are placed and adjusted using the software tools to represent the diameter of the airway. Red sphere is join point that defines volume of carina

DETAILS REGARDING 3-D PRINTING

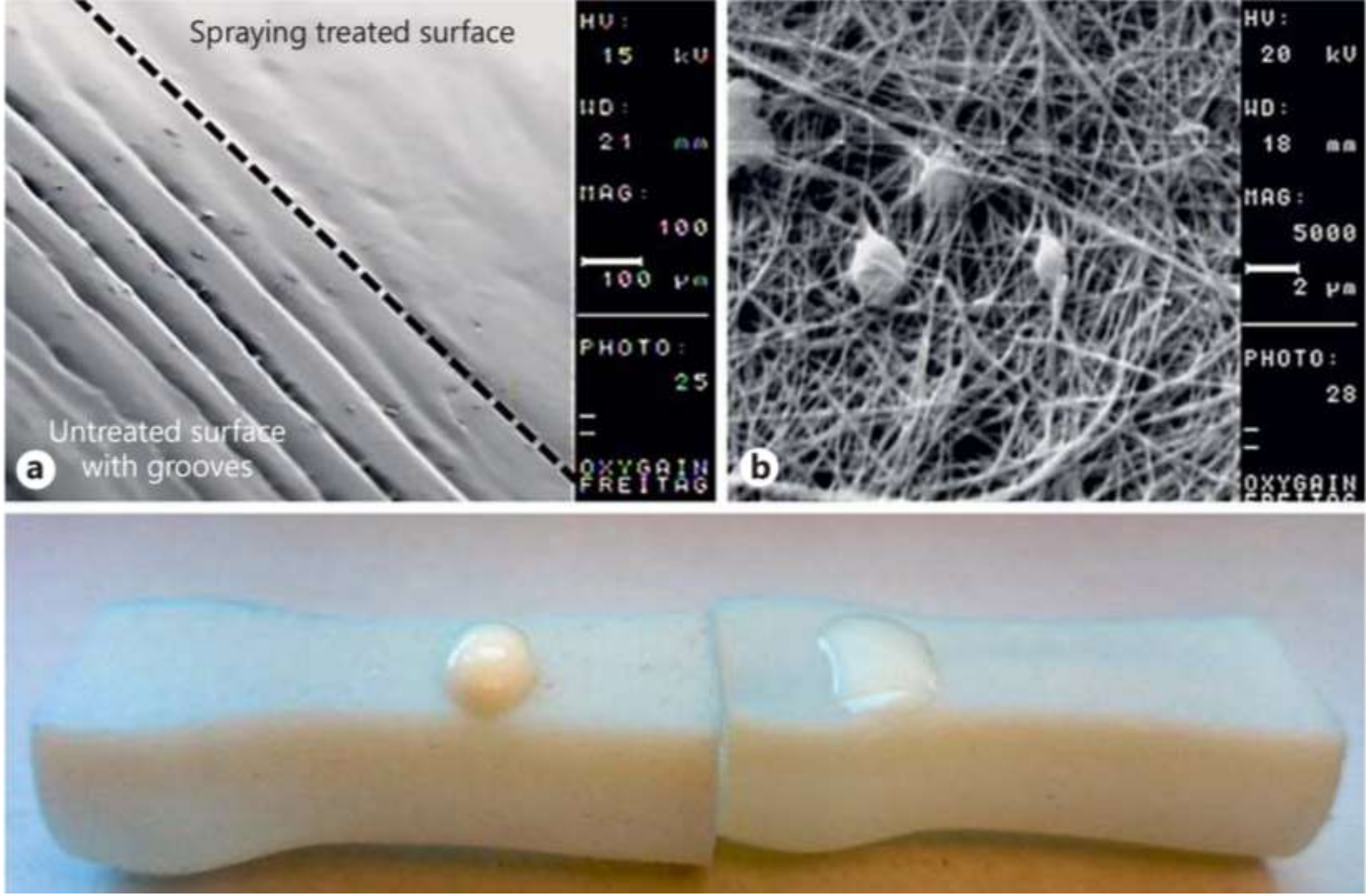
- Steps for 3D printing:

