【제6차 Postgraduate Course I, II】

흉부 영상 판독

서울대학교 의과대학 흉부외과학교실

조 석 기

흉부 엑스레이는 흉부외과 영역에서 가장 많이 접하는 검사이며, 환자 상태를 반영하는데 중요한 검사이기 때문에 정확히 판독할 줄 알아야 합니다. 따라서, 연수교육을 통해서 응급실과 수술 후 병실에서 흔히 볼 수 있는 질환과 합병증을 중심으로 특징적인 단순 흉부 사진을 소개하고자 합니다.

단순 흉부 사진은 그 자체로도 중요한 의미를 갖지만 이 결과를 바탕으로 필요한 추가 검사를 결정해야 하기 때문에 항상 의심되는 질환과 술 후 문제점 등을 염두 해 둔 상태에서 접근해야 합니다. 무엇 보다 단순 흉부사진이 정상이라는 본인만의 기준을 갖고 있어야 하며, 그 기준에서 벗어나는 부분이 있으면 유심히 관찰하고 이전 사진과의 변화를 확인하여야 합니다. 흔히 볼 수 있는 이상 소견을 중심으로 알아보도록 하겠습니다.

1. 이상 공기 음영 : 정상적인 단순 흉부사진에서 흉부에서는 기도, 기관지, 폐 실질 외에는 공기 음영이 존재하지 않습니다. 하지만 공기 음영이 보이는 다른 곳에 보이면 여러 가지 질환을 생각해 볼 수 있습니다.
   예) 일차성/이차성 기흉, 종격동 기종, 거대 낭종(giant bulla), 횡격막 파열, 식도파열, 기도 파열, 수술 후 공기 유출이 많은 경우 피하기종
2. 이상 흉수 음영 : 정상적인 단순 흉부사진에서는 보여서는 안 되는 흉수와 수술 후 예상되는 정도를 넘어서는 흉수. 필요한 경우 both decubitus, CT 등을 추가로 할 수 있습니다.
   예) 기흉이 동반된 혈흉, 전폐절제술 후 흉수 변화, 수술 후 혈흉, 유미흉
3. 폐허탈 또는 염증을 시사하는 음영: 수술 후 정상적인 폐 팽창을 보이지 않고 폐 허탈과 폐렴을 시사하는 단순 흉부사진 소견을 이해하고 원인에 대해서 알아본다.
   예) 단순 폐 허탈, 수술 후 lobar torsion, 수술 후 폐렴

상기 이상 소견들에 대한 임상적 의미를 정확히 파악하고 이를 해결하기 위해서는 질병에 대한 자세한 이해와 수술 방법과 수술 후 변화에 대한 이해가 있어야 합니다.

Preoperative Work Up for Thoracic Surgery

계명대학교 동산의료원 흉부외과학교실

금 동 윤

무엇을 확인할 것인가?

- 환자는 어떤 증상을 호소하는가?
- 환자의 몸 상태는 수술을 견딜 수 있는가?
- 병의 진행 정도는 수술이 합당한가?

Clinical presentation and physical examination
Anatomical staging of cancer
Physiologic staging of cancer

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Sixth Edition T/M Descriptor	Seventh Edition T/M
T1 (≤2 cm)	T1a
T1 (>2~3 cm)	T1b
T2 (≤5 cm)	T2a
T2 (>5~7 cm)	T2b
T2 (>7 cm)	T3
T3 invasion	
T4 (same lobe nodules)	
T4 (extension)	T4
M1 (ipsilateral lung)	
T4 (pleural effusion)	M1a
M1 (contralateral lung)	
M1 (distant)	M1b

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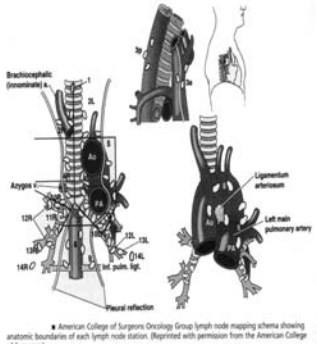
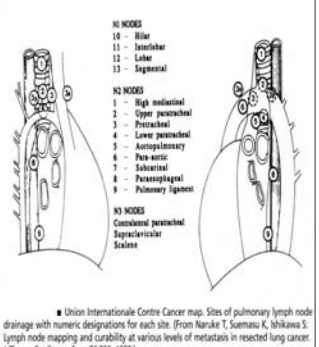
Lymph node mapping



■ American College of Surgeons Oncology Group lymph node mapping schema showing anatomic boundaries of each lymph node station. (Reprinted with permission from the American College of Surgeons.)



■ Union Internationale Contre Cancer map. Sites of pulmonary lymph node drainage with numeric designations for each site. (From Naruke T, Suemasu K, Ishikawa S: Lymph node mapping and curability at various levels of metastasis in resected lung cancer. J Thorac Cardiovasc Surg 76:832, 1978.)

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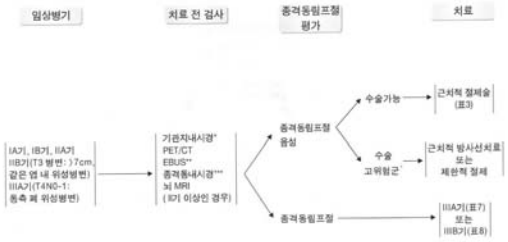

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Diagnostic Tools

- T stage: chest x-ray, chest CT, bronchoscopy, PET-CT, (MRI)
- N staging: chest CT, PET-CT TBNA, EBUS-TBNA, mediastinoscopy, mediastionotomy
- M staging: physical exam, bone scan, brain CT(MRI), PET-CT

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Enlarged L.N. on chest CT

- Positive CT result(> 1cm): 70% actual metastasis
  → histological confirm
- False-negative rate less than 10% in negative CT result(< 1cm)
  →T1/T2 + negative CT result: histologic confirm(?) (mediastinoscopy?)

cf. 28% false-negative rate on central T3
→ histological confirm(Daly et al. JTCS 94;664 1987)

cf. High rate of early metastasis in T1 adenoca, large cell ca

DSMC

Mediastinoscopy/Mediastinotomy

Histologic diagnosis
Accurate determine the N2
Identify extranodal extension of tumor/ involvement of contiguous structure (trachea/aorta)
Identify N3

Indication

1. L.N. enlargement more than 1cm on preop CT
2. Potential entry to neoadjuvant therapy protocol
3. Negative CT result in T2, T3 tumor and T1 adenoca/large cell ca(relative)

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Mediastinoscopy/Mediastinotomy

Routine mediastinoscopy (with negative CT scan)

- Low complication rate
- Resectable N2 without neoadjuvant Tx(single station, ipsilateral, lower paratracheal, no extracapsular extension
- High rate of thoracotomy(curative resection)
- 10-15% false negative rates on chest CT

Selective mediastinoscopy

- High rate of negative mediastinoscopic examination(70%)
- Possible complete resection of unsuspected N2

★ unsuspected N2: 8.9%(mostly inaccessable site; post subcarinal, periesophageal, anteroir mediastinal_)

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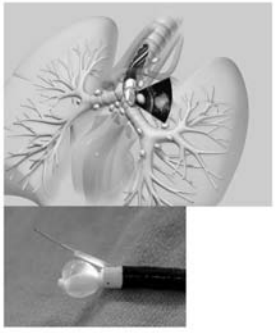
EBUS(+TBNA)



- 2007 ACCP: invasive staging mediastinoscopy대체 in stage Ⅱ or central cancer
- 2009 NCCN: ⅢB 치료전 종격동검사 방법으로 권유
- Node: 1R, 1L, 2R, 4R, 7, 10, 11(+) 5, 6, 8, 12(-)
- Sensitivity 95%, specificity 100%

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EBUS(+TBNA) 적용

- 폐암의 진단.
  peripheral lung cancer
  central parenchymal lung cancer, bronchoscopy(-)
- 폐암의 림프절 병기결정
  PET N2(+) lung cancer: 민감도 93%, 정확도97%, 음성예측율91%
  PET N2(-) lung cancer: 민감도 89%, 음성예측율 98.9%
  → adenocarcinoma/ >5mm mediastinal node
- Restaging the mediastinum after CCRT
  민감도 76%,정확도 77%.음성예측율 20%로 치료전 시행된 것에 비해 낮은 민감도와 정확도 → 추가적 수술확인 필요
- 원인 불분명한 hilar, mediastinal Lymphadenopathy
- Mediastinal mass

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EBUS(+TBNA)

EBUS-TBNA 에서 림프절을 몇 회까지 흡인하는 것이 적절한가?

Table 7. Cumulative Diagnostic Values of EBUS-TBNA Shown by the Number of Aspirations

Variables	Aspirations, No.			
	1	2	3	4
Sensitivity	69.5 (30/43)	83.7 (36/43)	95.3 (41/43)	95.3 (41/43)
Specificity	100 (83/83)	100 (83/83)	100 (83/83)	100 (83/83)
PPV	100 (30/30)	100 (36/36)	100 (41/41)	100 (41/41)
NPV	86.5 (83/96)	92.2 (83/90)	97.6 (83/85)	97.6 (83/85)
Accuracy	89.7 (113/126)	94.4 (119/126)	99.4 (124/126)	99.4 (124/126)

*Data are presented as % (No./total). We considered inadequate samples as negative results.

종격종 림프절의 최대한의 정확도를 얻기 위해서는 3회의 흡인이 필요하고 tissue core를 획득한 경우는 2회의 흡인이 필요하다.

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PET-CT

- 양전자방출, 동위원소: F-18 fluordeoxyglocose(FDG)
- 폐암세포는 정상세포보다 포도당흡수가 증가, 당분해(glycolysis)속도가 높다.
- PET-CT: CT 해부학적 구조(node size)
  + PET 기능적 구조(metabolism)
- Granulomatous lesion(tuberculoma, histoplasmosis, rheumatoid nodule), inflammatory disease에서 양성
- 크기가 1-1.2cm보다 작을경우 확인 안될 수도 있다.
  False (+) 20%, false (-) 20%
- Carcinoid tumor, bronchioloalveolar carcinoma: PET(-)
- PET detect unexpected distant meta in 10-15% NSCLC
  & unexpected mediastinal node meta in 10%
- 종격동 PET-CT(-): 술전 mediastinoscopy시행하지 않아도 됨. 양성인 경우는 invasive test(mediastinoscopy or EBUS) 필요

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Mediastinal staging of lung cancer: novel concepts

Kurt G Tournoy, Steven M Keller, Jouke T Annema

Clinical TNM staging is the standard method used to decide treatment for patients with non-small-cell lung cancer. Although integrated fluorodeoxyglucose (FDG) PET CT increases the accuracy of staging, it only guides direct tissue sampling. Histological assessment of mediastinal lymph nodes has traditionally been done with mediastinoscopy, a surgical procedure. Endobronchial and oesophageal ultrasound-guided lymph node sampling have been assessed as additions or alternatives to mediastinoscopy. We review endosonography and surgical staging, and show that both have a place in the mediastinal staging of lung cancer. We conclude that mediastinal tissue staging should preferentially start with a complete endosonographic assessment. A surgical mediastinoscopy should be reserved for those in whom the endosonography result is negative. Further refinement of this recommendation is likely in the near future because data suggest that the confirmatory mediastinoscopy is particularly useful for patients with enlarged or FDG-avid lymph nodes.

Lancet Oncol 2012; 13: e221–29

Ghent University Hospital, Department of Respiratory Medicine and Thoracic Oncology, Ghent, Belgium (K G Tournoy MD); Albert Einstein College of Medicine, Thoracic Surgery Weiler Division, Bronx, New York, NY, USA (S M Keller MD); Leiden University Medical Center, Department of Respiratory Medicine, Leiden,

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	Design	Patients enrolled (n)	Received EUS-FNA and EBUS-TBNA (n)	Analysed (n)	N2 or N3 prevalence (%)	Sensitivity (%, 95% CI)	NPV (%, 95% CI)
Ohnishi,* 2011*	Cohort	120	115	110	28%	84% (67-93)	94% (87-97)
Annema,* 2010	RCT	242	123 (1 group)	123	54%	85% (74-92)	85% (75-92)
Hwangbo,* 2010†	Cohort	150	149	143	31%	91% (78-97)	96% (90-98)
Herth,* 2010†	Cohort	150	150	139	51%	96% (88-99)	96% (88-99)
Szlubowski,* 2010*	Cohort	120	120	120	23%	68% (48-84)	91% (83-96)
Wallace,* 2008	Cohort	138	138	138	30%	93% (81-99)	97% (91-99)
Rintoul,* 2005‡	Cohort	20	7	7	57%	75% (19-99)	75% (19-99)
Vilmann,* 2005‡	Cohort	33	31	28	71%	100% (83-100)	100% (63-100)

95% CIs were taken from the article, or if not provided, were calculated with binomial expansion. RCT=randomised controlled trial. NPV=negative predictive value. EUS-FNA=endoscopic ultrasound-guided fine-needle aspiration. EBUS-TBNA=endobronchial ultrasound with real-time guided transbronchial needle aspiration. PET=positron emission tomography. CT=computed tomography. *Prevalence of malignant nodal metastasis was low because Ohnishi* included any clinical T<4N+M0 after imaging while Szlubowski* included only patients with normal mediastinal nodes (selected with CT, no PET CT available). †EUS-FNA and EBUS-TBNA done with a single (EBUS) endoscope. ‡Feasibility reports, not trials assessing test characteristics.

Table 1: Studies of complete endosonography to stage the mediastinum

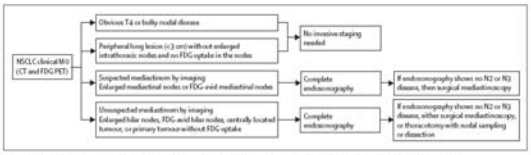

Figure 4: Proposed algorithm for mediastinal staging in patients with non-metastatic non-small-cell lung cancer based on CT PET findings
CT=computed tomography. PET=positron-emission tomography. FDG=fluorodeoxyglucose. NSCLC=non-small-cell lung cancer.

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Definitive Diagnosis

- CT-guided FNAB
- Transbronchial Bx
- VATS Bx with Marking tools
  - Needle
  - Methylene blue
  - intraoperative ultrasound (gamma probe)
  - Technetium-99m (percutaneous or transbronchial)

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Physiologic staging

- Age
- Pre-existing lung condition(lung function)
- Cardiovascular fitness
- Nutrition and performance status (recent weight loss)
- Smoking
- Obesity
- Patient attitude toward the disease

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The Society of Thoracic Surgeons Lung Cancer Resection Risk Model: Higher Quality Data and Superior Outcomes

Felix G. Fernandez, MD, MS, Andrzej S. Kosinski, PhD, William Burfeind, MD, Bernard Park, MD, Malcolm M. DeCamp, MD, Christopher Seder, MD, Blair Marshall, MD, Mitchell J. Magee, MD, Cameron D. Wright, MD, and Benjamin D. Kozower, MD, MPH

Emory University, Atlanta, Georgia; Duke Clinical Research Institute, Durham, North Carolina; St. Luke's Health Network, Allentown, Pennsylvania; Memorial Sloan Kettering Cancer Center, New York, New York; Northwestern University, Chicago, Illinois; Rush University, Chicago, Illinois; Georgetown University, Washington, DC; Medical City Hospital, Dallas, Texas; Massachusetts General Hospital, Boston, Massachusetts; and University of Virginia, Charlottesville, Virginia

Background. The Society of Thoracic Surgeons (STS) creates risk-adjustment models for common cardiothoracic operations for quality improvement purposes. Our aim was to update the lung cancer resection risk model utilizing the STS General Thoracic Surgery Database (GTSD) with a larger and more contemporary cohort.

Methods. We queried the STS GTSD for all surgical resections of lung cancers from January 1, 2012, through December 31, 2014. Logistic regression was used to create three risk models for adverse events: operative mortality, major morbidity, and composite mortality and major morbidity.

Results. In all, 27,844 lung cancer resections were performed at 231 centers; 62% (n = 17,153) were performed by thoracoscopy. The mortality rate was 1.4% (n = 401), major morbidity rate was 9.1% (n = 2,545), and the composite rate was 9.5% (n = 2,654). Predictors of mortality included age, being male, forced expiratory volume in 1 second, body mass index, cerebrovascular disease, steroids, coronary artery disease, peripheral vascular disease, renal dysfunction, Zubrod score, American Society of Anesthesiologists rating, thoracotomy approach, induction therapy, reoperation, tumor stage, and greater extent of resection (all $p < 0.05$). For major morbidity and the composite measure, cigarette smoking becomes a risk factor whereas stage, renal dysfunction, congestive heart failure, and cerebrovascular disease lose significance.

Conclusions. Operative mortality and complication rates are low for lung cancer resection among surgeons participating in the GTSD. Risk factors from the prior lung cancer resection model are refined, and new risk factors such as prior thoracic surgery are identified. The GTSD risk models continue to evolve as more centers report and data are audited for quality assurance.

(Ann Thorac Surg 2016;■:■–■)

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Table 1. Patient Baseline Characteristics

Variable	Values
Total	27,844 (100)
Age, years	67.2 ± 10.1
Male	12,647 (45.4)
Race	
White	24,099 (87.0)
Black	2,369 (8.6)
Other	1,217 (4.4)
Body mass index, kg/m^2*	27.6 ± 6.2
Coronary artery disease	6,196 (22.3)
Diabetes mellitus	5,158 (18.5)
Renal dysfunction	504 (1.8)
Induction chemotherapy or radiation	1,801 (6.5)
Cigarette smoking	
Never	3,895 (14.0)
Past (stopped more than 1 month)	17,368 (62.4)
Current	6,581 (23.6)
Steroids	965 (3.5)
Minimally invasive	17,153 (61.6)
Thoracotomy	10,691 (38.4)
Primary procedure	
Wedge resection	3,815 (13.7)
Segmentectomy	1,685 (6.1)
Lobectomy	19,836 (71.2)
Sleeve lobectomy	412 (1.5)
Bilobectomy	980 (3.5)
Pneumonectomy	1,116 (4.0)

* Missing values imputed to median by sex.

Values are n (%) or mean ± SD.

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Table 2. Frequency of Complications

Variable	Values
Tracheostomy	283 (1.0)
Reintubation	899 (3.2)
Initial ventilatory support >48 hours	148 (0.5)
Adult respiratory distress syndrome	159 (0.6)
Bronchopleural fistula	149 (0.5)
Pulmonary embolus	131 (0.5)
Pneumonia	1,116 (4.0)
Unexpected return to operating room	1050 (3.8)
Myocardial infarction	92 (0.3)
Deep vein thrombosis requiring treatment	148 (0.5)
Atrial arrhythmia requiring treatment	2,974 (10.7)
Renal failure, RIFLE criteria	209 (0.8)
Blood transfusion	
Intraoperative	696 (2.5)
Postoperative	1438 (5.2)
Sepsis	189 (0.7)
Chylothorax	
Requiring surgical ligation	49 (0.2)
Medical treatment only	100 (0.4)
Recurrent laryngeal nerve paralysis	139 (0.5)

Values are n (%).

RIFLE = Risk, Injury, Failure, Loss of kidney function, and End-stage kidney disease.

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Table 4. Predictors of Mortality, Major Morbidity, and Composite Mortality and Major Morbidity[a]

Variable	Mortality Model OR (95% CI)	*p* Value	Major Morbidity Model OR (95% CI)	*p* Value	Composite Model (Mortality or Major Morbidity) OR (95% CI)	*p* Value
Age, 10-year increase	1.64 (1.44–1.87)	<0.001	1.13 (1.08–1.19)	<0.001	1.14 (1.08–1.90)	<0.001
Male	1.54 (1.23–1.92)	<0.001	1.39 (1.28–1.52)	<0.001	1.41 (1.29–1.53)	<0.001
Body mass index, kg/m^2		0.006		<0.001		<0.001
≥18.5 to <25	1.00		1.00		1.00	
≥6.0 to <18.5	1.44 (0.85–2.44)		1.33 (1.07–1.65)		1.35 (1.09–1.66)	
≥25.0 to <30.0	0.96 (0.75–1.22)		0.83 (0.75–0.91)		0.83 (0.75–0.92)	
≥30.0 to <35.0	0.61 (0.43–0.85)		0.72 (0.64–0.82)		0.72 (0.63–0.82)	
≥35.0 to ≤99.9	1.17 (0.82–1.67)		0.81 (0.69–0.96)		0.83 (0.71–0.97)	
Hypertension	0.93 (0.73–1.17)	0.51	1.08 (0.98–1.19)	0.12	1.06 (0.96–1.16)	0.25
Steroids	1.72 (1.14–2.60)	0.01	1.28 (1.05–1.57)	0.017	1.33 (1.09–1.62)	0.005
Congestive heart failure	1.51 (1.01–2.25)	0.046	1.17 (0.95–1.44)	0.15	1.19 (0.97–1.46)	0.10
Coronary artery disease	1.32 (1.05–1.67)	0.019	1.13 (1.02–1.25)	0.022	1.14 (1.03–1.26)	0.011
Peripheral vascular disease	1.49 (1.13–1.96)	0.005	1.43 (1.26–1.62)	<0.001	1.43 (1.26–1.63)	<0.001
Reoperation	1.38 (1.00–1.94)	0.052	1.35 (1.16–1.58)	<0.001	1.32 (1.13–1.54)	<0.001
Cerebrovascular disease	1.42 (1.05–1.90)	0.021	1.08 (0.94–1.24)	0.29	1.11 (0.97–1.28)	0.14
Diabetes mellitus	1.08 (0.85–1.39)	0.53	1.01 (0.90–1.12)	0.93	1.01 (0.91–1.13)	0.84
% FEV_1, 10% decrease	1.07 (1.01–1.12)	0.02	1.13 (1.10–1.15)	<0.001	1.12 (1.10–1.15)	<0.001
Induction therapy	1.51 (1.09–2.10)	0.014	1.20 (1.02–1.40)	0.024	1.20 (1.03–1.39)	0.022
Renal dysfunction	1.74 (1.06–2.86)	0.029	1.07 (0.81–1.42)	0.64	1.11 (0.84–1.46)	0.47
Cigarette smoking		0.14		<0.001		<0.001
Never	1.00		1.00		1.00	
Past smoker	1.54 (1.00–2.38)		1.20 (1.02–1.41)		1.23 (1.05–1.44)	
Current smoker	1.54 (0.96–2.49)		1.64 (1.38–1.94)		1.64 (1.38–1.94)	

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Zubrod score		<0.001		<0.001		<0.001
0	1.00		1.00		1.00	
1	1.60 (1.25–2.04)		1.14 (1.04–1.25)		1.16 (1.06–1.28)	
2–5	2.21 (1.45–3.37)		1.57 (1.29–1.91)		1.60 (1.32–1.95)	
ASA		0.007		<0.001		<0.001
1 or 2	1.00		1.00		1.00	
3	1.67 (1.05–2.65)		1.25 (1.08–1.45)		1.27 (1.09–1.47)	
4 or 5	2.26 (1.34–3.80)		1.72 (1.42–2.09)		1.76 (1.45–2.13)	
Approach		<0.001		<0.001		<0.001
Minimally invasive	1.00		1.00		1.00	
Thoracotomy	1.87 (1.49–2.36)		1.49 (1.35–1.64)		1.51 (1.37–1.66)	
Pathologic stage		0.008		0.30		0.25
I	1.00		1.00		1.00	
II	1.15 (0.89–1.48)		1.07 (0.96–1.19)		1.05 (0.95–1.17)	
III	1.46 (1.10–1.96)		1.13 (0.99–1.29)		1.14 (1.00–1.30)	
IV	2.23 (1.23–4.02)		1.01 (0.73–1.40)		1.04 (0.75–1.42)	
Procedure		<0.001		<0.001		<0.001
Wedge	1.00		1.00		1.00	
Segmentectomy	0.98 (0.51–1.88)		1.19 (0.93–1.53)		1.24 (0.97–1.57)	
Lobectomy	1.69 (1.14–2.53)		1.96 (1.67–2.30)		1.93 (1.65–2.26)	
Sleeve	1.72 (0.72–4.09)		1.93 (1.36–2.75)		1.96 (1.39–2.77)	
Bilobectomy	3.57 (2.09–6.12)		2.98 (2.34–3.80)		2.91 (2.29–3.70)	
Pneumonectomy	4.80 (2.87–8.02)		2.74 (2.15–3.48)		2.83 (2.24–3.58)	
C-statistic	0.78		0.68		0.68	

* Intercept values for the models are −10.822 for mortality, −5.651 for major morbidity, and −5.657 for composite. Covariate specific coefficients can be obtained by taking natural logarithm of the odds ratios.

ASA = American Society of Anesthesiologists; CI = confidence interval; FEV_1 = forced expiratory volume in first second of expiration; OR = odds ratio.

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Age

- Perioperative morbidity increase with advancing age →preop careful assessment of co-morbid
- Clinically stage I, II over 70yrs: same with younger patients(beyond stage II, survival is very poor)
- In Stage I, over 80 is not contraindication to lobectomy
- Pneumonectomy is higher mortality risk(6-36%) in elder, Age should be a factor in deciding suitability for pneumonectomy

DSMC

TABLE 2-1 Scales for Assessing Individual Performance Status

Grade	ECOG[1]	Score	Karnofsky[2]
0	Fully active, able to carry on all predisease performance without restriction	100 90	Normal, no complaints; no evidence of disease Able to carry on normal activity; minor signs or symptoms of disease
1	Restricted in physically strenuous activity but ambulatory and able to carry out work of a light or sedentary nature (e.g., light housework, office work)	80	Normal activity with effort; some signs or symptoms of disease
2	Ambulatory and capable of all self-care but unable to carry out any work activities; up and about more than 50% of waking hours	70 60	Cares for self; unable to carry on normal activity or to do active work Requires occasional assistance, but is able to care for most personal needs
3	Capable of only limited self-care; confined to bed or chair more than 50% of waking hours	50	Requires considerable assistance and frequent medical care
4	Completely disabled; cannot carry on any self-care; totally confined to bed or chair	40 30 20 10	Disabled; requires special care and assistance Severely disabled; hospital admission is indicated although death is not imminent Very sick; hospital admission necessary; active supportive treatment necessary Moribund; fatal processes progressing rapidly
5	Dead	0	Dead

[1]Oken MM, Creech RH, Tormey DC, et al: Toxicity and response criteria of the Eastern Cooperative Oncology Group. Am J Clin Oncol 5:649-655, 1982.
[2]Hollen PJ, Gralla RJ, Kris MG, et al: Measurement of quality of life in patients with lung cancer in multicenter trials of new therapies. Cancer 73:2087-2098, 1994.

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Pulmonary Assessment

- Smoking
  minimum 1-2 week(~8 weeks)
- Sputum production
  preoperative sputum culture
- Ability to cough
  effective cough + incentive spirometry

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PFT

Poor resp function → perioperative morbidity/mortality
- postop long term disability
- poor quality of life

Additional test in poor, risk PFT test
- Ventilation/perfusion scan(ppoFEV1,ppoDLCO)
- VO_2max
- SaO_2 after exercise

3 most important predictors of severe pul complications: D_LCO, FEV1/FVC, A-aDO_2

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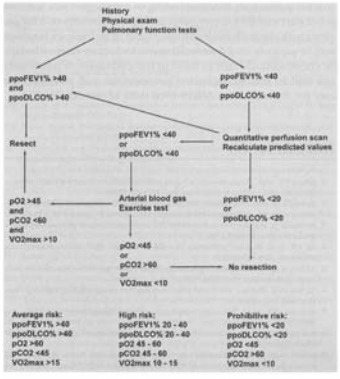

Suggested algorithm for evaluating patients for their suitability for major lung resection (ppoFEV$_1$ %: predicted postoperative FEV$_1$ expressed as a percent of normal; ppoDL$_{CO}$%: predicted postoperative diffusing capacity expressed as a percent of normal; PO_2: PO_2 in mm Hg; PCO_2: PCO_2 in mmHg; VO_2max: VO_2max in mL/kg per minute).

Low FEV1 postbrochodilator
Low DLCO postbronchodilator
↓
Quantative perfusion scan
ppoFEV1, ppoDLCO
↓
Exercise test
250m walking
Arterial blood gas/O2sat 감소
↓
Peak oxygen consumption test

Absolute contraindication for resection
- ppoFEV1 < 0.8 L
- VO2max < 10ml/kg/min
- ↑ CO2(cor pulmonale) in pneumonectomy

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TABLE 4–3 ■ Predictors of Postoperative Mortality and Morbidity

Test	Predictive of Increased Morbidity	Prohibitive
Clinical		
Stair climbing	<3 flights (12 m height)	<1 flight
Match test	Failed	
Dyspnea grade	2–4	4
Pulmonary Mechanics		
MVV	<50 L/min	<35% predicted
FEV_1	<50% FVC	<0.6 L
FVC	<50% predicted	<1.0 L
FEV_1/FVC	<60% predicted	<50%
Gas Exchange		
D_{LCO}	<50%	<30%
Po_2 and Sao_2	Desaturation on exercise	Po_2 <45 mm Hg
Pco_2 and actual HCO_3 elevated		Pco_2 >50 mm Hg
V/Q Scanning Prediction		
FEV_1	<30% predicted	<0.8 L predicted
VC		<1 L predicted
Exercise Testing		
Vo_2max	<20 ml/kg/min	<10 ml/kg/min
PVR		>190 dynes/s/cm^5

D_{LCO}, carbon monoxide diffusion capacity; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; MVV, maximal voluntary ventilation; PVR, pulmonary vascular resistance; VC, vital capacity; Vo_2max, maximal oxygen uptake; V/Q, ventilation/perfusion.
Data from multiple treatises.

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Cardiovascular Fitness

- All patients for lung resection should have preop ECG
- All patients with audible cardiac murmur should have echocardiogram
- After MI, operation for lung resection should not done within 6 weeks
- MI within 6 month, ask cardiology opinion
- CABG should not preclude lung resection
- Pt with significant lesion on coronary angiography should be considered for CABG before lung resection
- All patient with history of stroke, TIA, carotid bruits, should be assessed with carotid doppler

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Reason of cardiac complication after thoracic surgery

- Atelectasis, compliance ↓, diffusion capacity ↓ →myocardial oxygen supply ↓, demand ↑
- Postoperatively, patients change to hypercoagulable
- After lung resection, increased preload leads to congestive heart failure
- High catecholamine level associated with pain

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TABLE 4–5 ■ Goldman Cardiac Risk Index (1983)*

Factors	Points
History	
Age >70	5
Myocardial infarction, <6 mo	10
Physical	
Congestive failure	11
Aortic stenosis	3
Electrocardiogram	
Rhythm abnormality	7
PVCs >5/min	7
General	
Po_2 <60 mm Hg, Pco_2 >50 mm Hg, HCO_3 <20 mg/L	3
↑ Creatinine	
Liver disease	
↑ Performance status	
Type of operation	
Intraperitoneal or intrathoracic	3
Emergency	4
Total possible points	53

Class	Points	Severe Morbidity	Cardiac Death
1	0–5	0.7%	0.2%
2	6–12	5%	2%
3	13–25	11%	2%
4	>26	22%	56%

PVCs, premature ventricular contractions.
*With more modern perioperative care, the risks for each class are probably less than those originally predicted.

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Cardiovascular Fitness

Table 3 Importance of multiple risk factors

Risk factors:	High risk surgery (includes intrathoracic) Ischaemic heart disease Congestive heart failure Insulin dependent diabetes Creatinine >177 μM/l
Number of factors*	Major cardiac complications**
1	1.1%
2	4.6%
⩾3	9.7%

*As intrathoracic surgery is classified as a risk factor, all patients undergoing surgery for lung cancer have at least one factor.
**Myocardial infarction, pulmonary oedema, ventricular fibrillation or primary cardiac arrest, complete heart block.

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Weight loss, Performance status, Nutrition

- Patient with preop wt loss >10% or more
- And/or WHO 2 or worse→particular care staging assessment
- Measure of nutritional status(body mass index, serum albumin level)

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DETERMINANTS OF POSTOPERATIVE MORBIDITY AND MORTALITY*

- Cardiac disease
- Pulmonary disease
- Tumor characteristics
  - Stage
  - Type
- General medical conditions
  - Diabetes
  - Creatinine level
  - Hemoglobin level
  - Serum albumin level
  - Immnosuppressed status
    - Steroids
    - Chemotherapy
    - Other chronic illnesses
  - Weight loss >10%
  - Age >70
- Anticipated surgery
- Extent of resection
- Additional procedures
- Side of pulmonary resection (R > L)
- Previous surgery

*Significant cardiopulmonary disease, late tumor stage, and extent of resection appear to be the most significant determinants.

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Perioperative management of patients receiving Anticoagulants

- Balance between reducing the risk of thromboembolism and preventing excessive bleeding
- Wafarin
- Timing of anticoagulant interruption
  - Discontinuation
  - Bridging preoperatively
  - restarting

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Perioperative management of agents affecting hemostasis

Name or class of drug	Clinical considerations	Recommended strategy for surgery with brief NPO state	Recommended strategy for surgery with prolonged NPO state
Aspirin	Continuation may cause perioperative hemorrhage. Discontinuation may increase the risk of vascular complications. **Discussion with cardiologist appropriate for patients with cardiovascular indications.**	Discontinue aspirin approximately 7 days prior to noncardiovascular surgery.	Resume with oral intake.
P2Y12 receptor blockers (clopidogrel, prasugrel, ticlopidine, ticagrelor)	When used after cardiac stenting procedure, if discontinued can cause cardiac ischemia perioperatively. If continued can result in bleeding complications. Should discuss management with cardiologist.	Ideally, elective procedures should be delayed until the mandatory period of platelet inhibition with these agents is completed. When used for long-term stroke prophylaxis, should be discontinued 7 to 10 days. If discontinuing, stop clopidogrel and ticagrelor at least 5 days, prasugrel 7 days, and ticlopidine 10 days before surgery. When restarting clopidogrel, consider using a loading dose.	Resume with oral intake.
Warfarin	Refer to UpToDate topic on anticoagulation before and after elective surgery.		
Dabigatran	Refer to UpToDate topic on anticoagulation before and after elective surgery.		

Graphic 68513 Version 9.0

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Expected effects of anticoagulant drugs on commonly used coagulation tests

Drug class	Drug	Brand name(s)	PT	aPTT	Anti-factor Xa activity
Vitamin K antagonists	Warfarin	Coumadin, Jantoven	↑	↑/–*	–
	Acenocoumarol	Sintrom	↑	↑/–*	–
Heparins	Unfractionated heparin		–Δ	↑	↑
	LMW heparins		–	↑/–	↑
	Enoxaparin	Lovenox			
	Dalteparin	Fragmin			
	Nadroparin	Fraxiparine			
	Fondaparinux	Arixtra	–	↑/–	↑
Direct thrombin inhibitors	Argatroban	Acova	↑	↑	–
	Dabigatran	Pradaxa	↑/–	↑	–
Direct factor Xa inhibitors	Rivaroxaban	Xarelto	↑/–	↑/–	↑/–Δ
	Apixaban	Eliquis	↑/–	↑/–	↑/–Δ

PT and aPTT are measured in seconds; anti-factor Xa activity is measured in units/mL. Upward arrow (↑) signifies an increase above normal due to the anticoagulant (prolongation of PT or aPTT); increase in anti-factor Xa activity). The effect magnitude will vary depending on the reagent formulation and instrument used. Dash (–) signifies no appreciable effect. Normal ranges for the PT, aPTT, and anti-factor Xa activity vary among laboratories and should be reported from the testing laboratory along with the patient result. Refer to the UpToDate topic on coagulation testing for details.

PT: prothrombin time; aPTT: activated partial thromboplastin time; LMW heparin: low molecular weight heparin.

* Warfarin has a weak effect on most aPTT reagents. However, warfarin use will increase the sensitivity of the aPTT to heparin effect.

¶ While heparin, LMW heparin, and fondaparinux should, in theory, prolong the PT as indirect thrombin inhibitors, in practice most PT reagents contain heparin-binding chemicals that block any heparin effect below a concentration of 1 unit/mL, above concentrations of 1 unit/mL, heparin effect on the PT may be observed.

Δ Anti-factor Xa activity testing must be calibrated for the specific anticoagulant; this information should be verified with the clinical laboratory.

Graphic 91267 Version 6.0

DSMC

Reversing anticoagulation in warfarin-associated bleeding

Management option	Time to anticoagulation reversal	Comments and cautions
Discontinuing warfarin therapy	5 to 14 days	Five days is typical for patients with an INR in the therapeutic range
Vitamin K*	4 to 24 hours to correct the INR, longer to fully reverse anticoagulation	Recovery of factors II and II (prothrombin) takes longer than 24 hours Risk of anaphylaxis with intravenous injection Impaired response to warfarin lasting up to one week may occur after large doses (ie, >5 mg)
Fresh frozen plasma	Depends on the time it takes to complete the infusion; typically 12 to 72 hours for complete reversal	Effect is transient and concomitant vitamin K must be administered Potential for volume overload (2 to 4 L to normalize INR) Potential for TRALI Potential for viral transmission
Prothrombin complex concentrate	15 minutes after 10-minute to 1-hour infusion	Effect is transient, and concomitant vitamin K must be administered; limited availability Cost Variable factor VII content depending on the product: a 4-factor PCC is preferred Potentially prothrombotic
Recombinant factor VIIa	15 minutes after bolus infusion	Effect is transient, and concomitant vitamin K must be administered Cost Potentially prothrombotic

Please refer to the UpToDate topic on warfarin reversal in intracerebral hemorrhage for further details of management.

INR: international normalized ratio; TRALI: transfusion-related acute lung injury; PCC: prothrombin complex concentrate.

* A total of 10 mg intravenously by slow infusion given over 10 minutes.

Adapted with permission from: Aguilar MI, Hart RG, Kase CS, et al. Treatment of warfarin-associated intracerebral hemorrhage: Literature review and expert opinion. Mayo Clin Proc 2007; 82:82. Copyright © 2007 Dovden Health Media.

Graphic 79191 Version 15.0

DSMC

Perioperative management of oral direct thrombin inhibitors and factor Xa inhibitors

Anticoagulant	Renal function and dose	Interval between last dose and procedure NOTE: No anticoagulant is administered the day of the procedure		Resumption after procedure	
		High bleeding risk	Low bleeding risk	High bleeding risk	Low bleeding risk
Dabigatran	CrCl ≥50 mL/minute Dose 150 mg twice daily	Give last dose three days before procedure (ie, skip four doses on the two days before the procedure)	Give last dose two days before procedure (ie, skip two doses on the day before the procedure)	Resume 48 to 72 hours after surgery (ie, postoperative day 2 to 3)	Resume 24 hours after surgery (ie, postoperative day 1)
	CrCl 30 to 50 mL/minute Dose 150 mg twice daily	Give last dose five days before procedure (ie, skip eight doses on the four days before the procedure)	Give last dose three days before procedure (ie, skip four doses on the two days before the procedure)		
Rivaroxaban	CrCl ≥50 mL/minute Dose 20 mg once daily	Give last dose three days before procedure (ie, skip two doses on the two days before the procedure)	Give last dose two days before procedure (ie, skip one dose on the day before the procedure)		
	CrCl 30 to 50 mL/minute Dose 15 mg once daily				
Apixaban	CrCl ≥50 mL/minute Dose 5 mg twice daily	Give last dose three days before procedure (ie, skip four doses on the two days before the procedure)	Give last dose two days before procedure (ie, skip two doses on the day before the procedure)		
	CrCl 30 to 50 mL/minute Dose 2.5 mg twice daily				
Edoxaban	CrCl 30 to 95 mL/minute Dose 60 mg once daily	Give the last dose three days before the procedure (ie, skip two doses on the two days before the procedure)	Give the last dose two days before the procedure (ie, skip one dose on the day before the procedure)		
	CrCl 15 to 30 mL/min Dose 30 mg once daily				

Bleeding risk is determined primarily by the type of surgery; patient comorbidities may also play a role. In patients undergoing neuraxial anesthesia or a very high bleeding risk procedure, a longer period of interruption may be warranted. In many low bleeding risk procedures, the anticoagulant does not need to be interrupted. Bridging anticoagulation may be appropriate preoperatively in patients with a very high thromboembolic risk who require more prolonged interruption of the anticoagulant (eg, for renal insufficiency) and/or postoperatively in patients who are unable to resume the anticoagulant (eg, unable to take oral medication due to intestinal ileus). Refer to the UpToDate topics on perioperative management of patients receiving anticoagulants for further details.

CrCl: creatinine clearance.

Graphic 93240 Version 7.0

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Perioperative management of cardiovascular agents

Name or class of drug	Clinical considerations	Recommended strategy for surgery with brief NPO state	Recommended strategy for surgery with prolonged NPO state
Beta blockers	Abrupt withdrawal can result in hypertension, tachycardia, and myocardial ischemia. Perioperative initiation can prevent postoperative myocardial ischemic events in patients with significantly increased cardiac risk, but may increase risk for stroke. Perioperative initiation of beta blockers is: recommended in patients with CAD or ischemia on stress testing who are undergoing vascular surgery; and reasonable in patients with at least one cardiac risk factor who are undergoing vascular surgery, or with CAD or ≥1 cardiac risk factor undergoing intermediate risk surgery. Perioperative initiation of beta blockers is not recommended in patients with baseline heart rate <50 beats per minute, systolic blood pressure <90 mmHg, or when time is not sufficient for titration.	Continue therapy up to and including day of surgery.	Continue therapy up to and including day of surgery. Substitute IV propranolol, metoprolol, or labetalol during NPO state.
Alpha 2 agonists	Withdrawal can cause extreme hypertension and myocardial ischemia.	Continue therapy up to and including day of surgery.	Continue therapy up to and including day of surgery. Substitute transdermal clonidine.
Calcium channel blockers	Conflicting evidence on whether there is an increased risk of bleeding.	Continue therapy up to and including day of surgery.	Continue therapy up to and including day of surgery. No IV substitution necessary unless poor hemodynamics (hypertension or arrhythmia).
Ace inhibitors and angiotensin receptor blockers	Continuation can result in hypotension.	Discontinue night before surgery unless using for HF and baseline blood pressure is adequate.	Discontinue on night before surgery unless using for HF and baseline blood pressure is not low. Use parenteral analogs as needed in postoperative period.
Diuretics	Continuation can result in hypovolemia and hypotension.	Continue therapy up to day of surgery but discontinue morning dose.	Continue therapy up to day of surgery but discontinue morning dose. Use parenteral forms as needed in postoperative period.
Statins	Continuation may elevate risk of myopathy, but provides cardiovascular protection.	Continue statins.	Continue statins up to and including day of surgery.
Non-statin lipid-lowering agents	Niacin and fibric acid derivatives may cause rhabdomyolysis. Bile acid sequestrants interfere with absorption of other medications.	Discontinue day before surgery.	Discontinue day before surgery. Resume with oral intake.

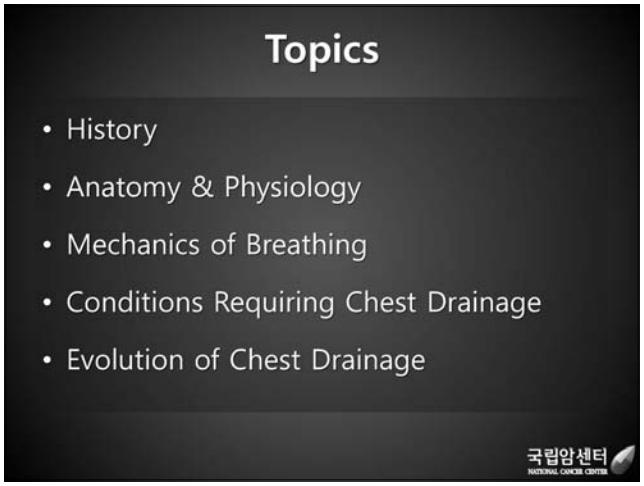
Graphic 62659 Version 4.0

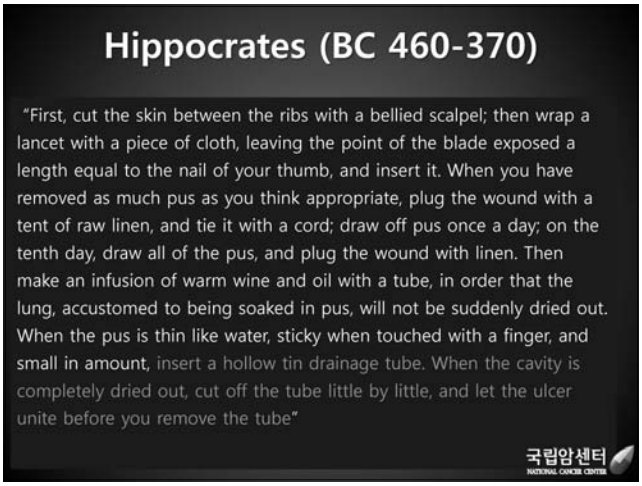
DSMC

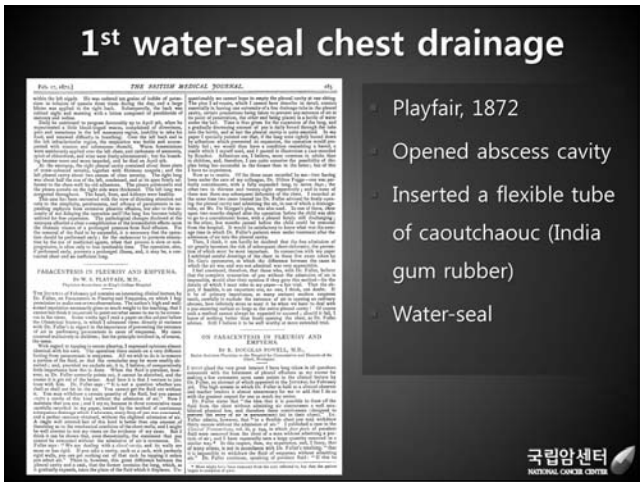
Chest Tube Drainage Management

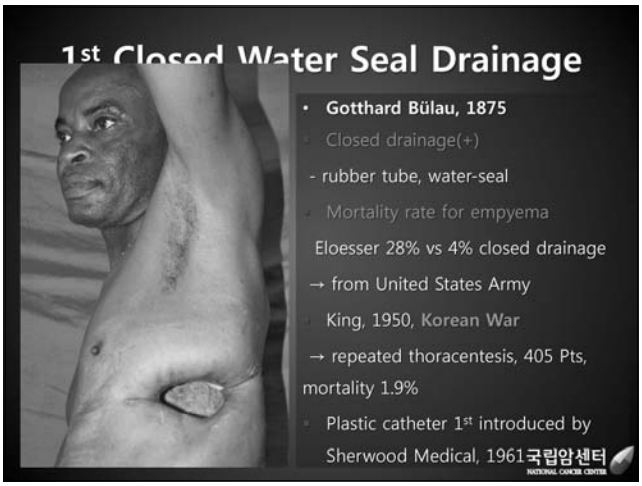
National Cancer Center

Jae Hyun Jeon

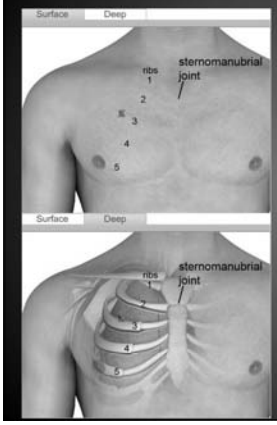








Needle Thoracostomy



- Urgent/Emergency situations
- History, Radiologic findings!
- Vincenzo Monaldi (1899-1969), 1950
- 2nd intercostal space, midclavicular line
- How to count ribs:
  First palpate the sternal notch, then palpate down to Sternomanubrial joint (angle of Lewis) – 2nd rib