- Image and data acquisition
- CAD designing – 3D model
- Creating a construction file – model electronically sliced into individual layers
- 3D Printing – Stereolithography printers uses photopolymers
- Surface treatment – Grinding, polishing and dipping in solvents or liquid polymers

3D PRINTING



Respirology, Volume: 25, Issue: 9, Pages: 953-962, First published: 11 March 2020, DOI: (10.1111/resp.13801)



a. Electrospray coating of antomically shaped 3D-printed stents for surface smoothing
b. Surface of polyurethane stent treated with antibiotics containing nanofibers produced by electrospinning
c. Effect of nanocoating on wettability: the left stent is nanocoated and extremely hydrophobic, the right is untreated

BRONCHOSCOPIC TECHNIQUES

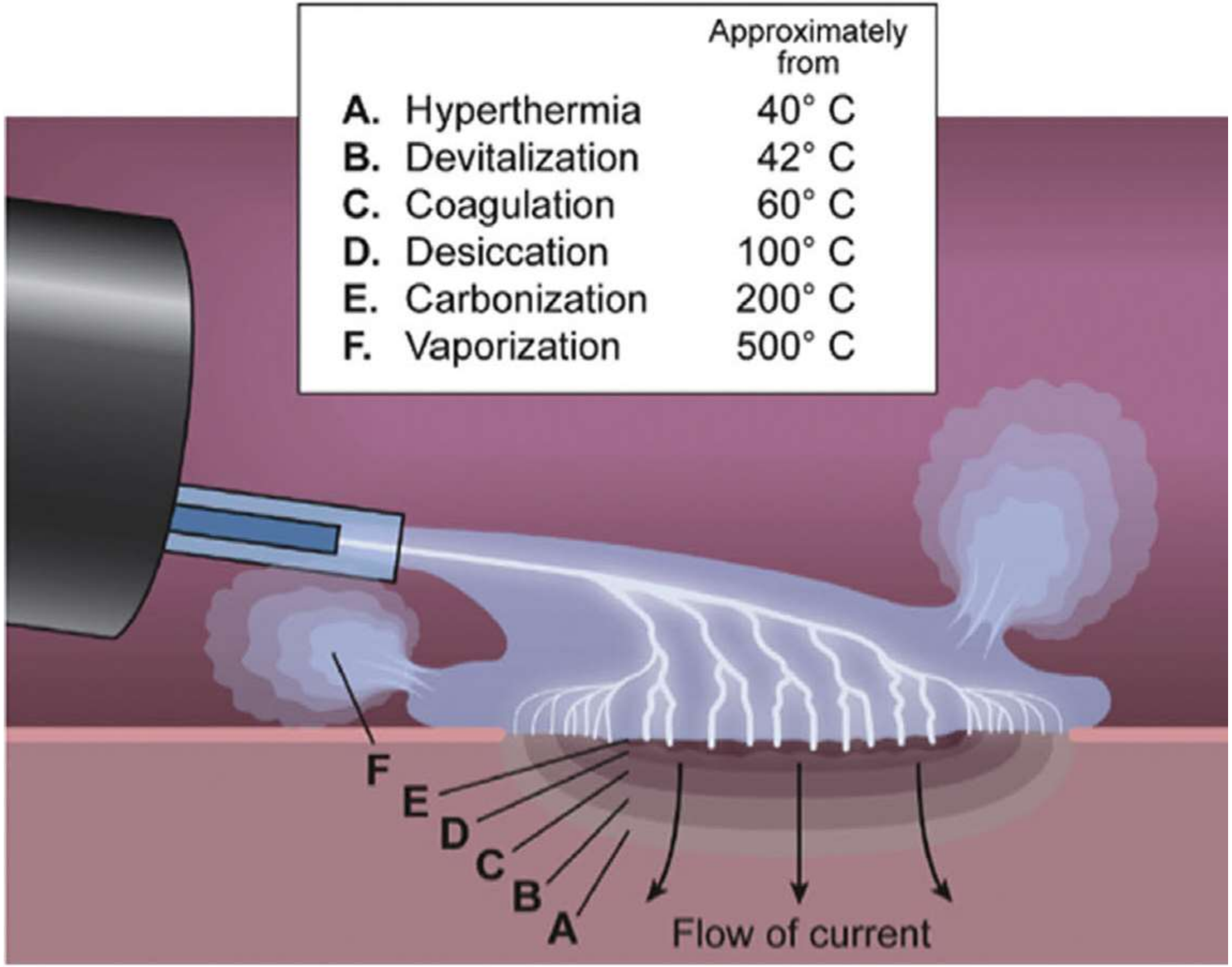
Electrosurgical technique/tool	Advantages and Disadvantages	Mechanism of action	Effect on tissue	Depth of penetration (mm)	Potential complications
Electrocautery	Advantages: • Tissue destruction • Hemostasis Disadvantage: • Variable penetration depths depending on tool used	Contact, alternating high frequency electric current passing through probe to generate heat	Protein denaturation, coagulation and direct tissue death	Variable depending on electrocautery probe used	- Airway perforation - Bronchial wall damage - Bleeding - Airway fire
Argon plasma coagulation (APC)	Advantage: • Hemostasis Disadvantages: • Difficult to achieve debulking effect due to noncontact nature	Non contact, APC catheter delivers an inert gas that acts as an effective conductor of high frequency monopolar current via flexible probe	Denatures protein and evaporates water, causing tissue destruction and coagulation	2-3	- Intracardiac gas embolism - Cerebral gas embolism - Airway perforation - Airway fire