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Anatomy

- Ribs, sternum, thoracic vertebrae interlaced with intercostal muscle
- Diaphragm is the "floor" of thoracic cavity

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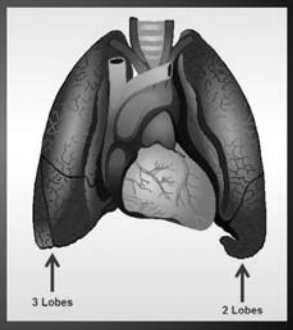
Anatomy

- 3 distinct areas:
- Mediastinum: esophagus, trachea, heart, aorta & major vessels
- Right thoracic cavity
- Left thoracic cavity



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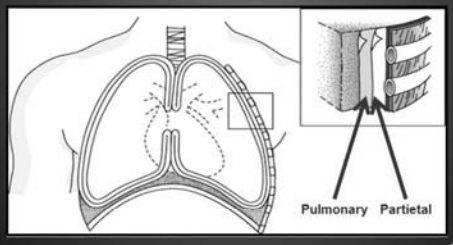
Anatomy

- Parietal pleura
- Pulmonary or Visceral pleura
- Pleural fluid



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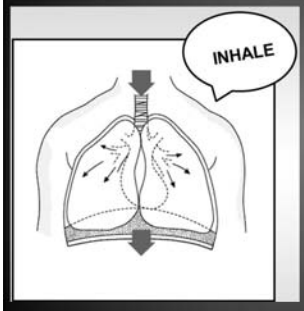
Mechanics of Breathing



- Inhalation:
  Diaphragm contracts down
  Pleural pressure : -8cmH2O
- Lung capacity enlarged
  Intrapulmonary pressure becomes lower (-) than AP

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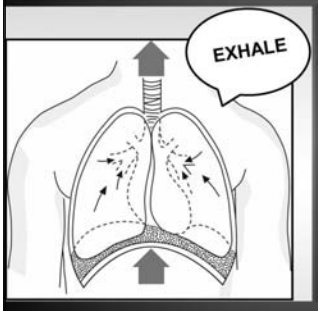
Mechanics of Breathing



- Exhalation:
  Diaphragm relaxes up
  Pleural pressure : -4cmH2O
- Lung capacity enlarged
  Intrapulmonary pressure becomes lower (-) than AP

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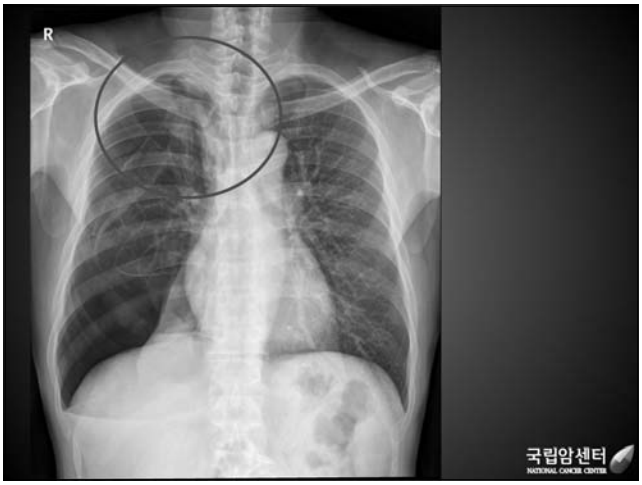
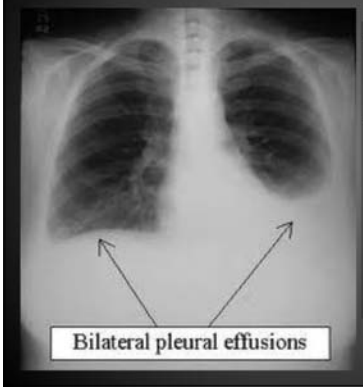
Indications for Tube Drainage

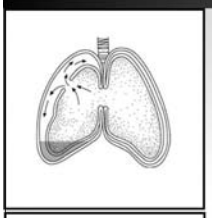
- Pneumothorax
  - Spontaneous (primary, secondary)
  - Open pneumothorax
  - Tension pneumothorax
  - Traumatic
  - Iatrogenic (c-line, thoracentesis, pleural/lung bx, positive pressure ventilation)
- Hemothorax - **with or** without **pneumothorax**
- Empyema
- Pleural effusion
- Chylothorax
- Postoperative Drainage

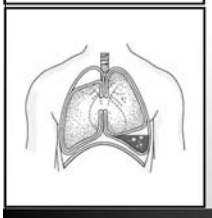


Pleural effusion / Hemothorax without pneumothorax



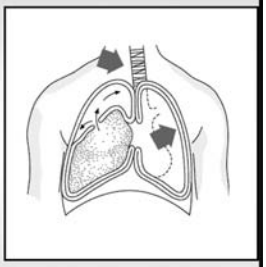
- Blunting of costophrenic angle (CPA)
- Only CPA blunting
  → 200-300mL





- **Pneumothorax:**
  Air in the pleural space
  (open or closed)
- **Hemothorax:**
  Blood in the pleural space
- **Hemopneumothorax:**
  Air and blood
  Caused by surgery, disease or trauma

- **Tension Pneumothorax:**
  One-way valve mechanism (air enters pleural space and cannot escape). Build-up of air under pressure can lead to…
- **Mediastinal Shift**:
  Pressure builds up and pushes the mediastinal cavity to the unaffected side. Lung may collapse creating a life threatening situation



Treatment

1. Remove fluid & air as promply as possible
2. Prevent drained air & fluid returning back into the thoracic cavity
3. Expand the lungs & restore negative pressure in the thoracic cavity
   → **Closed Thoracostomy!**

Before Tube Insertion

- Careful History Taking: esp. previous thoracic operation, h/o pleurodesis...
- Chest X-ray: location of air/fluid, adhesion의 유무
- Chest CT: previous CT scans/other imaging studies gives much information - loculated effusion, multifocal adhesion
- Cautions in patients with coagulopathy

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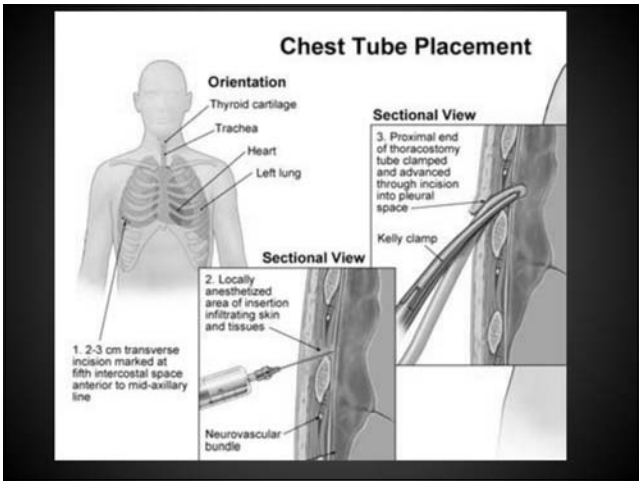
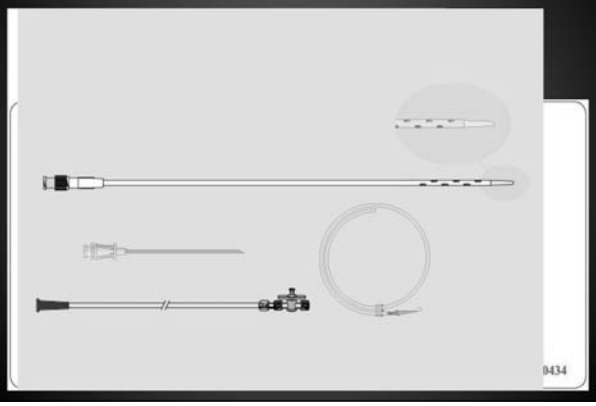


Chest tubes



Complications of Tube Thoracostomy

- Bleeding
- Creating of air leak d/t lung injury during procedure
- Malposition of the tube
  (intraperitoneal, subcutaneous)
- Other organ injury
  (Diaphragm, Liver, Esophagus, Heart, Aorta, ...)
- Horner Syndrome

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Complications of Tube Thoracostomy


Case report

A rare complication secondary to insertion of pleural chest tube in trauma patients

Yiu Ming Ho*, Michael Schuetz

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Complications of Tube Thoracostomy


Perforation of the Right Ventricle*

A Complication of Blind Placement of a Chest Tube Into the Postpneumonectomy Space

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Complications of Tube Thoracostomy

CHEST

Pectoriloquy

Editor's Note: *The poet writes, "As a medical student standing in the trauma resuscitation bay, I witnessed the placement of a chest tube into a patient with a tension pneumothorax. As the patient sprung to life, I felt inspired to capture both the sight and sounds of this experience in a poem." Kyle T. Amber is a medical student at the University of Miami Miller School of Medicine.*

CHEST TUBE

Gasp he cried with the sound of the breeze
Hollow and empty as the air swirled.
As bubbles shattered through the calm surface
So did vivacity through the empty whispers.
The roar of the lion sang with ferocity
Mutting beeps and concerned whispers.
Ignorant of the pandemonium he growled at last
As others stood in silence short of breath.

Kyle T. Amber, BS
Miami, FL

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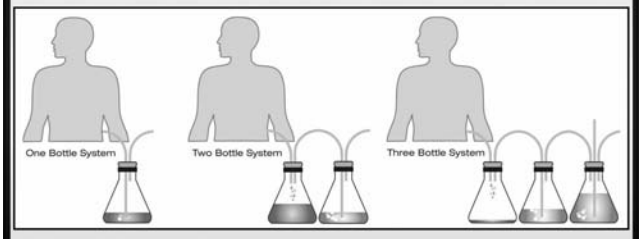
Drainage Bottle

Three Parts…



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One/Two/Three Bottle systems

Basic requirement is to drain lungs of air & fluid:

- "One-bottle" system has a water seal chamber and collection chamber (together)
- "Two-bottle" system has a water seal + collection chamber (separate)
- "Three-bottle" system has a water seal + collection + suction control chamber

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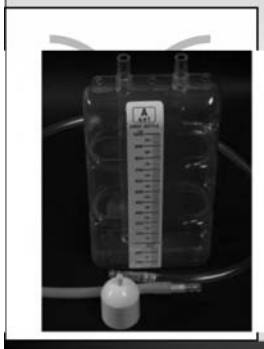
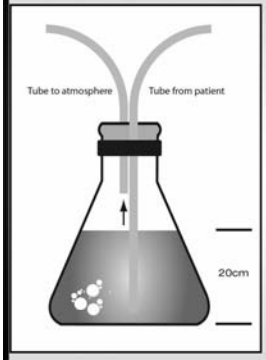
One-Bottle System



Creation of an *underwater seal*. It is a low resistance one-way valve allowing air & fluid to escape from the patient without possible return

Any positive pressure in excess of +2cmH_2O will be expelled to the atmosphere

One-Bottle System : Shortcomings

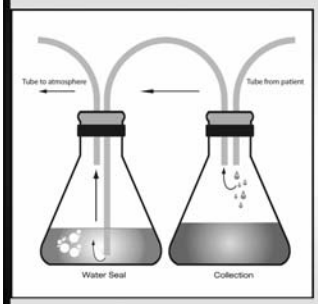


Drawbacks of a one-bottle system:

- Used for collection as well as water seal
- Water seal is not protected against "sloshing", siphoning or tip over
- As the bottle fills up, the 2cm water seal level increases making it more difficult for the patient to expel air

Try it at home with water and a straw!

Two-Bottle System



Benefits of a two-bottle system:

- Includes water seal and separate collection bottle
- Water seal is maintained at 2cm
- Having a separate collection bottle provides the ability to measure drainage

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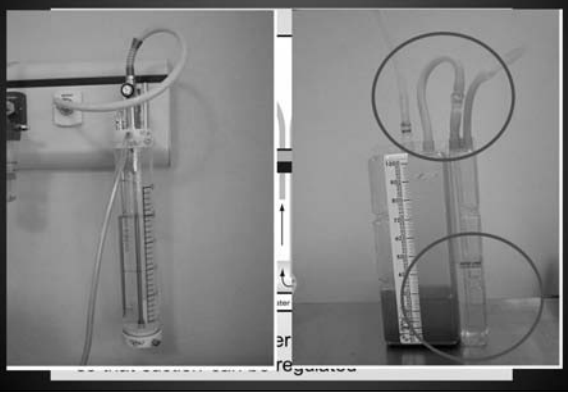
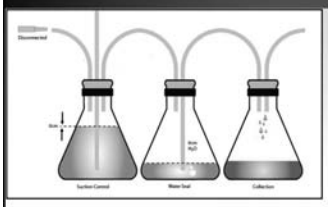
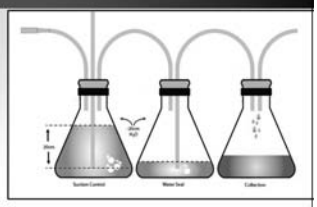
Three-Bottle System



The Suction Control Bottle





- Gravity Drainage/Water Seal
  - No suction connected
- On suction: vacuum draws atmospheric air into the straw and pushes water downward creating the bubbling

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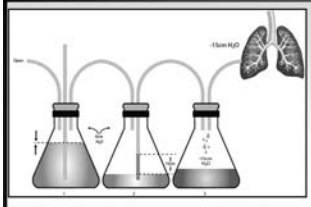
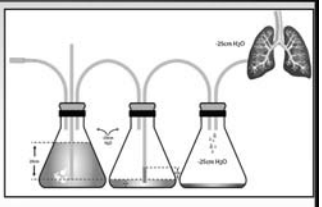
Monitorring Intrathoracic Pressure





- <u>On Gravity:</u> Intrathoracic pressure is read directly from the water seal. A rise in the water seal indicates that negative pressure is present in the pleural space (patient is healing). Bubbling indicates positive pressure (air leak)
- <u>On Suction:</u> Add readings of suction control chamber plus the level of the water seal chamber

For Example:

$-20cmH_20 + -5cmH_20 =$

$-25cmH_20$ intrathoracic pressure

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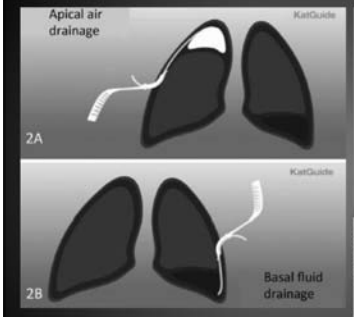
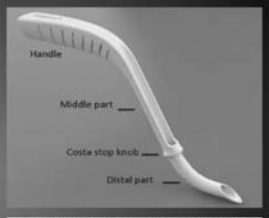
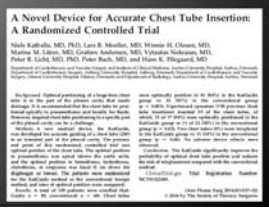
Newer Device



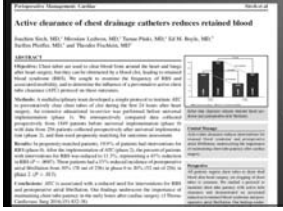




A Novel Device for Accurate Chest Tube Insertion: A Randomized Controlled Trial

Newer Chest Tubes

Superior Chest Drainage With an Active Tube Clearance System: Evaluation of a Downsized Chest Tube



Active clearance of chest drainage catheters reduces retained blood

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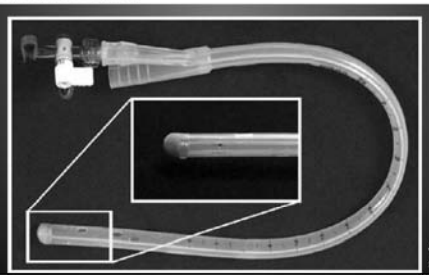
Newer Chest Tubes

Chest Tube–Delivered Bupivacaine Improves Pain and Decreases Opioid Use After Thoracoscopy

Todd L. Demmy, MD, Chukwumere Nwogu, MD, Patrick Solan, BS, Saikrishna Yendamuri, MD, Gregory Wilding, PhD, and Oscar DeLeon, MD

Departments of Thoracic Surgery, Biostatistics, and Anesthesiology and Pain Medicine, Roswell Park Cancer Institute and State University of New York, Buffalo, New York



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Newer Chest Bottles

Automatic High Negative Release Valve (Express)*

*Activates at -50cmH_2O

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Newer Chest Bottles

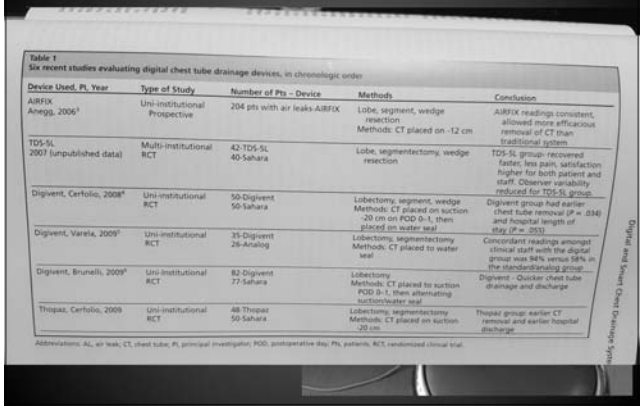


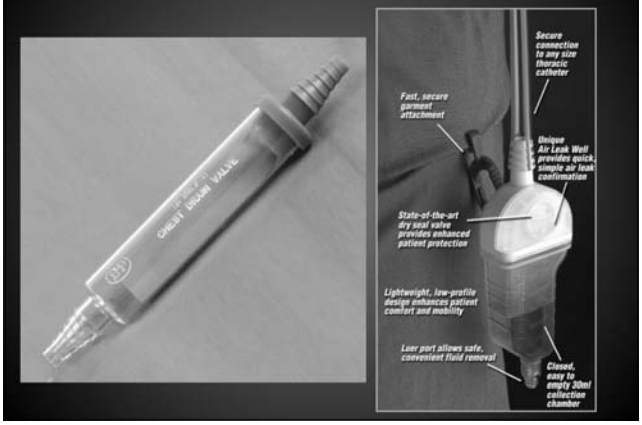
Table 1
Six recent studies evaluating digital chest tube drainage devices, in chronologic order

Device Used, Pt, Year	Type of Study	Number of Pts – Device	Methods	Conclusion
AIRFIX Anegg, 2006[3]	Uni-institutional Prospective	204 pts with air leaks-AIRFIX	Lobe, segment, wedge resection Methods: CT placed on -12 cm	AIRFIX readings consistent, allowed more efficacious removal of CT than traditional system
TDS-5L 2007 (unpublished data)	Multi-institutional RCT	42-TDS-5L 40-Sahara	Lobe, segmentectomy, wedge resection	TDS-5L group- recovered faster, less pain, satisfaction higher for both patient and staff. Observer variability reduced for TDS-5L group
Digivent, Cerfolio, 2008[4]	Uni-institutional RCT	50-Digivent 50-Sahara	Lobectomy, segment, wedge Methods: CT placed on suction -20 cm on POD 0-1, then placed on water seal	Digivent group had earlier chest tube removal ($P = .034$) and hospital length of stay ($P = .055$)
Digivent, Varela, 2009[5]	Uni-institutional RCT	35-Digivent 26-Analog	Lobectomy, segmentectomy Methods: CT placed to water seal	Concordant readings amongst clinical staff with the digital group was 94% versus 58% in the standard/analog group
Digivent, Brunelli, 2009[6]	Uni-institutional RCT	82-Digivent 77-Sahara	Lobectomy Methods: CT placed to suction POD 0-1, then alternating suction/water seal	Digivent - Quicker chest tube drainage and discharge
Thopaz, Cerfolio, 2009	Uni-institutional RCT	48-Thopaz 50-Sahara	Lobectomy, segmentectomy Methods: CT placed on suction -20 cm	Thopaz group: earlier CT removal and earlier hospital discharge

Abbreviations: AL, air leak; CT, chest tube; PI, principal investigator; POD, postoperative day; Pts, patients; RCT, randomized clinical trial.

Digital and Smart Chest Drainage Systems

Heimlich Valve



Process of Healing: Air Leakage

- Inspect both the Quality & Quantity aspect
- **Quality**
  - Continuous air leak (C)
  - Inspiratory air leak (I) – rare
  - Expiratory air leak (E) – most common
  - Forced Expiratory air leak (FE) - 기침시에만
- **Quantity**
  - amount of air leak, more easily measurable with newer generation chest bottles

" C → E → FE → air leak Stop "

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Management of Air Leaks : Introduction

- PAL (Prolonged Air Leak) : Leak lasting beyond POD#5
- Incidence of PAL : 8% ~ 26%
- Significance of PAL : increases pulmonary complications after pulmonary resection, increases length of stay(LOS) and cost as well
- Risk factors for AL/PAL :

severity of COPD, presence of adhesion, upper lobectomy and bilobectomy, lobectomy > lesser resections, steroid use >10mg daily for more than 1mo, Leak grade 4/7 in newer generation bottles

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Management of Air Leaks : Intraoperative Management –

Management of Air Leaks : Intraoperative Management – (2) Use of Topical Sealants

Table 1
Randomized controlled trials evaluating surgical sealants for intraoperative ALs

Author	Sealant	N	Patients with Postoperative ALs	Duration of AL	Duration of Chest Drain	Hospital Days
Allen et al[42]	Novel polymeric sealant	148	*			*
Belboul et al[60]	Visostat	40	*			
Fabian et al[58]	Fibrin glue	100	*	*	*	
Fleisher et al[57]	Fibrin glue	28				
Lang et al[64]	TachoComb	189	*			
Macchiarini et al[40]	Fibrin glue	26	*			
Moser et al[59]	Fibrin glue	25 (bilateral)	*	*	*	
Mouritzen et al[37]	Fibrin glue	114	*			*
Porte et al[39]	Advaseal	120	*	*		
Tansley et al[50]	Bioglue	52	*	*	*	*
Wain et al[41]	FocalSeal	172	*	*		
Wong and Goldstraw[36]	Fibrin glue	66				
Wurtz et al[38]	Fibrin glue	50	*			
Wurtz et al[43]	Fibrin glue	50	*			
Anegg et al[47]	Fleece-bound sealing	173	*	*	*	*
D'Andrilli et al[45]	Polymeric sealant	203	*	*		

* Significant improvement in treated group versus untreated group. The empty cells indicate no significant difference or a variable that was not assessed.

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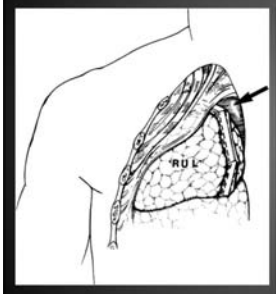
Management of Air Leaks : Intraoperative Management – (3) Use of Pleural Tent



- Risk of this procedure : development of a hemothorax

Two randomized trials :

Brunelli et al, Okur et al

→ clear result of reduced duration of AL, duration of chest drainage, LOS, with no significant difference in morbidity

- But these studies weren't able to identify the candidates who will derive benefit from pleural tenting !

Management of Air Leaks : Intraoperative Management – (3) Use of Intraoperative Pneumoperitoneum

after lower lobectomy or RML-RLL bilobectomy

Toker et al : nonrandomized trial, significant reduction in AL

(2.2 vs 6.0 days, P<0.0001)

Cerfolio et al : randomized 16 Pts.... significant reduction in AL

(13 vs 63% of AL on POD#1, P<0.001)

- weren't able to identify the candidates as well !!