Electrosurgical technique/tool	Advantages and Disadvantages	Mechanism of action	Effect on tissue	Depth of penetration (mm)	Potential complications
Radiofrequency ablation (RFA)	Advantages: • Tissue destruction • Hemostasis • Smoke evacuation Disadvantage: • Limited flexibility in bronchoscope	Contact, heat energy is induced by delivering high frequency pulses of radiofrequency at tip of RFA catheter to generate electrical plasma to heat up adjacent tissue	Protein denaturation, tissue dessication and vessel coagulation	1.9	Same as for electrocautery
Nd:YAG laser	Advantages: • Tissue vaporization • Vascular constriction Disadvantages: Deep penetration depth Precise cutting as CO_2 laser cannot be achieved	Non contact, light energy absorbed and converted to heat energy	Protein denaturation, coagulation and direct cell death	Upto 10	Same as electrocautery

ELECTROCAUTERY

- Ohm's law : I = V/R (I is current, V is voltage and R is resistance)
- Power in circuit proportional to square of current x resistance
- High frequency current passes through tissue opposed by resistance
- Resistance intrinsic property of tissue based on specific chemical composition. Tissue resistance decreases with good conductors of energy such as water and metal ions and opposite in tissues such as adipose, cartilage or bone

Homassom. Endobronchial electrocautery. Semin Respir Crit Care Med.1997


Approximately from
A. Hyperthermia 40° C
B. Devitalization 42° C
C. Coagulation 60° C
D. Desiccation 100° C
E. Carbonization 200° C
F. Vaporization 500° C
F
E
D
C
B
A
Flow of current

MODES

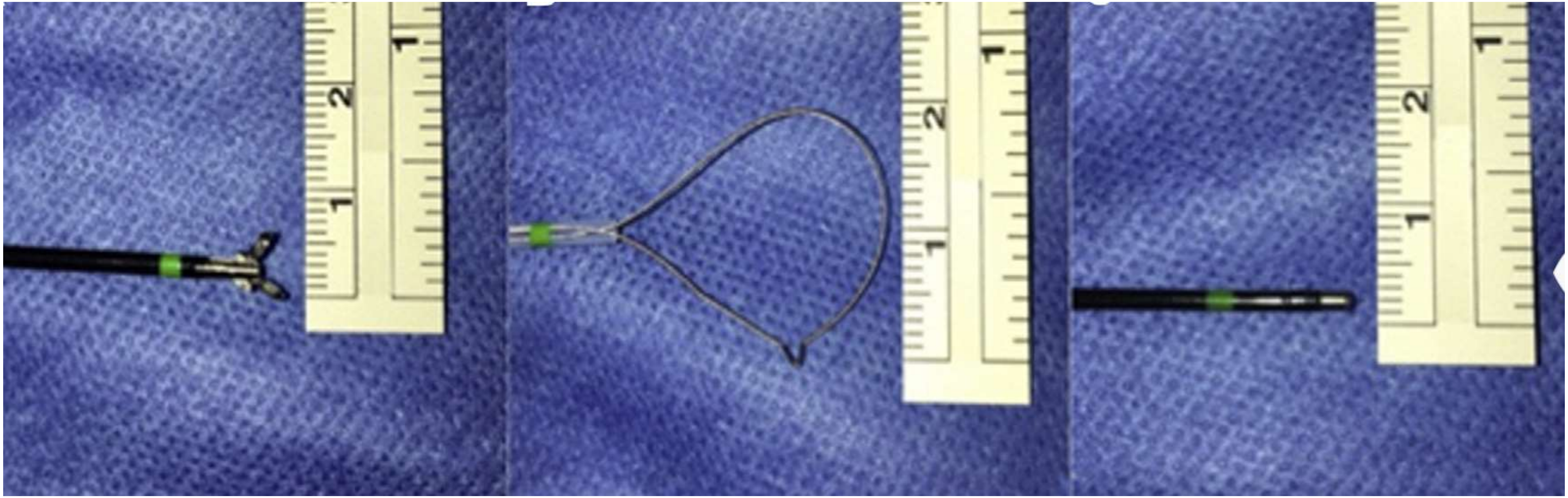
- CUTTING: At high voltages (>200 V) to create electrical arc between electrode and tissue, leading to immediate vaporization
- COAGULATION: Achieved by heating tissues (approx. 70° C)

- Soft coagulation – Voltage currents less than 200 V and unmodulated

Electrode is in direct contact with tissue avoiding direct arc formation and carbonization

- Forced coagulation (Dessiccation) : Procedure uses higher-voltage modulated currents (>500 V) but creates electrical arcs and may cause carbonization