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Management of Air Leaks : Postoperative Management – (1) Water Seal vs. Suction

Table 1
Recent studies evaluating the management of chest tubes in post-thoracotomy patients

Author, Year of Publication	Study Type	Comparison	Findings
Cerfolio et al,[10] 2001	Prospective randomized trial (postpulmonary resection)	Suction POD 1, then randomized to S versus W on POD 2	Water seal superior after POD 0 of suction
Marshall et al,[12] 2002	Prospective randomized study (postpulmonary resection)	Initially S, then randomized to S or W	Water seal shorted the duration of AL and CT duration
Ayed,[13] 2003	Prospective randomized (patients with spontaneous ptx)	S versus W	Water seal after brief period of suction decreased CT duration
Brunelli et al,[14] 2005	Prospective randomized trial (postlobectomy with air leak on POD 1)	S versus W	No difference
Brunelli et al,[15] 2004	Prospective randomized (postlobectomy)	Alternating S versus W	Alternating suction superior to water seal (reduced incidence of AL, decreased CT duration, LOS)
Cerfolio et al,[16] 2005	Retrospective review (patients with ptx and air leak)	S versus W	Water seal superior unless ptx is largely symptomatic or patient develops subcutaneous emphysema
Okamoto et al,[17] 2006	Retrospective	S versus W	No difference

Abbreviations: AL, air leak; CT, chest tube; LOS, length of stay; POD, postoperative day; ptx, pneumothorax; S, suction; W, water seal.

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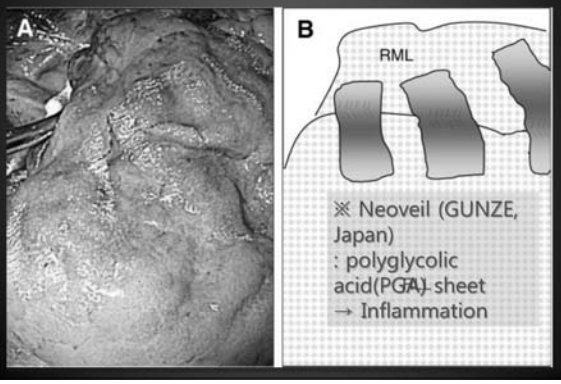
Management of Air Leaks : Postoperative Management – (2) Conservative measures to Invasive Reintervention



When to Remove a Tube - Classical

RECOMMENDATIONS

- **Level 1**
  - CT drainage should be ≤ 2ml/kg/day or ≤ 200 ml/day (whichever is less) before removal.
- **Level 2**
  - CTs can be removed equally safely at end-inspiration or end-expiration.
  - CTs may be safely removed on suction.
  - A brief trial of waterseal prior to CT removal may allow occult air leaks to become clinically apparent and reduce the need for CT reinsertion due to recurrent pneumothorax. Such trials, however, will generally increase hospital length of stay and the number of chest radiographs (CXRs) obtained.
  - After pulmonary resection, small air leaks will resolve significantly more quickly if the CT is placed to water seal
- **Level 3**
  - In non-mechanically ventilated patients, a routine CXR following removal of a CT is generally not indicated. The decision to obtain a CXR should be based on the individual clinical situation and the patient's signs and symptoms.
  - In mechanically ventilated patients, a CXR obtained between one and three hours after removal of a CT is sufficient to identify a recurrent pneumothorax.
  - A daily CXR is not indicated to monitor CTs in the intensive care unit. Routine monitoring and patient care will identify the need for CXR based on clinical necessity.

When to Remove a Tube

- Benefits of early removal have been reported:
  decreased pain, improved 6-min walking test,
  early mobilization
- Cerfolio and Bryant : 2077 pulmonary resections
  Tube removal when < 450mL/day
  Readmission for effusion 11Pts (0.6%)

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Tube Size in Infection ??

CHEST Original Research
INTERVENTIONAL PULMONOLOGY

The Relationship Between Chest Tube Size and Clinical Outcome in Pleural Infection

Najib M. Rahman, BM, BCh; Nicholas A. Maskell, DM; Christopher W. H. Davies, MD; Emma L. Hedley; Andrew J. Nunn, MSc; Fergus V. Gleeson, MBBS; and Robert J. O. Davies, DM

Background: The optimal choice of chest tube size for the treatment of pleural infection is unknown, with only small cohort studies reported describing the efficacy and adverse events of different tube sizes.
Methods: A total of 895 patients with pleural infection were prospectively enrolled into a multicenter study investigating the utility of fibrinolytic therapy. The combined frequency of death and surgery, and secondary outcomes (hospital stay, change in chest radiograph, and lung function at 3 months) were compared in patients receiving chest tubes of differing size (χ^2, *t* test, and logistic regression analyses as appropriate). Pain was studied in detail in 129 patients.
Results: There was no significant difference in the frequency with which patients either died or required thoracic surgery in patients receiving chest tubes of varying sizes (< 10F, number dying or needing surgery 21/58 [36%]; size 10-14F, 75/208 [36%]; size 15-20F, 28/70 [40%]; size > 20F, 30/959 [14%]; χ^2trend, 1 degrees of freedom [*df*] = 1.21, *P* = .27), nor any difference in any secondary outcome. Pain scores were substantially higher in patients receiving (mainly blunt dissection inserted) larger tubes (< 10F, median pain score 6 [range 4-7]; 10-14F, 5 [4-6]; 15-20F, 6 [5-7]; > 20F, 6 [6-8], χ^2, 3 *df* = 10.90, *P* = .013, Kruskal-Wallis; χ^2trend, 1 *df* = 6.3, *P* = .014).
Conclusions: Smaller, guide-wire-inserted chest tubes cause substantially less pain than blunt-dissection-inserted larger tubes, without any impairment in clinical outcome in the treatment of pleural infection. These results suggest that smaller size tubes may be the initial treatment of choice for pleural infection, and randomized studies are now required.
Trial registration: MIST1 trial ISRCTN number: 39138980. *CHEST 2010; 137(3):536-543*

Abbreviations: *df* = degrees of freedom; IQR = interquartile range; MIST1 = Multi-center Intrapleural Streptokinase Trial; MPS = median pain score

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Survey results

Factors in the Selection and Management of Chest Tubes After Pulmonary Lobectomy: Results of a National Survey of Thoracic Surgeons

Samuel S. Kim, MD, Zain Khalpey, MD, PhD, Sherry L. Daugherty, BA, Mohammad Torabi, PhD, and Alex G. Little, MD

Division of Cardiothoracic Surgery and Information Technology, University of Arizona, Tucson, Arizona

Background. This study determined patterns of chest tube (CT) selection and management after open lobectomy and minimally invasive lobectomy by thoracic surgeons.
Methods. Surveys were sent electronically to 5,175 thoracic surgeons, and 475 were completed. Responses, blinded so individuals could not be identified, were analyzed and compared according to surgeon characteristics (academic/private practice, years in practice, lobectomy volume, and geographic region). All indicated differences were statistically significant ($p < 0.05$ by χ^2 tests).
Results. CT selection: Most surgeons prefer rigid tubes, and the size most commonly used was 28F. Most place 2 CTs after open lobectomy and 1 CT after minimally invasive lobectomy. Academic surgeons are more likely than private surgeons to use 1 tube after open lobectomy, but both prefer 1 tube after minimally invasive lobectomy. Younger surgeons and high-volume surgeons are more likely to use 1 CT than senior surgeons and low-volume surgeons after both open lobectomy and minimally invasive lobectomy. CT management: Academic and younger surgeons remove the CT sooner after open lobectomy. Younger and high-volume surgeons remove the CT with greater drainage amounts. All groups remove CTs sooner after minimally invasive lobectomy than after open lobectomy. Approximately half of surgeons get a daily chest roentgenogram. Younger and low-volume surgeons are most likely to discharge patients with Heimlich valves, although overall use was in less than 5% (49 of 475) of respondents. Most surgeons believe clinical experience rather than training or the literature determined their CT strategy.
Conclusions. This survey determined the difference in CT management among various groups of surgeons. Clinical experience was the most important factor in determining their CT strategy.

(Ann Thorac Surg 2016;101:1082–8)

Adequate Tube Location May Be Beneficial

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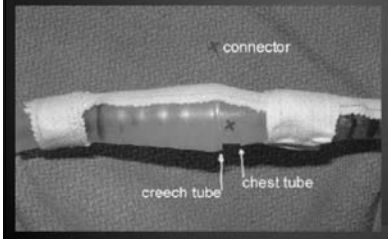
Troubleshootings

- Severe, unanticipated air leak from bottle
  → should we suspect BPF first ???
  → **Circuit Patency check should be 1st**
  (by sequential clamping try from distal)



※ Especially when 32Fr Chest tube inserted

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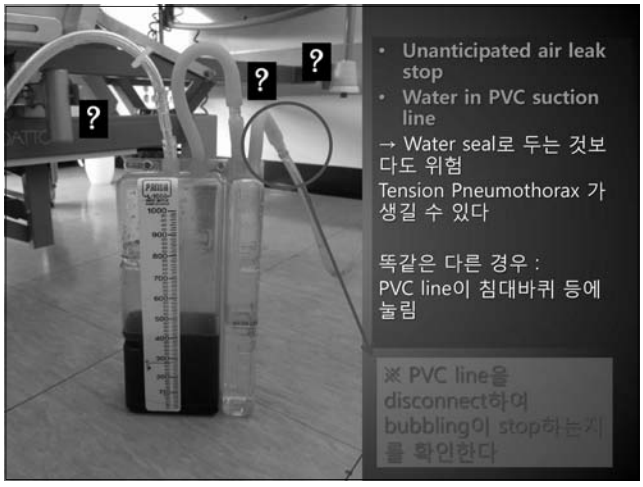
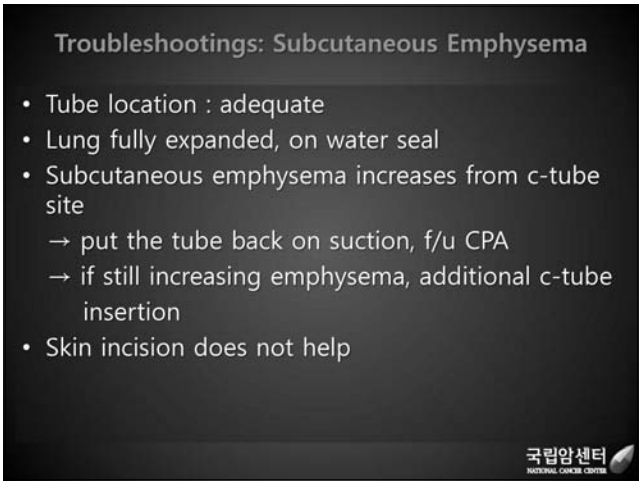
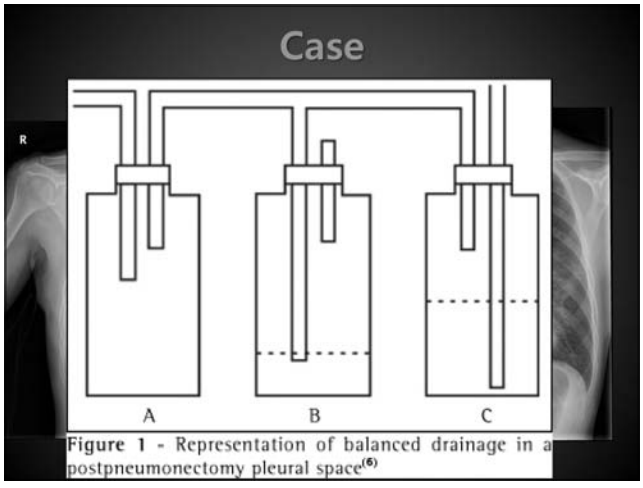

?
?
?
• Unanticipated air leak stop
• Water in PVC suction line
→ Water seal로 두는 것보다도 위험
Tension Pneumothorax 가 생길 수 있다
똑같은 다른 경우 :
PVC line이 침대바퀴 등에 눌림
※ PVC line을 disconnect하여 bubbling이 stop하는지를 확인한다


Troubleshootings: Subcutaneous Emphysema
• Tube location : adequate
• Lung fully expanded, on water seal
• Subcutaneous emphysema increases from c-tube site
→ put the tube back on suction, f/u CPA
→ if still increasing emphysema, additional c-tube insertion
• Skin incision does not help
국립암센터


Case
R
A
B
C
Figure 1 - Representation of balanced drainage in a postpneumonectomy pleural space[6]


Thank You Very Much !!!
국립암센터

Air Leak after Lung Resection

Korea University Anasan Hospital

Jinwook Hwang

Air leak from lungs "Alveolarpleural fistula"

Communication btw the distal to segmental bronchus and pleural space

Post operation air leak:

POD#1 : 30~50%
POD#2 : 20% Cerfolio 1998

Prolonged air leak (PAL) :

8~15% Brunelli 2004

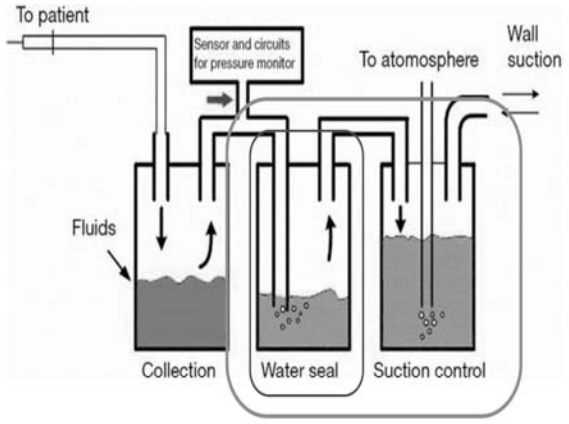
≠

"Bronchopleural Fistula"

Air Leak after Lung Resection

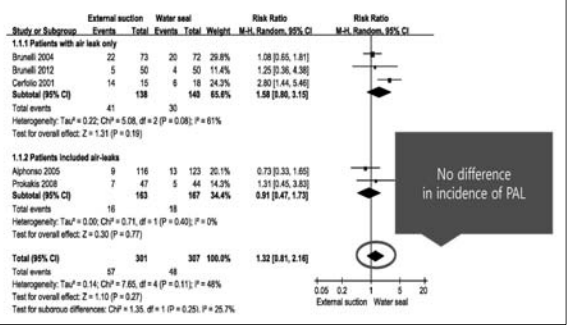
- torn or denuded of the visceral pleura
- incomplete fissure division
- staple lines
- the raw surface following segmentectomy
- Non anatomic resections for benign or metastatic lesion

Suction vs. Water seal



External suction versus water seal after selective pulmonary resection for lung neoplasm: a systemic review

Qiu 2013, PLoS ONE



External suction versus water seal after selective pulmonary resection for lung neoplasm: a systemic review

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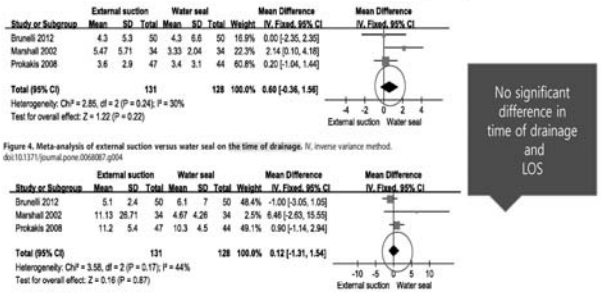
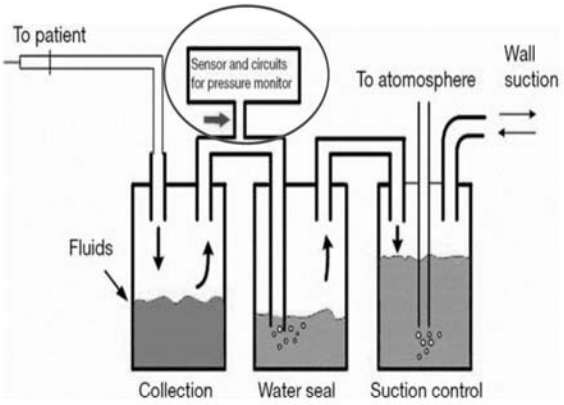


Figure 4. Meta-analysis of external suction versus water seal on the time of drainage. IV, inverse variance method.
doi:10.1371/journal.pone.0066087.g004

Figure 5. Meta-analysis of external suction versus water seal on the postoperative hospital stay. IV, inverse variance method.

Digital vs. Traditional



Muticenter international randomized comparison of objective and subjective outcomes between electronic and traditional chest drainage system

Pompilli 2014, ATS

Group 1 (digital): Patients with digital devices were managed by setting the pump to –20 cmH_2O until the morning of postoperative day (POD) 1 and then setting the pump on physiologic mode (–8 cmH_2O) thereafter. N=191

Group 2 (traditional): Patients with traditional devices (requiring connection to wall suction) were managed by applying suction (–20 cmH_2O) until the morning of POD 1 and were subsequently disconnected from suction thereafter. N=190

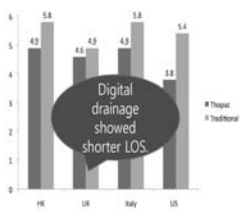


Fig 4. Differences in length of postoperative stay (days) in different centers by type of drainage system. (HK = Hong Kong; UK = United Kingdom; US = United States.)

Randomized trial of digital versus analog pleural drainage in patients with or without a pulmonary air leak after lung resection

Gilbert 2015, JTCS

TABLE 2. Clinical outcomes

Outcome	Group 1: Air leak absent			Group 2: Air leak present		
	Analog	Digital	*P* value	Analog	Digital	*P* value
Length of stay (d)	4.0 (3.0-5.0)	4.0 (3.0-5.0)	.09	6.0 (5.0-9.0)	6.0 (4.0-8.0)	.36
Chest tube duration (d)	3.0 (2.9-4.9)	2.9 (2.2-3.9)	.05	5.6 (4.0-8.9)	4.9 (3.1-6.4)	.11

Values are median (25th and 75th percentiles).

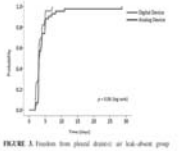


FIGURE 3. Freedom from pleural drain(s) air leak-absent group (n = 87).

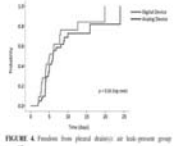


FIGURE 4. Freedom from pleural drain(s) air leak-present group (n = 85).

Although digital devices decreased clamping trials, their impact on chest tube duration or LOS was not statistically significant.

The usefulness of Wi-Fi based digital chest drainage system in the post-operative care of pneumothorax

Cho 2016 JTD

-20 cmH_2O until removal of the tubes

Total=60 Group 1(digital) n=30
Group 2 (traditional) n=30

Variable	Group I	Group II	P value
Drainage time (days)	2.2	3.1	0.006
Pain score			
Day 0 (operation day)	5.43	5.79	0.337
Day 1 (postoperation 1)	3.73	4.14	0.275
Day 2 (postoperation 2)	3.26	3.67	0.213
Recurrence (number/%)	1/3.3	1/3.4	0.746

Conditions associated with air leak

Prolonged air leak (PAL)

Subcutaneous emphysema (SE)

Postresection intrapleural spaces (PRI)

Prolonged Air Leak (PAL)

Prolonged Air Leak

Longer than 5 days after pulmonary lobectomy
(adopted by STS and ESTS)

Prolong hospital stay
Hospitalization costs problem
Risk of empyema
Cardiopulmonary complications

Risk factors to PAL

- Reduced pulmonary function
- Damaged and fragile lung parenchyma
- Use of steroids
- Upper lobectomy
- Pleural adhesion

Risk predictors model

Characterization and Prediction of Prolonged Air Leak After Pulmonary Resection: A Nationwide Study Setting Up the Index of Prolonged Air Leak

Rivera 2011, ATS

IPAL(Index of PAL)
Gender(F=0;**M=4**)-(**BMI**-24)+2x **dyspnea score**+**pleural adhesion**(no=0;yes=4)+pulmonary resection(wedge=0; lobectomy or segmentectomy=7; bilobectomy=11; bulla resection=2; **volume reduction=14**)+location(lower or middle lobe=0; **upper=4**)

Risk probability: 1/(1+exp(-(-4.213+0.1167x**IPAL**)))

IPAL≤5 5% or less(low risk)
5<IPAL ≤10 5% and 10%(moderate risk)
IPAL>19 greater than 10%(high risk)

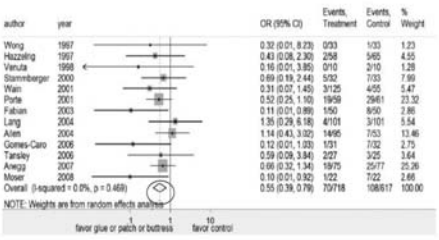
Management of PAL

- Water seal vs. suction vs. alternate suction
- Sealant
- Intrapleural sclerotherapy
- Heimlich Valve
- Surgical repair

Surgical sealant for the prevention of prolonged air leak after lung resection: Meta-analysis

Malapert 2010 ATS

Fig 2. Forest plot of the meta-analysis of outcomes of air leak more than 7 days. (CI = confidence interval; OR = odds ratio.)



13 RCTs

Buttress 4
Fibrin glue 3
Synthetic sealant 4
Collagen patch 2

Intrapleural instillation of autologous blood in the treatment of prolonged air leak after lobectomy: a prospective randomized controlled trial

Shackcloth 2006 ATS

Table 1. Classification of Air Leaks

Size of Air Leak	Description
0	No air leak
1	Air leak on vigorous coughing only
2	Small continuous air leak on gentle respiration
3	Large continuous air leak on gentle respiration

Table 4. Overall Outcomes

Variable Median (IQR) Days Postoperative	Study Group	Control Group	*p* Value
Time to leak seal	5 (5–7)	11 (10–12)	< 0.001
Time to drain removal	6.5 (6–8)	12 (11–13)	< 0.001
Time to hospital discharge	8 (7–9)	13.5 (12–14)	< 0.001
Interval from first pleurodesis to seal of air leak	1 (1–3)	3 (1–4)	0.32

IQR = interquartile range.

Subcutaneous Emphysema

Swelling of neck
Swallowing difficulty
Sore Throat
Chest PAIN
Wheezing
Hamman's syndrome
Neck Pain
Difficulty breathing

Tearing the parietal pleura, membrane lining the inside of chest wall, allowing air to escape into the subcutaneous tissues

Stab wound/Gunshot
Rib fractures (27%)
Barotrauma

Tissue paper
Crackling noise
Rice Krispies

Massive subcutaneous emphysema

- Tension pneumomediastinum→Airway obstruction
- Pneumopericardium→Cardiac tamponade

In patients with extensive subcutaneous emphysema, which technique achieves maximal clinical resolution: infraclavicular incisions, subcutaneous drain insertion or suction on in situ chest drain?