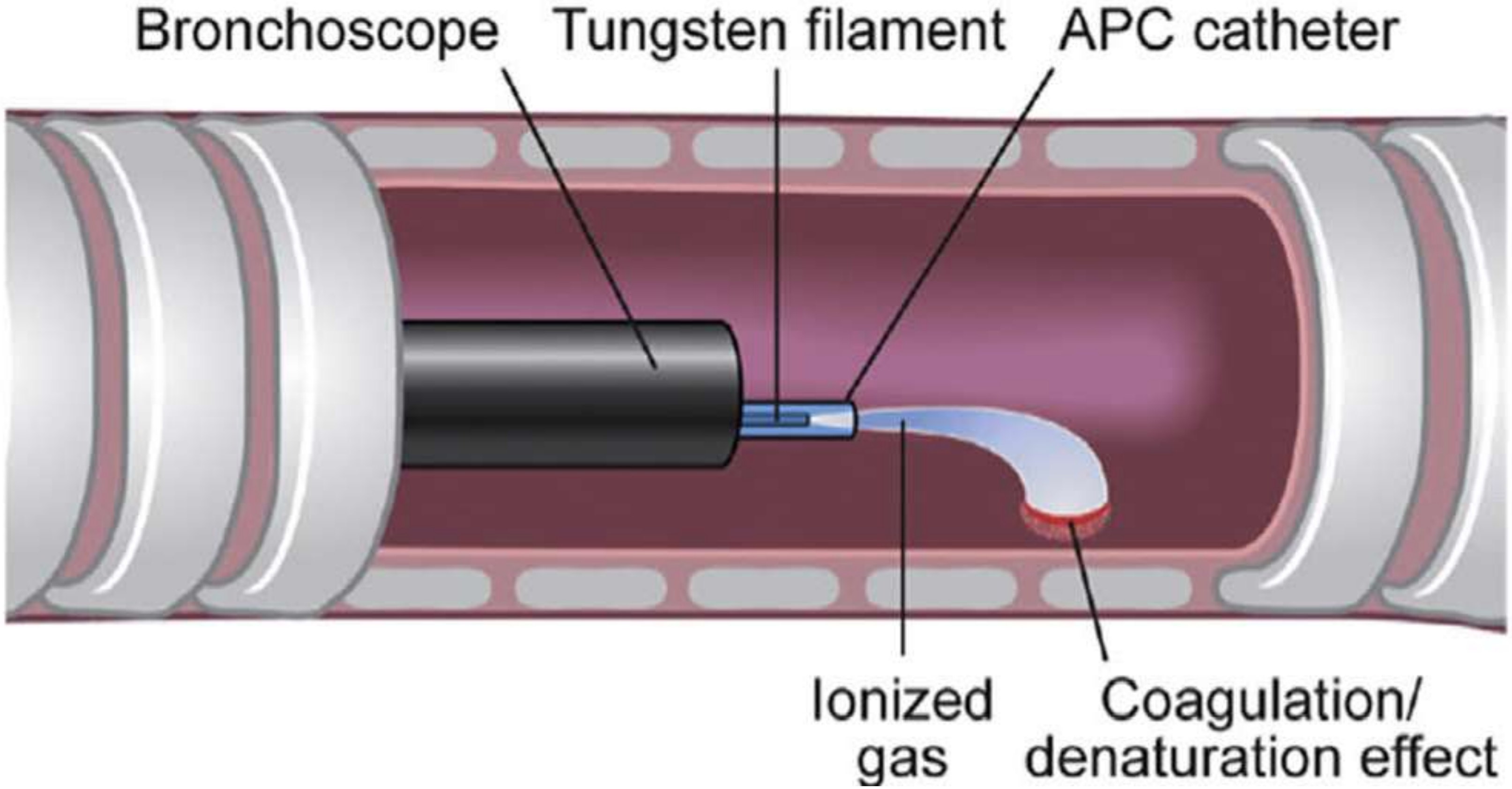
- SPRAY COAGULATION (Fulguration) – High voltage (>2000 V), strongly modulated currents used in non contact mode
- Coagulation – Happens when proteins and glucose containing coagulam heated above 70°C
- Vaporisation – Disruption of cell structure and cellular necrosis



HOT FORCEPS – to perform endobronchial biopsies and mechanical debridement of highly vascularized tumors

WIRE SNARE – Endobronchial lesions
Achieves hemostasis

ELECTROCAUTERY PROBE –
- Both coagulation and cutting effects
- Can be used in rigid or flexible
- Most effective in treatment of lobar or segmental bronchi



- High voltage current delivered by tungsten wire ionizing the gas which is delivered at tip of catheter
- Plasma refers to electrical conducting medium produced when atoms in gas become ionized
- APC devitalizes tissue (> 100°C), surface becomes less electrically conductive
- Positively charged gas proceed to closest negatively charged areas, allowing target to be in front, tangential, radial or around anatomic corners
- Gas is directed to adjacent tissue with less electrical resistance, resulting in more uniform, superficial penetration (2 to 3 mm depth) decreasing risk of airway perforation

Reichle et.al. Pneumologie 2000;54(11):508-516

ARGON PLASMA COAGULATION

- Dreaded side effect:

- Local infiltration of gas and systemic air embolism through bronchial veins or systemic veins

- Related to flow rate of argon gas, proximity to tissue and vessel exposure

- To prevent air embolism, argon gas flow rate to be set at lowest possible rate

- Argon itself is not combustible gas nor promote combustion of combustible materials. Ignition is only possible in presence of combustible gas like oxygen

Reddy et.al. CHEST.2008;134(5):1066-1069
Shaw et.al. RESPIRATION.2012;83(3):267-270

Gastroenterology

Effects of argon plasma coagulation on human stomach tissue: An ex vivo study Gong et.al.

- APC performed on 10 freshly resected human stomachs
- Effect on tissue were compared across power settings (40, 60 and 80W), durations (5, 10, 15, 20 and 25s) and between injection (submucosal injection of normal saline) and control (without injection) groups
- **RESULTS** – Without submucosal injection, incidence of damaging muscularis propria increased with power and duration
- To avoid injury to muscularis mucosa, total energy applied did not exceed 800 J without submucosal injection and 2,000 J with submucosal injection

Gong et.al. JGH, 32: 1040-1045

LASER ABLATIVE THERAPY

- Multiple biomedical lasers – neodymium doped yttrium-aluminum-garnet (Nd:YAG), neodymium doped yttrium-aluminum-perovskite (Nd:YAP), CO_2 laser, potassium titanyl phosphate (KTP) laser
- Nd:YAP – cheaper, more portable and better coagulating properties than Nd:YAG laser

Nd:YAG LASER

- Non contact modality
- Creates light energy by directing excited electrons at focused medium
- Neodymium – Pink colored rare earth element, doped into crystal structure of yttrium, aluminium and garnet
- Creates infrared light with wavelength of 1,064 nm → absorbed by local tissue → Photokinetic energy
- Generation of heat that denaturates protein, causes vascular photocoagulation, and vaporizes tissue
- Compared to CO_2 laser, Nd:YAG laser poorly absorbed by both water and hemoglobin leading to tissue penetration of 10 mm

Nd:YAG LASER

- Should be avoided in hemoptysis

- High depth of tissue penetration and increased risk of airway perforation

- Limited efficacy with dark tissues (i.e. charred tissue) as such tissue absorbs more light and limits depth penetration and reduced effectiveness in photocoagulation of vessels

- Bleeding is most common complication

- POPCORN EFFECT – explosion of steam when power density exceeds target tissue power density resulting in hemorrhage, airway damage or perforation

Cavaliere S CHEST 1988;94(1):15-21

MEHTA'S RULE OF FOUR

- For application of Nd:YAG laser with flexible bronchoscope

- Length of lesion <4 cm

- Duration of atelectasis <4 weeks

- Initial settings

- Power (noncontact) 40W

- Pulse duration 0.4 sec

LASER BEAM SHOULD BE FIRED PARALLEL TO WALL OF AIRWAY AND NOT DIRECTLY AT IT

Book of interventional bronchoscopy by Atul Mehta, Year 2013

MEHTA'S RULE OF FOUR

- For application of Nd:YAG laser with flexible bronchoscope

- Distances

- Endotracheal tube to lesion >4 cm

- Fiber tip to lesion 4 mm

- Distal end of scope to fiber tip 4 mm

- Fraction of inspired oxygen ≤0.4

Book of interventional bronchoscopy by Atul Mehta, Year 2013

MEHTA’S RULE OF FOUR

- For application of Nd:YAG laser with flexible bronchoscope
- Number of pulse between cleaning <40
- Procedure time <4h
- Total number of laser treatment <4
- Life expectancy >4 weeks
- Laser team ≥4