Johnson 2014 ICVTS

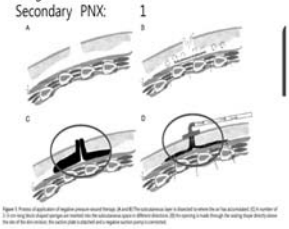
• Best evidence papers

	Intervention	Pt No.	Outcomes	Results	Comments
Cerfolio 2008, ATS	Suction via chest tube	255	Significant SE -bedside CTD -VATS CTD --Resolution (1day)	85/255(33%) 21/85 64/85 63/64	Immediate VATS CTD
Leo 2002, Chest	Microdrainage via fenestrated angiocath	12 (1=Media)	Time to resolution	1-3 ds (5ds)	3-4 massage/d
Cesaria 2002, Chest	Drainage via Penrose drain	20	Ave. duration of Tx	3.7 days (2-6ds)	supraclavicular incision
Herlam 1992, Chest	Bilateral infraclavicular incisions	4	Time to resolution	<4 ds	

Modified blowhole skin incision using negative pressure wound therapy in the treatment of ventilator-related severe subcutaneous emphysema • Son 2014 ICVTS

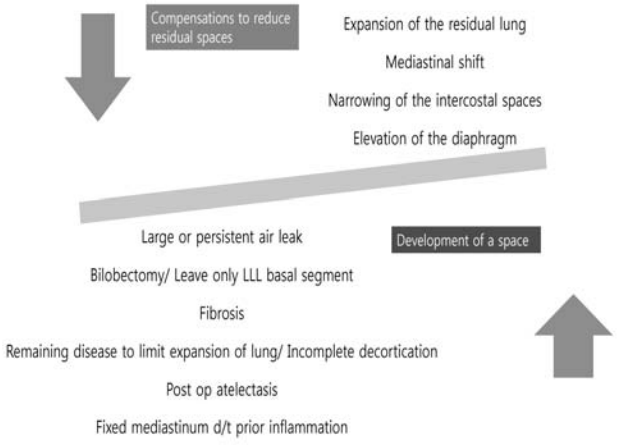
N=10
Lung surgery: 2
Blunt trauma: 1
Ventilator barotrauma: 5
Lung TPL: 1
Secondary PNX: 1

The mean duration of NPWT: 7.3±4.8 (3-14) days
The mean No. of dressing changes 1.4±0.5(1-2)



Postresection Intrapleural Spaces

"No space, No problem"



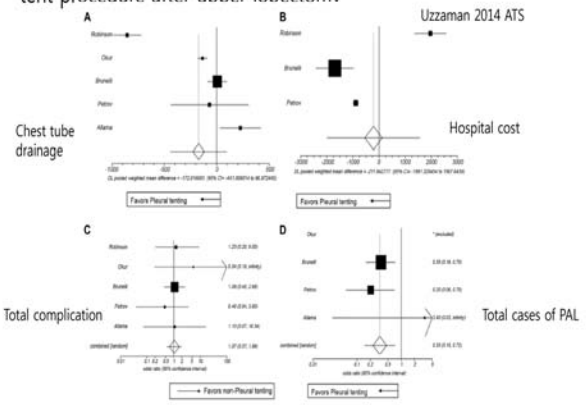
Management of Postresection intrapleural space

- Pleural tent
- Phrenic crush
- Transplant diaphragm
- Pneumoperitoneum
- thoracoplasty

Pleural tent

- Miscall 1956
- Apical parietal pleural dissection from the level of thoracotomy
- Mobilization of parietal pleura and fixation to upper border of intercostal muscle.

A meta-analysis assessing the benefits of concomitant pleural tent procedure after upper lobectomy



Summary

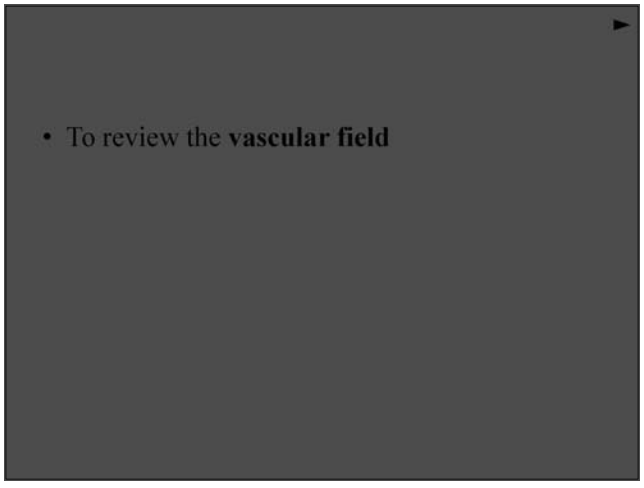
- Traditional management of pleural drainage should be reconsidered to improve the result of air leak after lung resection.
- Prolonged air leak should be managed by immediate and aggressive maneuver.
- Massive subcutaneous emphysema should be drained to decrease discomfort and risk of airway obstruction.
- Various surgical intervention could be applied to reduce the postresection intrapleural space in selective patients.

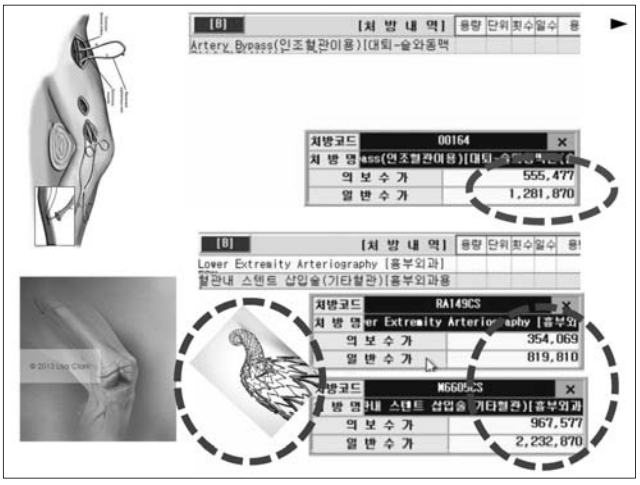
Mythbusters!

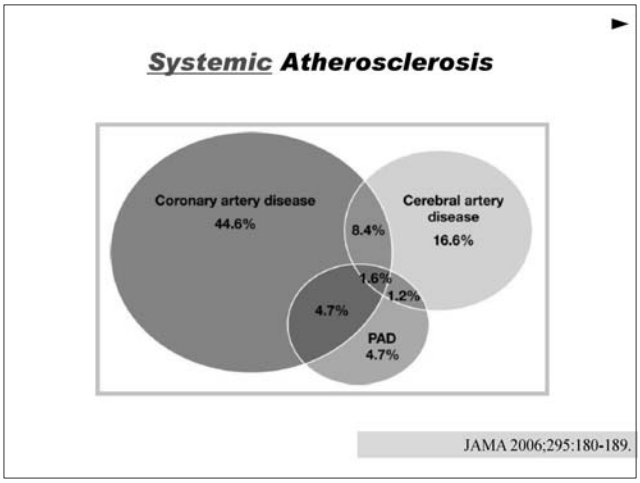
말초혈관 수술환자의 준비(Prepareation of Vascular Operation)

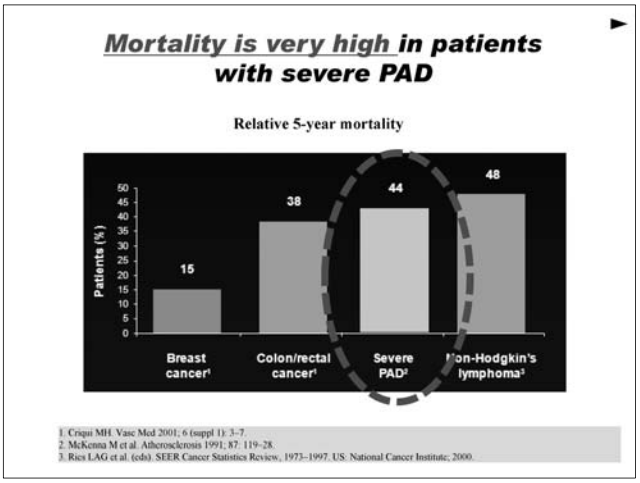
Department of Cardiovascular Surgery,
Sejong General Hospital

Joon Hyuk Kong







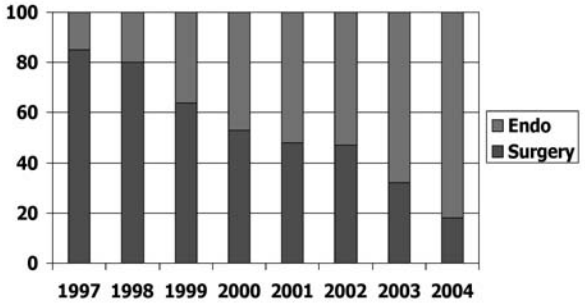


PVD is not Benign!!!

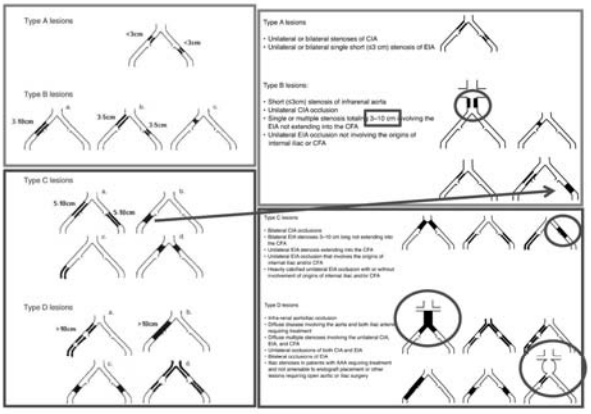
- The diffuse nature and high association of PVD with **other medical conditions (ie, diabetes, renal disease, coronary disease, wound care)** demand **a multidisciplinary approach t**oward patient care at a PVD center of excellence.
- Every patient with PVD needs a multidisciplinary work-up and needs treatment.
- This treatment may be as simple as *risk factor modification* and *follow- up, medications*, or *complex treatments requiring interventional or surgical treatment.*

Establishing aPeripheral VascularCenter of Excellence. DAVID E. ALLIE, MD; CHRIS J. HEBERT, RT, R-CIS; AND CRAIG M. WALKER, MD. FEBRUARY 2005 I ENDOVASCULAR TODAY I 41

Endo Vs Surgery POAD Volume (1997-2004) in the US



TASC 2000 and TASC II 2007



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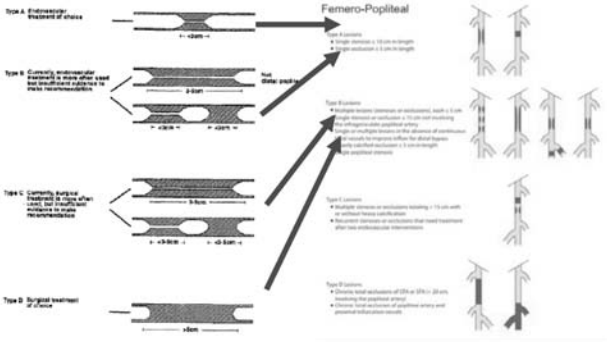
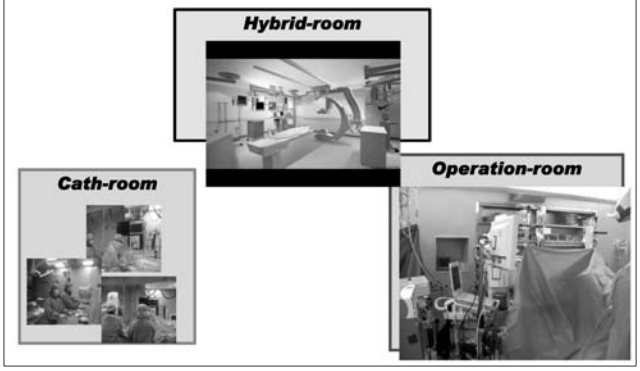


C-arm vs Cath room vs Hybrid-room



Field of Vascular Care !!

Lower Extremity Disease

Iliac artery disease

SFA ds – long occlusion, femoropopliteal disease

Below the Knee

Renal, Carotid, Subclavian Artery Stenosis

Venous disease – SVC, DVT, Vein occlusion

Aorta Disease – Aortic dissection, aneurysm, AAA

Adult congenital and structural heart disease (TAVI, ASD closure, percutaneous MVP)

Comparison bet. OR and Angio. Suite

	C-Arm based OR OEC9800 with Vascular Program	Angio Suite (Artis Zee Biplane System)
OR Time Controlled by	Anestheologist or Not at Local Anes.	IR or IC
Image	Low Quality Limited Time 12 inch	High Quality Longer Time 9, 12, 14, 12*16 inch
Table	Limited Sliding Perfomance	Sliding Table without Tilting and Bending Function
Space	Congested	Relatively Better
Clean Room	Laminar Flow	Air Filter System
Anestheology	Friendly or Not at Local Anes.	Hostile and Limited Help
Inventory	Limited	Diverse
Characteristics	Open Friendly	Endo Friendly

- To review the patient **symptoms and exam findings**

Goal of Medical History

- To record the patient's symptoms at time of presentation.
- To organize the events which have lead to presentation.
- To summarize the evidence which supports diagnostic hypothesis.
- To provide basis and direction for care.

Goals of Physical Exam

- To record the state of patient's health at the time of the examination.
- To provide a longitudinal record of the patient's health.
- Allow assessment of progression of disease.
- Allow prognostication of natural history.
- Allow recommendations for care.

Vascular Physical Exam

Bruit

- Sound made by vibrating arterial wall
- Caused by turbulent blood flow making arterial wall vibrate
- Indicates the presence of an arterial lesion

Vascular Physical Exam

Ischemia

- Decreased blood supply results in metabolic compromise.
- Grades of severity reflect acuity of condition as well as the magnitude of the reduction in circulation.
- ACUTE vs CHRONIC

Vascular Physical Exam

Acute Ischemia

- 5 'P's
  - Pulseless
  - Pain
  - Pallor
  - Paresthesia
  - Paralysis
  - Poikilothermia (Cold)

Acute Ischemia

Vascular Physical Exam

Acute Ischemia

- Implies that without prompt restoration of blood supply there will be significant permanent damage to tissues.
- Susceptibility to Acute Ischemic Injury
  - Nerve +++
  - Muscle ++
  - Tendon and Bone +

Vascular Physical Exam

Chronic Ischemia

- A process where the gradual onset and magnitude of ischemia has allowed the body time to compensate for the decreased blood supply.
- Key Concept: "Collateral Circulation"
- Compensation is never as good as original.
- The vascular bed survives with less blood.

Vascular Physical Exam

Chronic Ischemia

- Changes in the Limbs
  - Skin …….. Growth slowed
  - Nails beds …… Growth slowed
  - Hair follicles ……. Lost
  - Sebaceous glands …… Lost
- Result: Thin, dry, skin with loss of hair, abnormal nail growth / fungal infections.

Cyanosis with acute ischemia

Vascular Physical Exam

Ulceration

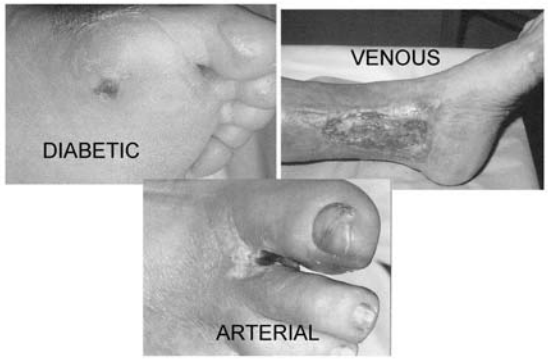
- A discontinuity in the integrity of the skin which persists despite sufficient time for healing.
- Must be able to distinguish three types: Arterial, Venous, *Neuropathic*.

Ulcers

Differential Presentation of Ulcers

		Arterial	Venous	Neuro
Location		distal	maleolar	plantar
Symptoms		painful	+ / -	no pain
Outline	sharp		irregular	punched
Assoc findings	Art sx		CVI sx	other Dx
		no pulse	OK pulse	OK pulse

Ulcers



Vascular Physical Exam

Gangrene

- Death of tissue
  - Related to absent blood supply
  - Infections
  - Tissue Toxins
  - Radiation, Trauma
- WET Gangrene vs DRY Gangrene
  - Bacterial superinfection
  - Mumefaction or mumyfication

Vascular Physical Exam

Methods:

Prepare your patient for exam:

- be sure room temperature is correct
- be sure limb position is as needed
- be sure privacy is respected
- place patient in correct position: supine on exam table is generally best
- uncover area to be examined

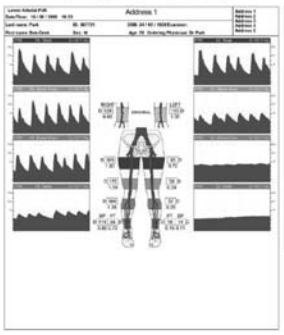
- To review the **diagnostic tools**

Diagnostic Exams

- **Angiography = Gold Standard for diagnosis with peripheral vascular disease**
- Ultrasound-detection by sound waves
- Doppler-Measures blood flow
- Computed Axial Tomography (CAT/CT Scan)-x-ray pictures in slices
- Magnetic Resonance Imaging (MRI)-uses radio waves and a magnetic field to provide the 3-D views (can move in any direction unlike CT and is nonradioactive)

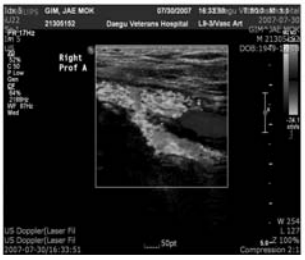
동맥폐색의 진단

- 혈류역학검사



동맥폐색의 진단

– 혈관초음파



동맥폐색의 진단

- 컴퓨터 단층촬영

적외선 체열 검사

- To review **the attitude** before OR or Angio-suite or Hybrid-room

Preparing for the OR on your rotation

- The day before…
- The day of…
- The hour before…

The day before the OR

- Find the OR schedule (write it down)
  - OR
  - secretary
- (Try to) plan what cases you will be involved in; discuss this with the team (everyone); be flexible
- Read about the patient (H&P by the attending, indications, radiology)

The day of the OR

- Find out about timing of the case (ask residents/OR front desk)
- Make sure the patient is prepared -pre-op: labs, EKG, x-ray, NPO, consent, etc.(index card, check boxes)

The hours before the OR

- Be early
- Refresh yourself regarding the patient/case (note card)
- Check the OR schedule (again)
- Confirm with the team
- Meet the patient
- Use the bathroom, eat/drink

The hours before the OR

- Meet the anesthesia team
- Meet the scrub/circulator, ask for help
- Walk back with the patient
- Watch how the team gets the patient ready, ask how you can help

What to say…

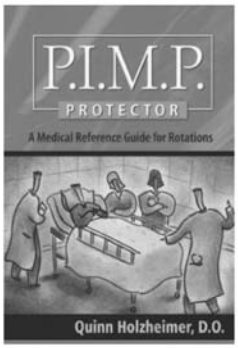
- Best to speak when prompted
- Don't ask questions during critical portion of case
- Limit conversation to case-related talk

What to say…

- Best to speak when prompted
- Don't ask questions during critical portion of case
- Limit conversation to case-related talk

And…

- Answer questions
- Pay attention
- Learn
- Have fun



- To review intra-operative preparation: **anestheisa, medication, positioning, preps, drapes**

Anesthesia

- Patient dependent: general, spinal, epidural, or local
- All spinal/epidural patients get a foley catheter
- CAE: will use an EEG to monitor brain activity and determine if a shunt is needed during the procedure. Can be done by CRNA or an EEG technician

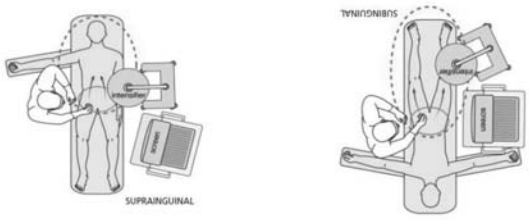
Medications

- Saline with antibiotic irrigant of surgeon choice or one patient is not allergic to
- Heparin saline irrigation for washing inside artery to prevent clot during surgery (usually 250ml NS to 1,000units Heparin)
- Papaverine antispasmodic/smooth muscle relaxant 120mg to 250ml NS (distention, prep, storage of vein grafts)
- Topical Hemostatic Agents: Surgicel, Gelfoam with Thrombin, Avitene, others
  (Surgeon choice)

Positioning

- Extreme Care Taken with Positioning due to limited Circulation of these Patients
- Try to position while awake to get feedback from patient
- Pay attention to anatomical alignment
- Padding bony prominences
- DO NOT lay heavy instruments on patient
- Supine with arms tucked or on armboards
- Pillow under knees
- Pads under heels and arms
- Pillow, headrest, or donut under head (avoid neck hyperextension)

환자의 수술실 내 위치
(for a right-handed operator)



Prep (Considerations)

- Doctor preference/Patient allergy: Hibiclens, Betadine
- Non-open wounds an Ioban is preferred due to fact that are operating on vasculature which is a potential opening to septicemia
- If scrubbing a carotid or aneurysm BE GENTLE! You could loosen plaque or rupture an already ready to rupture artery!

Drapes

IMPERVIOUS DRAPES
- Extremity drapes
- Universal drapes
- Pediatric Laparotomy sheet
- U-sheet

How to Enter the OR

- Change into clean scrubs
- Remove all jewelry, watches and rings
- Remove your pager and cell phone
- Put on a surgical cap, mask, shoe covers
- Hair must be completely covered
- Mask must be tied before entering the OR

Once you are scrubbed in, gowned and gloved.....

Where is the sterile field??

Or, What am I allowed to touch??
and…
Where do I put my hands??

Where is the sterile field?

- **You:**
  - Front of the gown from chest to the waist
  - Gloved hands and arms to the elbows
- **Patient:**
  - Draped part down to the OR table
  - Anything that falls **below** the level of the patient table is considered contaminated
- **Sterile Field:**
  - Covered part of the "Mayo stand" (small table where the most commonly used instruments are kept)
  - Top of the "Back Table" where additional instruments are kept. The sides of the Back Table are **not** considered sterile
  - Disposable light handles

The Sterile Field

- To review **basic supplies, equipment, intstrumentation**

Basic Supplies, Equipment, Instrumentation

- Cardiovascular or peripheral vascular instrument tray
- Carotid Tray
- If above not available→ Basic Laparotomy Tray and add following:
- Vascular clamps of surgeon choice (peripheral debakeys, fogarty clamps, satinskys, cooleys, henleys, etc.)

Basic Supplies, Equipment, Instrumentation

- Fine needle holders of surgeon choice (castros, ryders, or other fine NH)
- Fine forceps of surgeon choice (dietrich debakeys or fine debakeys, potts or geralds, etc.)
- Micro/delicate Scissors (potts, tenotomy)
- Bulldogs/small vessel clamps
- Surgeon preferred self-retaining retractor (Omni, Henley, Myerding, Gelpi, Weitlander, Cerebellar, Beckman, etc.)
- Freer or Penfield for endarterectomies
- Beaver handle (Surgeon Preference)

X-ray protection

X-ray badge

Mobile X-ray barrier

Thyoid X-ray collar lead apron

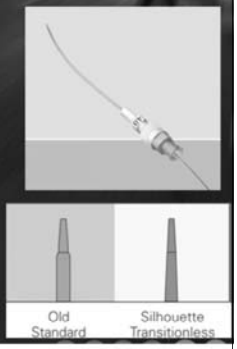
X-ray goggle

X-ray barrier

Micropuncture Introducer Set, Silhouette™ Transitionless: Cook

- For placement of .035"or .038" inch diameter wire guides into the vascular system when a small 21 gage needle stick is desired.
- Transitionless Stiffened Cannula
- Smooth shaft to tip transition to eliminate hang-up on skin

Antegrade puncture
Popliteal aretry, tibial artery puncture



Unit

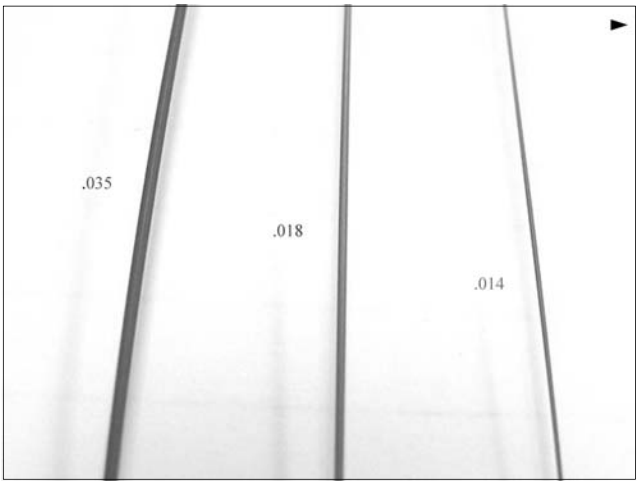
- Inch - Wire
- French - Sheath, Catheter
- mm - Balloon, Stent

- 1mm = 0.039 inch = 3F
- 25.2mm = 1 inch

- Wire(inch): Outer wall

Guidewire Functions

- **First device IN, last device OUT !!!**
- Insert sheath introducers.
- Straighten the vessel to help advance the catheter or interventional device.
- Facilitate the exchange of catheters.
- Guide and help place a catheter or interventional device.
- Access and cross the lesion site.



Hydrophilic Wires

- Angiodynamics: AquaLiner
- Angiotech: CanaliZer
- Asahi: Regalia 1.0XS
- Boston Scientific: Transend Steerable, Fathom-14,16 Steerable, Zipwire
- Cook: HiWire, Roadrunner
- Cordis: Aquatrack
- Medtronic: Cougar, Zinger, Thunder, Persuader 3/6/9
- Merit: H2O
- Microvention: Headliner, Traxcess
- Micrus: Watusi
- St Jude: Hydrosteer
- Terumo: Glidewire, Glidewire Gold J, straight
- Vascular solutions: VSI

Coiled Stainless Steel Wires

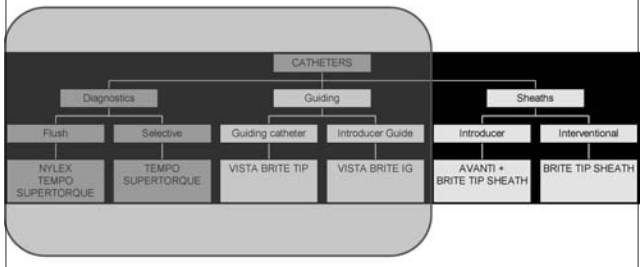
- Abbott: Hi-Torque Supra Core/ Steelcore/ Spartacore
- Angiodynamics: PTFE-coated
- B.Braun: Guidewires
- Boston Scientific: Amplatz Super Stiff, Meier, Starter, Schneider
- Cardiovascular Systems: Viperwire
- Cordis: Emerald
- ev3/Invatec: Nitrex, Babywire
- Cook: Safe-T-J, Bentson, Newton, Rosen, Amplatz Extra Stiff/Ultra Stiff/ Tapered, Lunderquist, Double flexible tip, Tefcor
- Merit: InQwire
- Covidien (Tyco/Mallinckrodt): Wholey Hi-Torque, TAD, Flex Hi-Torque
- St Jude: GuideRight
- Vascular Solutions: VSI, Jiffy, VSI

SHAFT STIFFNESS

- Catheter(French):Outer wall

- 15F = 5mm
- 16F = 5.333mm
- 17F = 5.667mm
- 18F = 6mm
- 19F = 6.333mm
- 20F = 6.667mm
- 21F = 7mm
- 22F = 7.333mm
- 23F = 7.668mm
- 24F = 8mm

Classification of Catheter

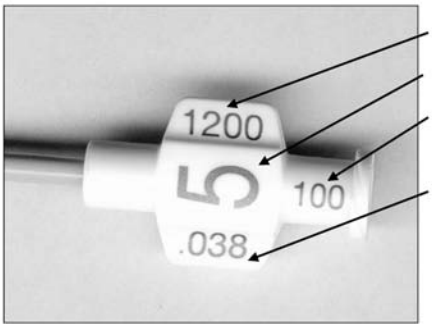


Catheter(French):Outer wall

- Diagnostic catheter: flushing/selective

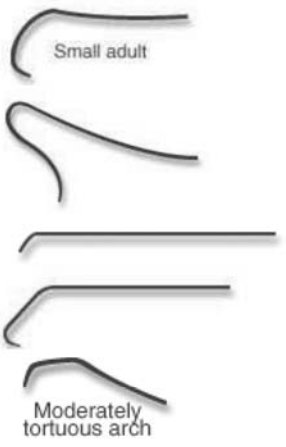
- Guiding catheter:

All Information on the Hub..

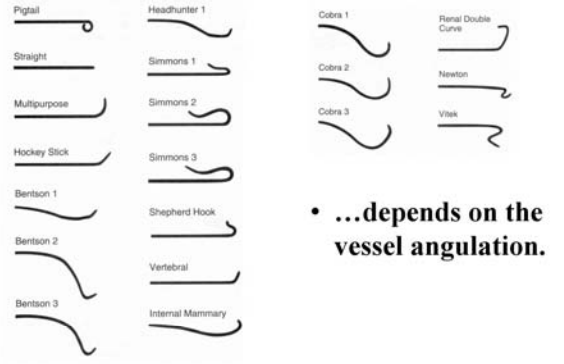


- 1- PSI (max)
- 2-French size
- 3-Shaft length (usable)
- 4-GW accept.

TOP 5
Selective



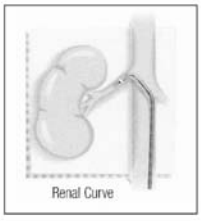
Choosing a Catheter Shape



- …depends on the vessel angulation.

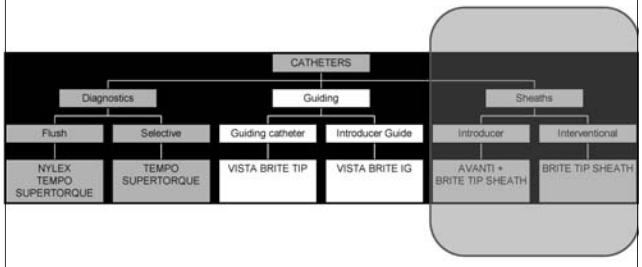
Guiding Catheters

- From 6F to 10F
- For safe balloon and stent delivery
- Designed to be introduced in vessel ostium
- For back up support
- Mainly in renal arteries

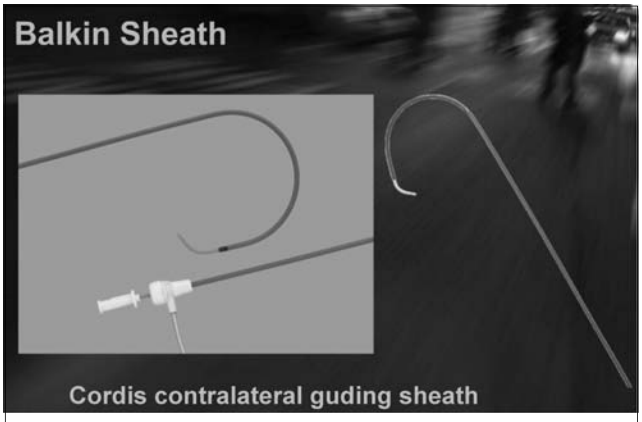


- Sheath(French): Inner wall

Classification of Catheter



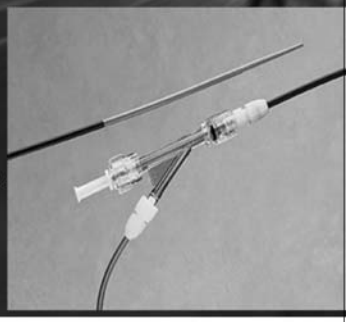
Sheath(French): Inner wall



Shuttle Sheath

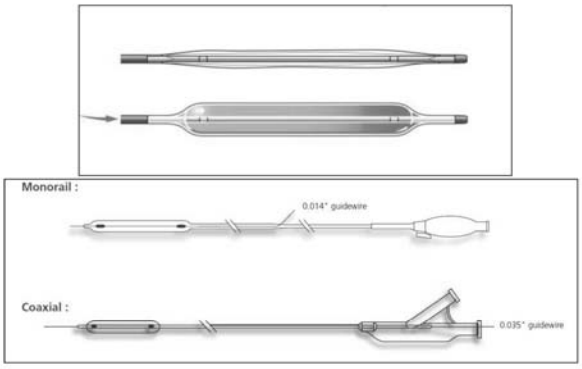
- 90 cm long
- Kink resistant
- Soft SL tip design
- Hydrophilic coating
- 6 Fr sheath compatible with most carotid stent platforms

4 F sheath compatible
With BTK intervention



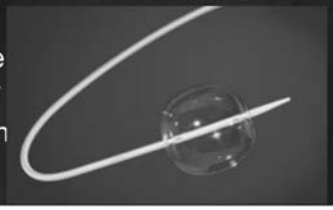
- Balloon(mm): Outer wall
- Stent(mm):Outer wall

Balloon(mm): Outer wall



Temporary Occlusion/Vascular Prostheses Post Dilatation Balloons

- Coda Balloon Catheter (Cook)
- RELIANT® Stent Graft Balloon Catheter (Medtronic)
- Berenstein Large Balloon Catheter
- Equalizer Balloon Scientific)



Stent(mm):Outer wall

Balloon expandable

Advantages :
- Radiopacity
- Radial force
- Precise delivery

Disadvantages:
- Flexibility
- Trackability

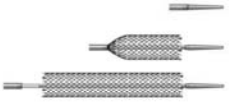
Indications:
- Short, calcified stenoses

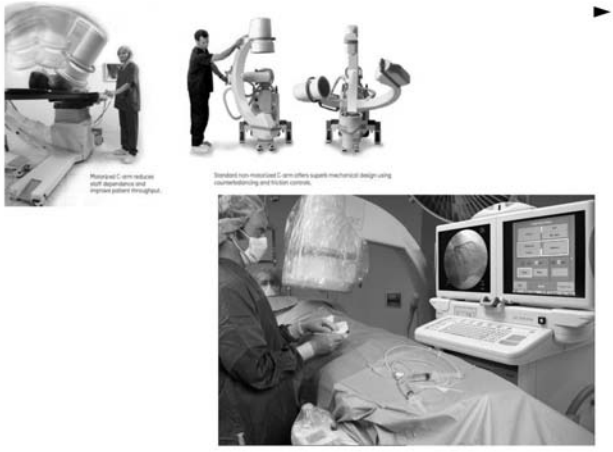
Self expandable

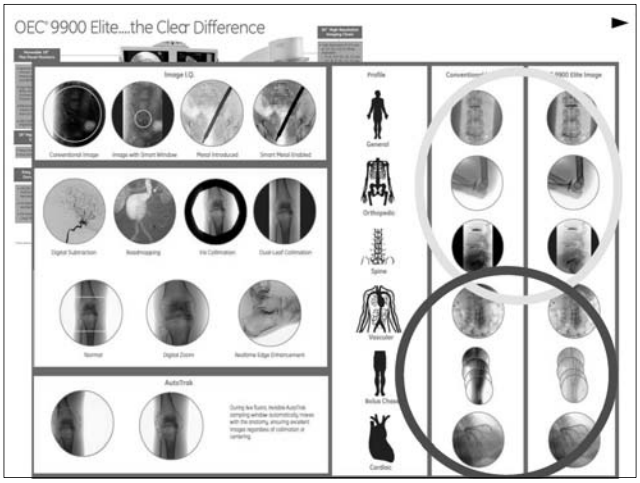
Advantages :
- Flexibility
- Trackability

Disadvantages :
- Radiopacity (advantage of distal radio-opaque markers)
- Radial force

Indications :
- Long lesions, tortuous arteries







- Summary

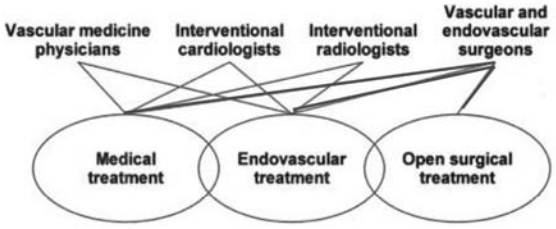
Human Technology => Human Philosophy

- Certainly, our patients have benefited greatly from new technologies, devices, and cardiovascular treatment strategies, and these are integral to improving outcomes, but they do not ensure a successful cardiovascular center of excellence.
- The creation of a true multidisciplinary team approach is at the very core of the center of excellence concept.
- Perhaps when creating any center of excellence, the first technology to get right is the "human philosophy."

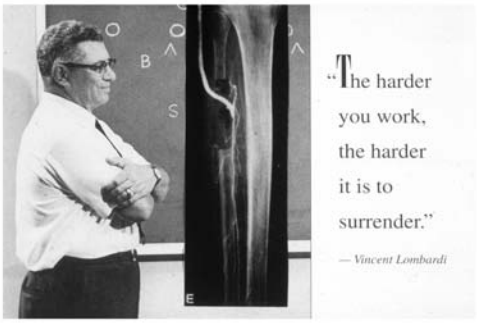
Establishing aPeripheral VascularCenter of Excellence. DAVID E. ALLIE, MD; CHRIS J. HEBERT, RT, R-CIS; AND CRAIG M. WALKER, MD. FEBRUARY 2005 I ENDOVASCULAR TODAY I 41

Good luck to all Bi-Vascular Surgeons !

Vascular Specialists



Questions?



"The harder you work, the harder it is to surrender."

— *Vincent Lombardi*

소아심장 수술환자의 준비

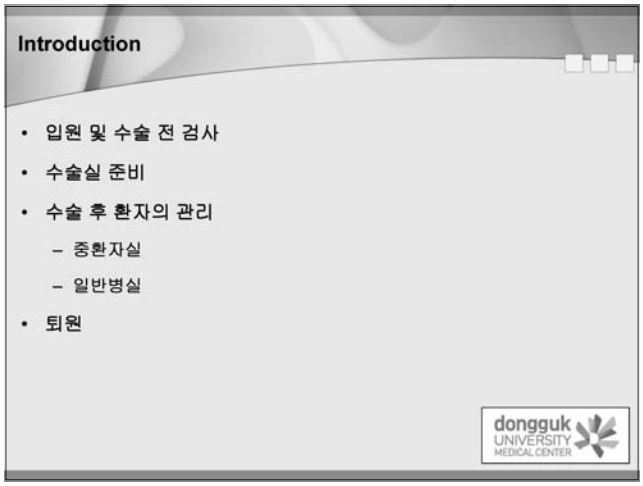
세종병원 흉부외과

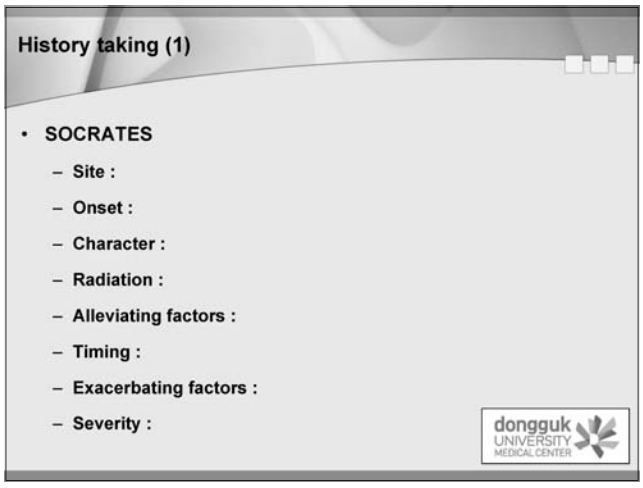
최 은 석

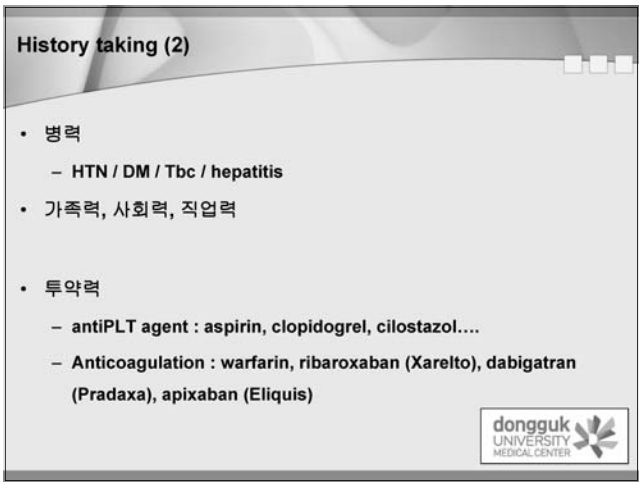
성인심장 수술환자의 준비

일산동국대병원 흉부외과

이 재 항







ROS (review of system) & P/Ex (Physical examination)

- Chest pain
  - Duration
  - Character
  - Aggravation & relieving factors
- DOE
- Auscultation
  - Murmur, crackle, wheezing, rale, rhonchi

Preop W/U (1)

- Laboratory data
  - Inflammatory marker : WBC, ESR, CRP
  - Cardiac marker : CK-MB, Troponin, myoglobin..
  - Coagulation lab : PT INR, aPTT, fibrinogen, d-dimer
  - Renal & liver panel : BUN/Cr, E'(Na-K-Cl), OT/PT, bilirubin
  - ABGA (room air)

Preop W/U (2)

- CXR
  - Chest PA & AP
- ECG
  - Presence of arrhythmia, ischemia, infarct....

Preop W/U (3)

- Echocardiography
  - LV function (EF = ?)
  - RWMA (regional wall motion abnormality)
  - Valvular dysfunction
  - Atrial & ventricular size
  - Ascending aorta diameter

Preop W/U (4)

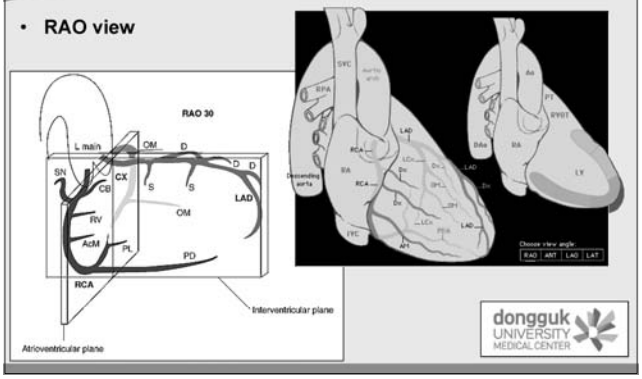
- CT angiography (thoracic & abdominal aorta)
  - Asc.Ao. Calcification
  - Subclavian a. & internal thoracic artries
  - Neck vessel (CCA, ICA, vertebral a.....)
  - Visceral a. (renal a. celiac a.....)
  - Extremity a. (CIA, EIA, CFA.....)
    - considering IABP & ECMO insertion
  - Adhesion (esp. redo cardiac op.)

Preop W/U (5)

- Coronary angiography
  - For CABG
    - 가장 기본적인 술 전 검사
    - 병변의 위치, 관상동맥질환의 진행 정도
    - 수술 문합에 대한 계획
    - Int. thoracic artery 에 대한 평가
  - For other OHS
    - 고령의 환자에서 CAD의 가능성을 배제하기 위해 실시

Coronary angiography (CAG)

- RAO view



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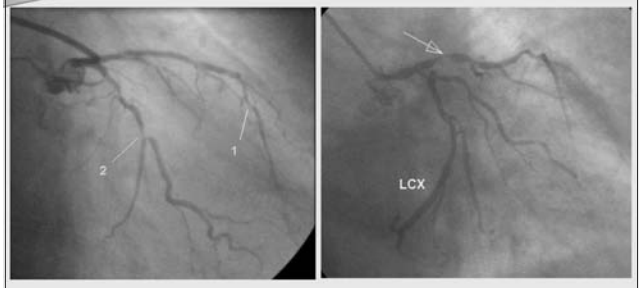
CAG – RAO view



- *For LCX & OM*

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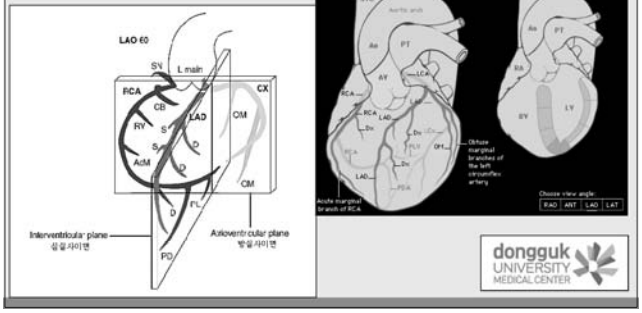
Coronary angiography (CAG)

- LAO view



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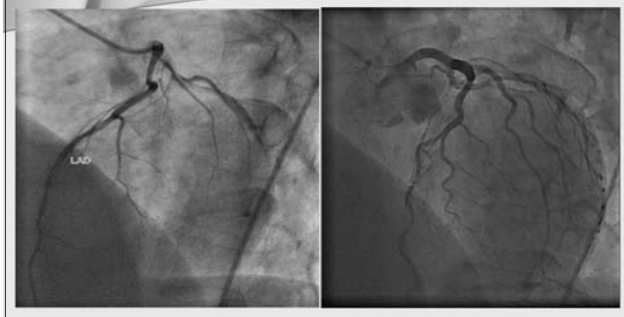
LAO view



- *For LAD & D, RI*

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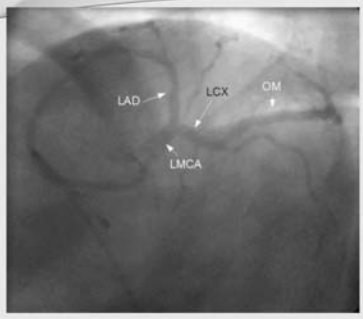
LAO view – caudal (Spider view)



- *For LM*

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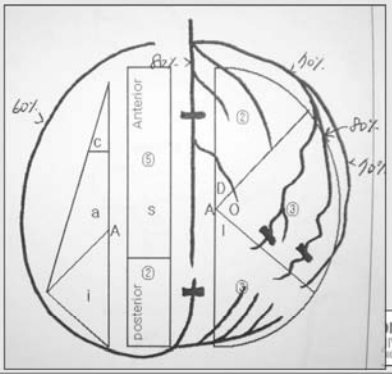
Diagrammatic representation



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Preop W/U (6)

- Others
  - Brain evaluation
  - Carotid sono
  - ABI (ankle-brachial index)
  - DM control

수술실 준비

수술실에서 고려해야 할 사항

- ECG : 5-lead
- SaO2 : finger or ear
- A-line : single vs. dual vs. triple
- C-line : AVA (advanced venous access) & Swan-Ganz cath
- Foley cath : position of bag
- Bovie plate
- .....

Draping

- Betadine soap → solution (+/- alcohol)
- 안 → 밖 (나선형)
- 위 → 아래 (소독액이 흘러내리는 상황에서는..)
- 회음부는 마지막에..
- 일반적으로, 턱선 ~ 무릎 아래
  - CABG or aorta 는 연장

수술실에서 고려해야 할 사항

- 팔 고정
  - 팔은 손바닥이 하늘을 보게 : ulnar neuropathy 방지
  - 너무 꽉 조이지 않게 : hand edema 방지
- 어깨받침
  - 융포나 소방으로 한 겹 감아서 : sore 방지
- Defibrillation patch (if, redo surgery)
- 수술 중 적절한 위치 및 고정
  - Cell-saver, cardiotomy sucker, pressure line (for retroCPS cannula), pacemaker,

수술 후 관리

성인 심장 수술 후 환자 관리

- **ICU care**
  - **Cardiac Monitoring**
  - **Mechanical ventilation**
  - **Cardiac medication**
  - **CPR**
- **General ward**
  - **PO medication & F/U**

Basic approach to hemodynamic problems

BP	PCWP	CO	SVR	treatment
↓	↓	↓	↓	Volume
N	↑	↓	↑	Venodilator or diuretic
↓	↑	↓	↑	inotropics
↑	↑	↓	↑	vasodilator
↑↓	↑	↓	↑	Inotrope / vasodilator / IABP
↓	N	N↑	↓	α –agent

LCOS (low cardiac output syndrome)

- **PCWP > 20mmHg**
- **SVR > 1500 dyne-s/cm^5**
- **Poor peripheral perfusion with pale, cool, sweating skin**
- **Poor urine output (<0.5ml/kg/h)**
- **Pulmonary congestion and hypoxia**
- **Metabolic acidosis**

LCOS management

- **Check correctable causes**
  - **Ventilator, acid-base & E' imbalance**
  - **Correct ischemia or coronary spasm**
  - **Maintain enough preload**
    (PCWP or LAP = 18~20mmHg)
  - **Maintain heart rate (90~100/min with pacing)**
  - **Control arrhythmia**
  - **Correct anemia**
  - **Use situation-specific cardiotonics**

	Dosage (ug/kg/min)	α1	α2	β1	β2	dopaminergic
norepinephrine	0.01~0.5	+++	+++	+	0	0
epinephrine	0.01~0.5	+++	+++	++	++	0
dopamine	2~20	++	+	+	+	+++
Dobutamine	5~20	0	0	+++	++	0
isoprotenerol	0.01~0.1	0	0	+++	+++	0

- **α1 : vascular smooth muscle receptor – vasoconstrictor**
  Myocardial receptor – weak positive inotropic and negative chronotropic
- **α2 : presynaptic vasoconstriction**
- **β1 : myocardium – positive inotropic and chronotropic**
- **β2 : smooth muscle – vasodilation, bronchodilation**
- **Dopaminergic : mesentric and renal arterial vasodilation**

Nitroglycerin

- **0.1~10 ug/kg/min**
- **Dilates coronary vessels & improves blood flow to ischemic zones**
- **Indications**
  - **Hypertension, myocardial ischemia, coronary spasm, pul HTN….**
- **Hypovolemia, marginal cardiac output**

  → **should be avoided**

β - blokers

- Negative inotropic and chronotropic
- Reduce contractility, lowering stroke volume, cardiac output
- Depressing SA node → slow HR
- Indications
  - Control of postoperative systolic HTN associated with satisfactory cardiac output
- hypertensive or tachyarrhythmic patients with compromised cardiac output

  → IV β – blokers should be avoided.!