FACTORS AFFECTING OUTCOME OF LASER PHOTORESECTION

Factors	Favorable	Unfavorable
Location	Trachea and right or left main-stem bronchi	Lobar and segmental bronchi
Type of lesion	Predominantly endobronchial	Predominantly extrinsic
Endoscopic appearance	Exophytic	Submucosal
Length of lesion	<4 cm	>4 cm
Distal lumen	Visible and free of tumor	Not visible or diffusely infiltrated with the tumor
Duration of atelectasis	<4–6 weeks	>4–6 weeks
Mediastinal anatomy	Normal	Distorted
Pulmonary vascular supply	Intact	Compromised due to infiltration or compression by the tumor
Hemodynamic status	Stable	Unstable
Performance status	Good	Poor
Cardiopulmonary reserve	Adequate to withstand anesthesia	Inadequate
Oxygen requirement	≤40 %	>40 %
Coagulation profile	Normal	Abnormal

Nd-YAG Laser Damage to Metal and Silicone Endobronchial Stents

Delineation of Margins of Safety Using an *In Vitro* Experimental Model

Dalupang et.al.

- Experimental in vitro study simulating a patient-care environment
- METHODS - Stents tested – Uncovered and covered metal Wallstent and Dumon silicone stents (FiO_2 – 40%)
- Nd-YAG laser (1064nm) procedure using fiber to target distance of 10 mm and 20 mm and non-contact continuous mode, 1-s pulses at power setting of 10W, 30W and 40W
- Assessment done at 6 power densities: 75 W/cm², 172 W/cm², 225 W/cm², 300 W/cm², 518W/cm² and 690 W/cm²

- RESULTS –

- Uncovered Wallstent and silicone stent remained intact at power densities of 75 W/cm² (10 W, 20mm) and 172 W/cm² (10 W, 10 mm) but were damaged at power densities > 225 W/cm² (30 W, 20 mm)
- Covered Wallstent damaged at all power densities tested

Dalupang et.al. CHEST 2001; 120:934-940

RADIOFREQUENCY ABLATION

- CONTACT TOOL – Achieving concurrent tissue destruction and coagulation and activated before tissue contact
- Generates plasma arc by ionizing air between catheter and tissue to produce heat
- Stiff nature of RFA catheter allows forceful, contact debridement of tissue along with tissue ablation

CRYOTHERAPY

- CONTACT MODE
- Placed on target tissues in succession of adjacent areas i.e. freeze zone overlap; repeated (usually 3) freeze thaw cycles, each lasting for 30 secs
- Uses nitrous oxide gas and rigid or flexible probes
- Cooling governed by Joule Thompson principle – Decrease in temperature with expansion of gas as it moves from area of high pressure to area of low pressure
- Rapid decrease in pressure as gas released from tip of probes causing rapid cooling to temperature below - 70°C that causes tissue surrounding probe to freeze within few seconds

MECHANISM

- Repeated cycles of freezing and thawing causes cellular injury and death
- Intracellular ice damages vital cell organelles such as mitochondria
- Extracellular ice crystals cause osmotic injury and cellular dehydration
- Delayed ischemic injury due to vasoconstriction, platelet aggregation and vascular thrombosis developing after 6-12 hrs after procedure
- Maximum damage observed when tissue is frozen at rapid speed and thawed at slow speed
- Number of freeze-thaw cycles and water content of tissue – determinants of ultimate effect

BENEFITS

- Because of low water content, fibrous tissue, and cartilage are inherently resistant to cryodestruction - low incidence of airway perforation
- Suitable for highly vascular tumors (carcinoids and adenoid cystic carcinoma)
- Can be performed regardless of need of high-flow oxygen therapy as no risk of airway fire

DISADVANTAGES

- Delay in treatment response – novel extension – cryorecanalisation
- Delayed necrosis of tumor needed over 5-10 days
- Clean up bronchoscopy needed

CRYORECANALISATION

- Greater freezing power and more stable joint between gas channel and tip which can withstand 50 N
- Probe – 2.3 mm and can be used with any standard therapeutic bronchoscope
- No clean up bronchoscopy needed

APPROACH FOR BENIGN AIRWAY OBSTRUCTION