Calcium channel blockers

- Relaxing vascular smooth muscle and producing peripheral vasodilation
- Coronary vasodilation, negative inotropic
- Slowing the sinus mechanism, slowing of AV conduction
- Indications
  - Hypertension with satisfactory cardiac output
  - Coronary spasm
- Low ventricular function

  → Diltiazem and verapamil shoud be avoided

Calcium channel blockers

	Nicardipine	Diltiazem	Verapamil	Nifedipine	Amlodipine
inotropy	0	↓	↓↓	0↑	0
Heart rate	0	↓	↓	↑	0↑
AV conduction	0	↓↓	↓↓	0	0
Systemic vascular resistance	↓↓	↓↓	↓↓	↓↓	↓↓
Coronary vascular resistence	↓↓	↓↓	↓↓	↓↓	↓↓

Sodium nitroprusside

- Relaxes arterial smooth muscle
- Reduce systemic and pulmonary vascular resistance
- Ischemic heart
  - Should be avoided
    - d/t coronary steal syndrome
    - Diastolic transmyocardial gradient for coronary blood flow will be reduced
- Very rapid onset of action
  - Always required close monitoring with indwelling arterial cannlua

CPR (cardiopulmonary resuscitation)

- CPR의 시작은 누가?
  - 처음 발견한 의료인 **vs.** 당직주치의 **??**
- CPR은 어느 시점부터?
  - Mental change
  - No respiration, pulsation
  - Hypotension, bradycardia
- 적절한 CPR의 방법은??
  - Cardiac compression & ambu-bagging, IV line 확보
  - ECG monitoring & Defibrillation
  - IV epinephrine & sodium bicarbonate

Thank you for your attention ~ !

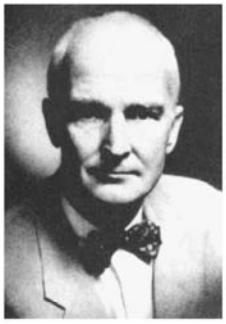
Technique and Pathophysiology of Cardiopulmonary Bypass

Department of Thoracic and Cardiovascular Surgery,
Chungbuk National University College of Medicine, Cheongju

Hong Ju Shin

Introduction

- The surgeon must have a comprehensive understanding of all aspects of CPB
- Film and bubble oxygenators
- Membrane oxygenators were introduced in the 1950s
- The first membranes were relatively impermeable to gases, requiring huge surface areas and massive priming volumes



Dr. John H. Gibbon, Jr. (1903-1973).

- In 1953, CPB was successfully used to correct an atrial septal defect
- Film and bubble oxygenators

Contents

1. Technical Aspects of Cardiopulmonary Bypass
2. Pathophysiology of Cardiopulmonary Bypass
3. Heparin–Protamine Axis
4. Biomaterial-Dependent Strategies to Minimize Blood Activation from CPB
5. Organ Derangement Related to Cardiopulmonary Bypass

Contents

1. Technical Aspects of Cardiopulmonary Bypass
2. Pathophysiology of Cardiopulmonary Bypass
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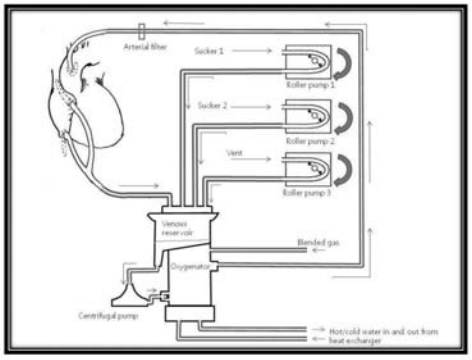
Device Overview



Principles of Current Oxygenator Design and Function

- Currently used membranes are very permeable to O2, but they are often less permeable to CO2
- The problem of poor diffusion of CO2 was solved by the introduction of microporous membranes
- When the O2 is dissolved in plasma or blood, its diffusivity is 25 times less than that of CO2

- Two modifications
  1. The path length has been maximized
  2. Disturbed flow patterns are used to promote mixing and to bring deoxygenated blood closer to the exchange surface

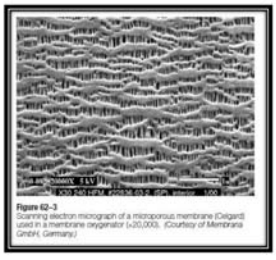


Figure 62–3
Scanning electron micrograph of a microporous membrane (Celgard) used in a membrane oxygenator (×20,000). (Courtesy of Membrana GmbH, Germany.)

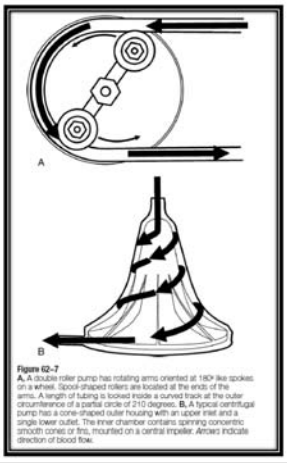


Figure 62–7
A. A double roller pump has rotating arms oriented at 180° like spokes on a wheel. Spool-shaped rollers are located at the ends of the arms. A length of tubing is locked inside a curved track at the outer circumference of a partial circle of 210 degrees. **B.** A typical centrifugal pump has a cone-shaped outer housing with an upper inlet and a single lower outlet. The inner chamber contains spinning concentric smooth cones or fins, mounted on a central impeller. Arrows indicate direction of blood flow.

- 원심 펌프의 박출량은 콘의 회전수가 아니라 후부하에 의해 좌우되며 공기가 차는 현상(air-lock) 등이 나타날 수 있기 때문에 사용에 보다 세심한 주의가 요망된다.
- 그러나 다량의 공기가 예기치 않게 급속히 환자에게 들어가는 소위 "air pumping"의 위험도가 낮으며 회로의 원위부가 갑자기 막혔을 때 롤러 펌프와 같이 회로가 터진다거나 하는 일을 생기지 않는 것이 원심 펌프의 또 다른 장점이다.

Hypothermia and Acid–Base Balance

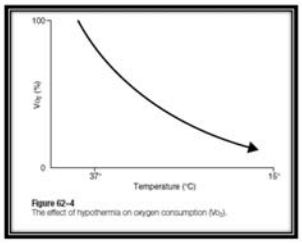


Figure 62–4
The effect of hypothermia on oxygen consumption ($\dot{V}_{O_2}$).

- O2 consumption decreases by 50% for every 10° C drop in temperature
- pH-stat strategy
- alpha-stat management (i.e., no active correction of pH with hypothermia)

http://www.yongwoon.kr/files/attach/images/130/217/3e9596717f8c97efe04b2bd83b452d94.jpg

- pH-stat strategy results in excessive CBF, which may increase embolic load

pH management strategy

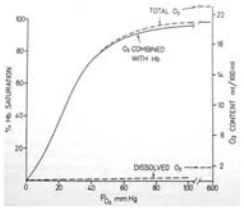
de Henderson Hasselbach equation

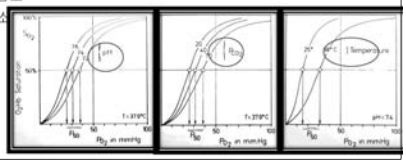
$$pH = pK_a + \log_{10}\left\{\frac{[A^-]}{[HA]}\right\} \qquad \mathbf{pH = 6.1 + \log\frac{[HCO3-]}{0.03 \times PaCO2}}$$

Oxyhemoglobin Dissociation Curve

Shift to Left
: ↑ *pH*, ↓ P_aCO_2, ↓ Temp, ↓ 2,3-DPG
[Alkalosis, Hypothermia]
: Oxygen에 대한 Hb의 Affinity가 증가
: 같은 산소분압에서 포화도는 증가
: 말단조직에서 산소유리가 감소

Shift to Right
: ↓ *pH*, ↑ P_aCO_2, ↑ Temp, ↑ 2,3-DPG
[Acidosis, Hyperthermia]
: Oxygen에 대한 Hb의 Affinity가 감소
: 같은 산소분압에서 포화도는 감소
: 말단조직에서 산소유리가 증가





pH-stat

- Mechanism prevailing in hibernating animals
- Aims
  - Maintaining NORMAL acidemia and blood gases [***pH*** 7.40, P_aCO_2 40 mmHg] in the HYPOTHERMIC BLOOD
  - In the **REWARMED** [37℃] blood, the blood becomes **acidemic** and **hypercapnic**
- Methods
  - Maintains the **Temperature CORRECTED *pH* 7.4 and P_aCO_2 40 mmHg**
  - Add CO_2 during the cooling phase of CPB → Lowering ***pH*** → Partially offset of LEFTWARD shift of Oxy-Hb curve

α-stat

- Mechanism prevailing in reptiles
- Aims
  - Maintaining **NORMAL** acidemia and blood gases [***pH*** 7.40, P_aCO_2 40 mmHg] **in the REWARMED [37℃] blood**
  - Maintenance of constant *α*
    Maintains the NON-Temperature Corrected ***pH*** 7.4 and P_aCO_2 40 mmHg [measured at 37 ℃]
  - Keeping total CO_2 CONTENT constant
  - Allowing P_aCO_2 to vary with temperature

	pH-stat	*α*-stat	
Moderate hypothermia in Adults			
Usual case	≒ / ≤		***α***-stat is preferable
Longer than 90 min	≤		better in neurologic and neuropsychologic outcome
DHCA			
Cooling phase before DHCA	>		better in terms of $CMRO_2$
Maintenance phase of DHCA	<		Prevent excessive acidosis & impairment of Enzyme function
Rewarming phase of CBP	<		

Switch strategy; *pH*-stat during cooling and *α*-stat during maintenance of hypothermia and rewarming *in an attempt to prevent excessive lowering of cbr intracellular pH and impairment of intracellular enzyme function*

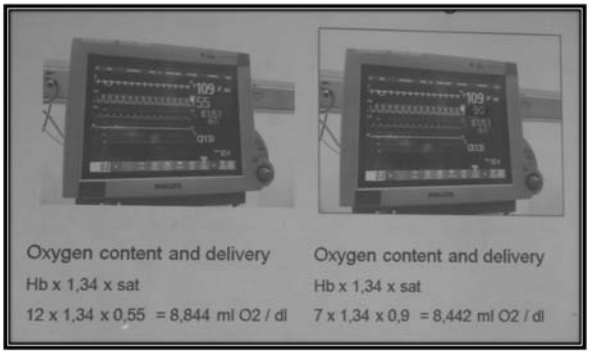
Acid-Base (CO2) Management

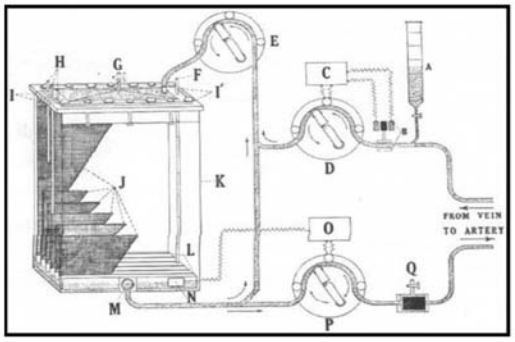
	Alpha-stat	pH-stat
Temperature-corrected	Uncorrected	Corrected
Blood pH	Alkalotic	Normal
Intracellular pH	Normal	Acidotic
Cerebral blood flow	↓	Maintained
Intracellular enzymatic function	Maintained	↓
Technically demanding	No	yes

Hematocrit and Priming

- Hct - between 20% and 25% during CPB
- The drop in O2 content at most levels of moderate hemodilution is more than compensated for by augmented cardiac output (CO), so total O2 delivery (CO × O2 content of blood) is increased;
- The optimal Hct - in the range of 30%
- Hemodilution results in a significant increase in flow without a parallel increase in perfusion pressure
- Hypothermia complicates the effects of hemodilution, as the decreased temperature causes increased viscosity and induces vasoconstriction

Oxygen delivery and Hemoglobin

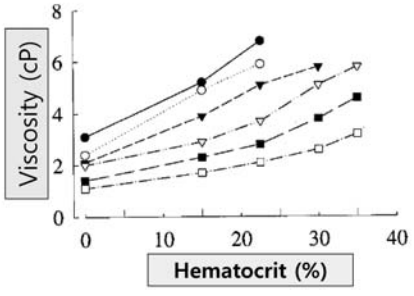




Priming volume : *6 L*

Introduced in the 1950s

Lower viscosity at lower hematocrit



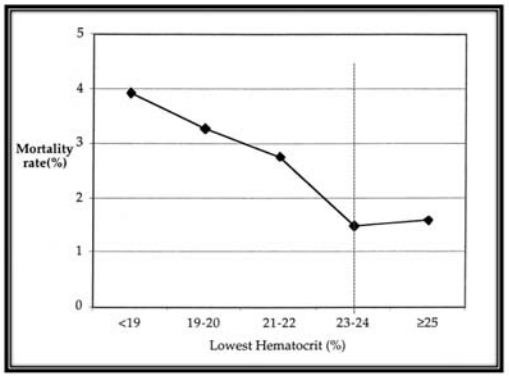
Eckmann, et al. 2000

Factors influencing Critical Hematocrit

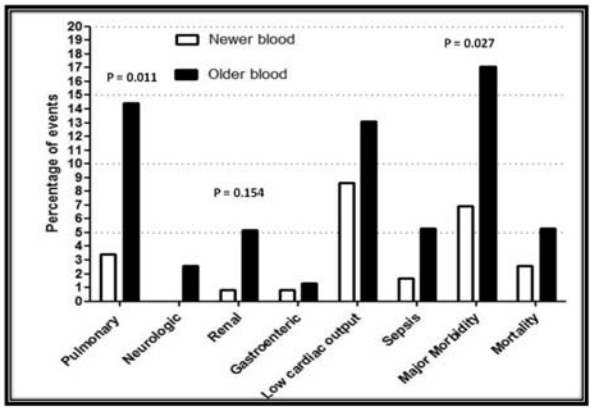
- CPB temperature
- Re-warming
- Perfusion pressure
- Conditions where autoregulation is impaired such as diabetes mellitus or increased age

Recent large databased investigations in **Adults**

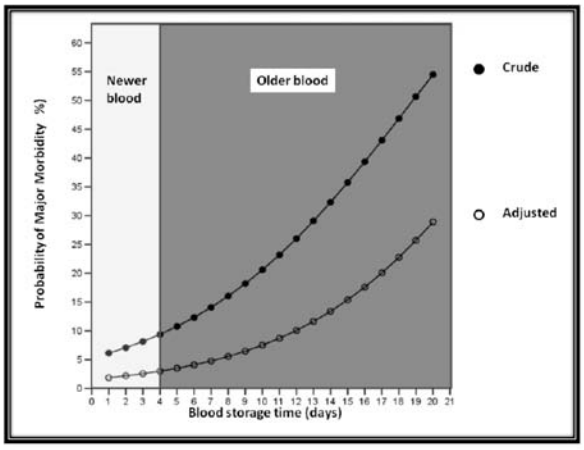
Author	No. of patients	Critical Hct Values	Results from lowest Hct
DeFoe et al. 2001	6980	23%	Increased In-hospital mortality, need for IABP, and return to CPB
Habib et al. 2003	5000	22%	Increased mortality, morbidity and resource utilization
Swaminathan et al. 2003	1404	NI	Creatinine rise
Karkouti et al. 2005	10949	NI	Increased risk of stroke
Habib et al. 2005	1760	24%	Increased risk of creatinine rise and acute renal failure
Ranucci et al. 2005	1766	23%	Increase risk of low cardiac output and acute renal failure



DeFoe et al. 2001 (n=6980)



Ranucci et al (Critical Care 2011)



Flow Rates, Perfusion Pressure, and Autoregulation

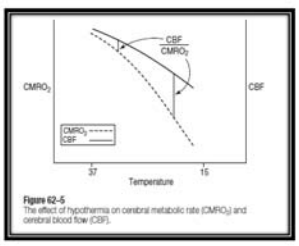


Figure 62-5
The effect of hypothermia on cerebral metabolic rate ($CMRO_2$) and cerebral blood flow (CBF).

- A target mean BP of 50 to 70 mm Hg at normothermia
- At lower temperatures, a mean pressure of 35 mm Hg is still generally accepted as safe
- Temperature is the most important element influencing CBF during CPB

Flow Rates, Perfusion Pressure, and Autoregulation

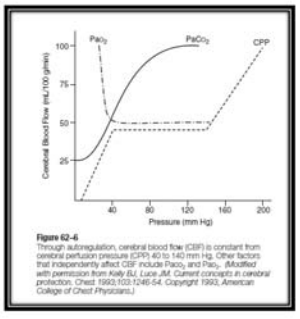
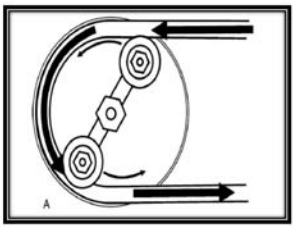


Figure 62-6
Through autoregulation, cerebral blood flow (CBF) is constant from cerebral perfusion pressure (CPP) 40 to 140 mm Hg. Other factors that independently affect CBF include $Paco_2$ and Pao_2. *(Modified with permission from Kelly DJ, Luce JM. Current concepts in cerebral protection. Chest 1993;103:1246-54. Copyright 1993, American College of Chest Physicians.)*

- At normothermia, a mean pressure of 50 mm Hg is the threshold at which the brain autoregulates flow, but with hypothermia (26° C), the threshold drops to 30 mm Hg
- CBF varies linearly with the Paco2, in the range of 20 to 80 mm Hg, whereas a Pao2 of less than 50 causes cerebral vasodilation, which overrides pressure-flow autoregulation

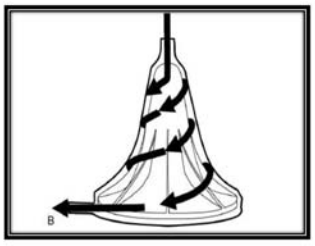
Pumps for CPB



Roller pump

- A low compression will result in inadequate flow, whereas excessive compression may aggravate hemolysis and tubing wear

Pumps for CPB



Centrifugal pump

- In pediatric cardiac surgery
- Anticipated long CPB runs
- The flow in a centrifugal pump is afterload dependent, and it is not predictable solely on the basis of the calculated revolutions per minute, so an in-line flowmeter is essential

Cardiac Venting for CPB

- To aid visualization, avoid chamber distension
- Related to bronchial artery flow and return from the thebesian veins.
- Pulmonary artery, Superior pulmonary vein Left atrium, Left ventricle

Cardiotomy

- Mechanical injury, such as hemolysis, may result from the air–blood interface at the sucker, the compressive effects of the roller pump
- The formation of particulate emboli including fibrin, macroaggregates of denatured proteins and lipoproteins, fat globules

Cannulation for CPB : Venous Cannulation

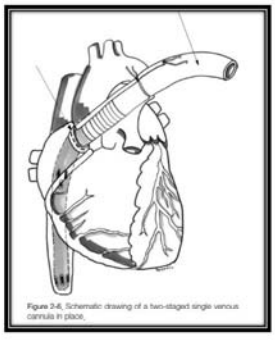
- Siphonage

http://www.studor.net/blog/wp-content/uploads/f3395f26-1669-4a7a-9984-68472cfd45c4.jpg

- The determinants of drainage
  - Height of the patient above the venous reservoir
  - Patient's blood volume
  - Resistance of the tubing
  - Cannula dimensions

  this is the narrowest part of the venous return
- Vacuum-assisted venous drainage

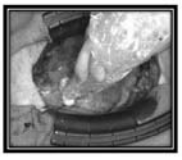
- Cavoatrial cannulation
  - the use of a two-stage venous cannula
- Placing tourniquets around the SVC and IVC during bicaval cannulation allows the institution of total as opposed to partial bypass



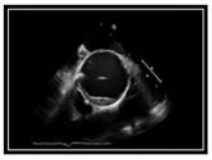
Cannulation for CPB: Arterial Cannulation

- Gradients in excess of 100 mm Hg associated with hemolysis
- Complications of ascending aortic cannulation
  - aortic intramural hematoma and dissection (0.01 to 0.09%)
  - atheroemboli either directly from the cannula
  - carotid hypoperfusion
  - air embolism
  - injury of the back wall of the aorta
  - misdirection of the tip of the cannula

- The dissection rate with femoral cannulation between 0.2% and 3%.
- Epiaortic scanning



http://www.fac.org.ar/tcvc/llave/c187/fig9a.jpg



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Contents

Noncellular Response

- Biomaterial-dependent processes
- The effect of non-pulsatile flow - VAD

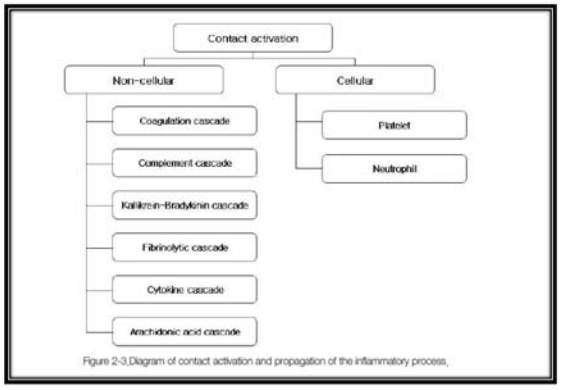


Figure 2-3,Diagram of contact activation and propagation of the inflammatory process.

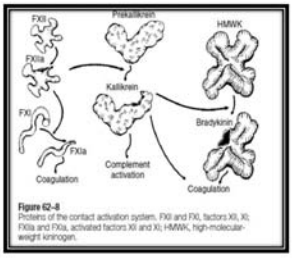
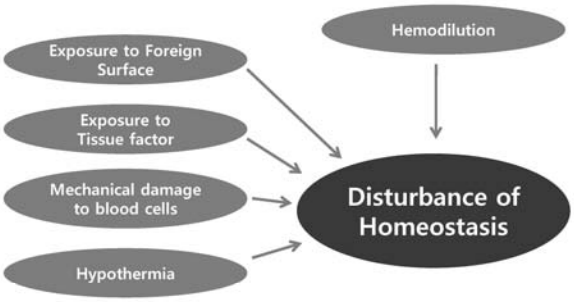


Figure 62-8
Proteins of the contact activation system. FXII and FXI, factors XII, XI; FXIIa and FXIa, activated factors XII and XI; HMWK, high-molecular-weight kininogen.

- Bradykinin
- Increased capillary permeability and the development of tissue edema

Damaging Effect of CPB



Exposure to Foreign Surface

- Protein coating on foreign surface
  - Protein change into active form
- Protein bindings characteristics of surface
  - Hydrophobic surface
  - Rough surface
- Heparin coated surface
  - change the surface protein composition, but produce thrombotic stimulus

Intrinsic Pathway

- Major coagulation stimulus during CPB

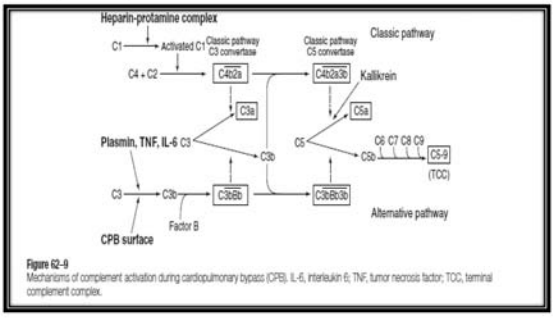


Figure 62-9
Mechanisms of complement activation during cardiopulmonary bypass (CPB). IL-6, interleukin 6; TNF, tumor necrosis factor; TCC, terminal complement complex.

Cellular Activation during CPB: Platelets, Endothelial Cells, Leukocytes

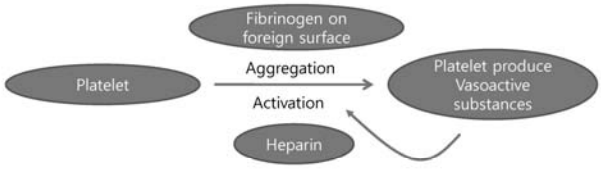
- Surface-adsorbed fibrinogen - the key mediator of platelet accumulation on foreign materials
- Activated platelet GP IIb/IIIa receptor
- CPB - associated with a consistent increase in the proportion of activated circulating platelets
- Physical activators of platelets
  - hypothermia
  - the process of cardiotomy blood collection

Platelets

- CPB - thrombocytopenia commonly
- Platelet counts dropping more than 50%
- Platelet adhesion to surfaces, hemodilution
  Platelet aggregate formation
  Formation of platelet–leukocyte complexes
- platelet dysfunction

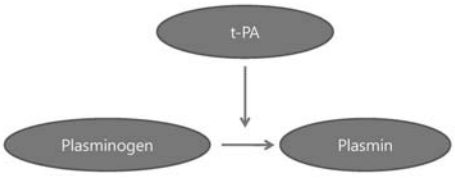
Platelets

- Major cause of postoperative bleeding (Number, function decrease)
- Cause a decrease in platelet numbers (30~50%) during CPB
  - Plt. adhesion, aggregation, hemodilution
- Platelet number normalize in 3~7 days



Fibrinolysis

- Endothelial cell produce tissue plasminogen activator(t-PA) during CPB



주로 fibrin에 흡수된 plasminogen에서 진행

Platelet Dysfunction

- Bleeding time(plt. function)
  - Prolonged for several hours (4~12hrs)
  - Even after protamine supply
- Glycoprotein Ib receptor(key receptor for hemostasis) decreased surface density due to internalization
  - caused by low concentration of plasmin
- Reduced plt sensitivity to agonist, reduced TBXB2 density
- Degranulated platelet in circulation

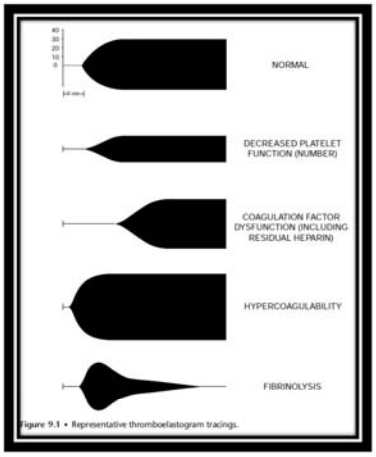


Figure 9.1 • Representative thromboelastogram tracings.

Neutrophils

- Central role in inflammatory response associated with CPB
- Activation by C5a, C5b-9, kallikrein, XIIa, interleukin….
- Produce inflammatory substances
- Activated neutrophil accumulate in lungs
  - increased capillary permeability, and interstitial edema
- Neutrophil elastase inhibitor

Nonbiomaterial-Related Activation during CPB

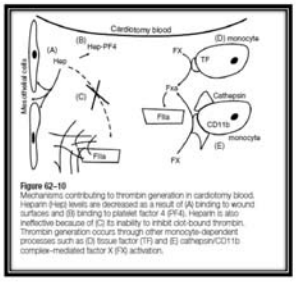


Figure 62–10
Mechanisms contributing to thrombin generation in cardiotomy blood. Heparin (Hep) levels are decreased as a result of (A) binding to wound surfaces and (B) binding to platelet factor 4 (PF4). Heparin is also ineffective because of (C) its inability to inhibit clot-bound thrombin. Thrombin generation occurs through other monocyte-dependent processes such as (D) tissue factor (TF) and (E) cathepsin/CD11b complex–mediated factor X (FX) activation.

- Exposure of cardiotomy blood well to wound surfaces is probably the most important source of thrombin generation during CPB
- Cardiotomy blood contributes to fibrinolysis induction and this may enhance systemic fibrinolysis after cardiotomy blood re-administration

Contents

Heparin: Pharmacology, Dosage, and Complications

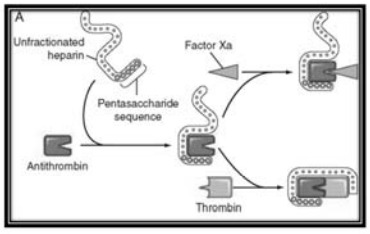
- Native heparin polymer, 3 kDa to 30 kDa
- Commercial heparin 12 kDa to 15 kDa
- Block end step of coagulation
  → File up variable substances.
  → activate other systems..
- Increase platelet sensitivity
  → increase bleeding time
- Activation of neutrophil

- 동물의 비만세포가 합성하는 글리코사미노글리칸의 일종. 황산기, 카르복시기의 대부분이 음전하를 갖는 고분자전해질이다. 원래 간에 존재하는 혈액응고저지물질로서 얻어지며, 의약품으로서 장점막 등으로부터 단백질을 함유하지 않는 제품이 공업적으로 생산된다. 비만세포에서는 거대분자의 전구체 프로테오헤파린으로서, 즉 다른 글리코사미노글리칸과 같이 단백질과 결합한 프로테오글리칸(세리글리신)의 형으로 합성된다

[네이버 지식백과] 헤파린 [heparin] (생명과학대사전, 초판 2008., 개정판 2014., 도서출판 여초)

Mechanism of Action

- Bind to AT III -> 4000-fold
- Half-life: 23 minutes-2.5H(1H)



- During CPB, heparin is generally used in 300 U/kg, with an aim to achieve and maintain a target ACT of 400 to 480 seconds
- UFH may contribute to platelet dysfunction directly or through its ability to bind to vWF

- Heparin resistance : low Antithrombin III patient
  → FFP (antithrombin supply)
  Premature, cyanotic infants, advanced liver or renal disease, cachexic patients, woman taking estrogen, recent heparin infusion patient
- Heparin-protamine complex: potent complement activator
- PF4: bind heparin and inactivate heparin

HIT

- IgG-mediated immune thrombocytopenia referred to as heparin-induced thrombocytopenia and thrombosis (HITT)
- The syndrome is secondary to platelet activation from an IgG that binds the FcγII receptor
- HITT usually begins 5 to 15 days after the commencing of heparin therapy
- The incidence is lower with bovine heparin

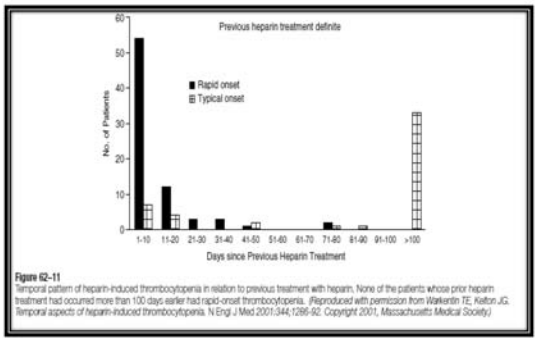


Figure 62–11
Temporal pattern of heparin-induced thrombocytopenia in relation to previous treatment with heparin. None of the patients whose prior heparin treatment had occurred more than 100 days earlier had rapid-onset thrombocytopenia. *(Reproduced with permission from Warkentin TE, Kelton JG. Temporal aspects of heparin-induced thrombocytopenia. N Engl J Med 2001;344:1286-92. Copyright 2001, Massachusetts Medical Society.)*

Protamine

- Polycationic protein derived from salmon sperm
- + charged protamine, - charged heparin complex
  → Inactivate heparin
  → Potent complement activator
  → 1 mg per 100 units of heparin
- Anaphylactic reaction
- Rarely severe pulmonary vasoconstriction and reduces LV loading → bypass restart

Protamine

- Onset
  - Rapid, neutralization occurs within 5 min
- Duration
  - 2 hr, dependent on body temperature

- The most common problem related to protamine
  - Heparin rebound
  - Hypotension
  - Anaphylactoid reactions
  - Catastrophic pulmonary vasoconstriction
  - Direct antiplatelet effect

Protamine anaphylaxis

- Especially in patients with
  - allergies to fish
  - previous exposure to protamine (through previous use of protamine or protamine-containing insulin)
  - infertile or vasectomized males

Causes of a prolonged ACT

- Heparin
- Hypothermia
- Hypofibrinogenemia
- Other clotting factor deficiencies
- Hemodilution
- Thrombocytopenia
- Qualitative platelet abnormalities

- The rationale for heparinizing to an ACT of between 400 and 480 seconds during CPB is based on early work that demonstrated that at this level of ACTs, no gross evidence of thrombosis occurred in the reservoir
- In particular, there is clear evidence that the ACT does not reflect the heparin level accurately, particularly after a long duration of CPB, and that other factors, such as hypothermia, hemodilution, and drugs, may contribute

PHARMACOLOGIC ADJUNCTS TO MINIMIZE THE CONSEQUENCES OF CPB

- Steroids (methylpPD 30mg/kg) decrease
  - Complement activation
  - Upregulation of glycoprotein CD 11b
  - Release of histamine, TNF, IL-6, IL-8, neutrophil elastase
- 기도의 NO 농도를 감소시켜 기관지 상피세포의 iNOS 발현을 억제
- Stabilizing effects of steroids on hemodynamics after CPB
- 고혈당을 조장하고 술 후 창상 감염을 비롯한 감염의 위험도를 높일 수 있음

Contents

Biomaterial-Dependent Strategies

- 유사 생체막(biomembrane mimicry)
- 헤파린 도포(heparin-coated circuits)
- 단백질 흡착(modified protein adsorption)

Biomembrane Mimicry

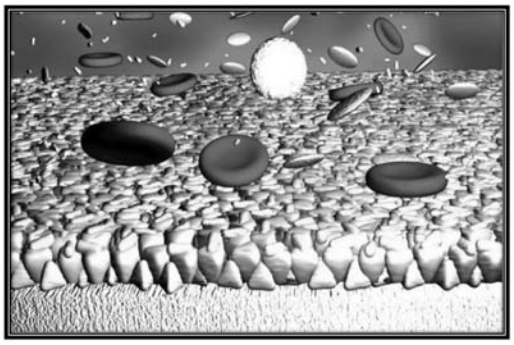
- Coated with a derivative of phosphorylcholine which is the major lipid headgroup component found on the outer surface of biologic cell membranes
- Inhibiting fibrinogen adsorption and platelet deposition

Heparin-Coated Circuits

- 염증 반응과 헤파린의 사용량을 줄이기 위한 가장 보편적인 방법이다
- Two type of heparin-coated circuits
  - 이온 결합을 이용하여 헤파린을 표면으로 부터 slowly release 시키는 방법
  - 공유결합을 이용하여 헤파린을 접촉면에 permanent immobilization하는 방법
- 헤파린의 투여량을 줄여 수술 후 출혈량과 혈액제재의 사용량을 모두 줄일 수 있다는 긍정적인 보고가 있음
- 동일량의 헤파린을 투여시 헤파린 도포 회로는 기존의 회로에 비해 큰 잇점이 없는 것으로 나타났다

BIOLINE Coating

- Improves the biocompatibility of extracorporeal circulation system devices by mimicking human tissue
- Combines albumin and heparin
- Albumin is adsorbed on the extrinsic surface and is linked to the heparin molecules
- Stable attachment of the heparin molecules is achieved by the formation of covalent bonds and ionic interactions between the heparin molecule and the immobilized albumin



http://www.maquet.com/int/products/bioline-coating/

Surfaces with Modified Protein Adsorption

- 표면변형첨가제(surface modifying additive, SMA)를 이용한 기술
- SMA를 첨가하여 넣고 만든 중합체(polymer) 생체 소재는 표면에 혈액이 접촉하게 되면 fibrinogen의 고른 흡착을 유발하여 생체적합성 표면을 생성하게 된다
- 이 단백질 흡착을 이용한 표면의 변형 기술은 아직 임상자료가 부족하나 차세대 생체소재 기술로 각광받고 있다

Contents

Neuroendocrine Response to CPB

- Growth hormone ↑
- Vasopressin ↑↑
- Thyroid hormone dysfunction
- Renin, angiotensin II and aldosterone ↑

CNS Injury with CPB

- Three major types of neurologic injury
  - Stroke
  - Delirium
  - Cognitive decline

  (postoperative cognitive deficit, POCD)

Stroke

- 가장 인지 및 진단이 쉬운 형태
- Incidence
  - 3% after CABG / 8% after isolate valve surgery
  - 11% after CABG combined with other surgery
- 여자, 고령일수록 증가
- 원인 : 주로 대동맥에서 유래하는 색전

Delirium

- Up to 3% of pts
- Confusion과 disorientation : 의식의 변화를 보임
- Risk factor
  - Increase age
  - Hypertension
  - History of previous CABG
  - Pulmonary disease
  - Alcohol abuse

Cognitive decline (postoperative cognitive deficit, POCD)

- 정의 : 기억과 집중력 및 psychomotor speed or dexterity
- 간과하고 넘어가는 수가 많으나 생각보다 발생률이 높음
- POCD after CABG
  - From 35% to 75% early postopeatively
  - 11% to 40% after more than 6 months
- 인지력의 저하가 회복되어도 훗날에 치매 등이 발생할 가능성이 높아짐

- There is strong experimental evidence cardiotomy suction blood may be the most important source of lipid emboli

Pulmonary Dysfunction with CPB

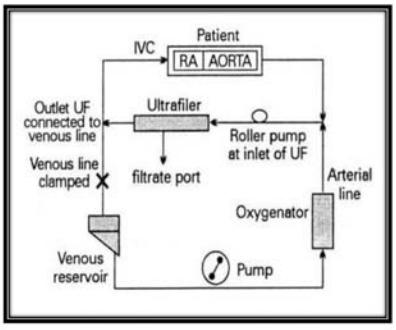
- ARDS
- Older adults, the obese, and patients with low cardiac output or pulmonary hypertension, and after long CPB
- Leukocyte depletion may limit pulmonary reperfusion injury after CPB and result in improved lung function
- Heparin-coated circuits have been shown to improve lung compliance and pulmonary vascular resistance

Renal Dysfunction with CPB

- Incidence
  - 개심술 후 7.7%의 환자에서 신장 기능 이상
  - 1.4%에서 투석이 필요
- Contribution of CPB to renal damage
  - Increased postop. Serum Cr and urea
  - GFR and urinary microalbumin-to-creatinine ratio : worse
  - Off-pump group에 의해 좋지 않은 결과를 보임

변형초여과법 (modified ultrafiltration)

- 전통적 초여과법(conventional ultrafiltration) : 수술 중에만 적용할 수 있는 여과법
  - 체외순환 중에만 실시하기 때문에 다량의 충전액이 필요하고, 이로 인한 수혈이나 다른 수액의 보충이 필요하며, 많은 양을 효과적으로 여과하기 힘들다는 단점이 있다
- 변형초여과법 (modified ultrafiltration) : 수술이 끝난 후에 환자의 체내혈액만을 10-20 분 정도 여과해 주는 방법이다



변형초여과법의 장점

1) 혈역학적 변화 : 혈압상승, 심박출지수의 상승
(체내 수분량 감소 → 심근과 폐의 부종 감소 → 심근기능 향상)
2) 염증반응의 매개체들을 제거 : TNF-α, IL-2, IL-6, IL-8, leukocyte elastase 의 제거
3) Hct치의 증가 : 혈액점도 상승 → 말초혈관의 체저항 증가 → 혈압상승
4) 폐혈관저항 감소 : 폐수분의 감소와 가온산화혈이 폐혈관에 주입되면서 폐혈관저항이 감소되어 폐동맥압이 떨어진다.
5) bypass rewarming 기간에 사용하였던 vasodilator 나 anesthetic 등을 체외순환직후 제거 할 수 있다

References

- Sabiston and Spencer, Surgery of the chest, 8TH Edition Chapter 62
- 김용진, 심장외과학
  Chapter 2 체외순환 by 백완기

Thank You

CHUNGBUK NATIONAL UNIVERSITY HOSPITAL

CPB in Minimally Invasive Cardiac Surgery

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제 형 곤

서 론

최근 대동맥판막과 승모판막 그리고 삼첨판막에 대한 최소 침습수술은 술 후 출혈량이 적고, 호흡기 합병증과 심방세동의 발생이 드물며, 수술 후 통증이 적고 회복이 빨라 정중흉골절개술을 이용한 고식적인 심장수술의 접근방법을 점차 대치하고 있다. 이러한 최소침습 심장판막수술의 여러 장점들로 인해 동료 의사 및 환자들의 요구가 증가하고 있으며, 이러한 술기를 더욱 용이하게 하는 새로운 캐뉼라, 심폐기 회로 및 발전된 심폐기 가동 기술에 대한 연구 및 보고가 끊이지 않고 있다. 이번 강의에서는 부산대학교 양산병원에서 550예 이상의 최소침습 심장수술을 시행하면서 국내 실정에 맞추어 단순화한 수술, 마취 및 심폐기 가동 원칙의 변화를 살펴보고 본원에서 시행되고 있는 최소침습 심장수술에서의 환자선택, 마취방법, 동-정맥 삽관의 방법, 캐뉼라의 선택, 심근보호법 및 심폐기 가동 원칙에 대해서 문헌고찰과 함께 살펴 보았다.

본 론

1. 환자의 선택

최근의 여러 연구에서는 최소침습 심장수술은 심장판막 질환 및 일부 선천성 심질환의 수술 시 정중흉골절개를 이용한 수술법과 동등한 수술 결과를 보여주고 있다. 따라서 최소침습 심장수술의 적응증은 심장수술의 복잡성 보다는, 심장 및 대혈관의 해부학적 구조에 따라 결정된다. 최소침습 수술을 위해서 필수적인 말초삽관을 위해 수술 전 환자 혈관의 해부학적 구조 및 이상소견을 확인해야 하며, 이를 위해 가장 적절한 검사는 CT angiography 이다. 이를 통해 수술이 요하는 심장 병변의 3차원적인 영상을 통해 수술의 계획을 수립하고 동반된 심-폐 질환을 확인하는데 유용하다. 수술 전 CT angiography를 시행함으로써 얻는 정보는 아래와 같다.

가) 우측 흉강의 흉막유착을 예측, 동반 절제 가능한 종양 확인
나) 동맥내 동맥경화성 변변 확인; 대동맥, 장골동맥, 대퇴동맥
다) 정맥이상 확인: 하대정맥, 상대정맥
라) 동반심장질환; 관상동맥 질환, 폐색전증

2. 마취과와의 협조

제한적인 시야에서 진행되는 최소침습 심장수술의 특성상 마취과 의사와의 협조는 매우 중요하다. 따라서 수술 과정 전반에 완벽한 정보공유가 요하며, 최소침습 심장수술을 시행함에 있어서 마취과 의사의 협조가 요하는 부분은 아래와 같다.

가) 경피적 상대정맥 삽관: 우측 내경정맥
나) TEE 수행:

① 대퇴 동정맥 삽관시 철선 및 캐뉼라 위치 확인
② 전향적 심정지액 투여시 대동맥 역류 확인
③ 심장 수술 결과 확인: 판막 성형술, 좌심실 기능 확인, 심장내 잔존공기
④ Endoclamp (Intracluder), ProPlege, EndoVent (Edwards Lifesciences; Irvine, CA)

다) 폐 환기 조절; double lumen tube vs. single lumen tube
라) 조기 발관 노력 (Fast tract protocol), 술 후 통증관리

3. 동맥관 삽관

A. 동맥관 삽관의 위치 결정

최소침습 심장수술시 동맥관 삽관의 위치는 절개방법 및 대동맥내 병변의 유무에 따라서 결정된다. 상부 혹은 하부 부분 흉골절개술을 시행하는 경우 상행대동맥에 삽관하는 경우가 가장 흔하며, 우측 혹은 좌측 개흉술을 통해 수술을 진행하는 경우 대퇴동맥이 가장 흔한 삽관 위치가 된다. 최근 몇몇 보고에서는 대퇴동맥을 이용한 최소침습 수술 시 수술 후 신경학적 합병증의 빈도가 더 흔하다는 보고가 있으나, 다른 문헌에서는 수술 전 CT를 이용하여 동맥내부의 죽상경화성 병변을 면밀하게 검사하며, Endoballon을 이용하지 않은 경우에는 신경학적인 합병증의 빈도가 증가하지 않는다고 보고하였다. 저자는 최소침습 심장수술을 계획하는 모든 환자에서 CT angiography를 수술 전 기본검사로 시행하고 있다. 수술 전 CT angiography 검사에서 대퇴동맥을 이용한 삽관이 불가능할 것으로 판단되는 경우에는 우 쇄골하동맥이나 액와동맥을 이용하여 삽관이 가능하다.

B. 캐뉼라의 선택

대동맥내 풍선차단을 시도하는 경우라면 환자의 우측 대퇴동맥을 통해 EndoReturn (Edwards Lifesciences; Irvine, CA) 캐뉼라를 삽입 후 IntraClude Intra-Aortic Occlusion Device (Edwards Lifesciences; Irvine, CA) 를 이용하여 전신 관류, 대동맥 차단 및 심근보호에 이용이 가능하다. 하지만 2015년 5월 현재 국내에서 허가 승인을 획득한 대동맥내 풍선차단용 카테터 및 캐뉼라는 전무한 실정이며, 국내에서 사용가능 한 대퇴동맥용 캐뉼라는 2015년 5월 현재 아래의 3종류 이다.

가) Fem-Flex II (Edwards Lifesciences, Irvine, CA)
나) Bio-Medicus (Medtronic, Minneapolis, MN)
다) DLP (Medtronic, Minneapolis, MN)

가장 흔하게 쓰이는 것은 나) 이며, 다) 캐뉼라의 경우 17Fr에서 혈류에 따른 압력값이 낮다는 장점을 가지고 있다. 개별 캐뉼라의 장단점에 대해서는 강의 슬라이드를 통해 설명한다.

C. 대퇴 동정맥을 이용한 삽관 술기

경피적 대퇴 동정맥 삽관도 가능하나, 대퇴동맥의 경우 수술 후 노출하여 삽관부위를 교정해야 하며 삽관과 관련된 합병증이 증가할 수 있으므로, 보다 안전한 삽관을 위해 부분 개방성 방법을 이용하고 있다. 우측 서혜부에 피부주름을 따라 2-3 cm 정도의 사선절개를 가하여 우측 대퇴동정맥을 노출한다. 대퇴동정맥의 박리시에는 피하조직까지 사선절개 후 지방층부터는 종절개 하여 주변의 임파관의 손상을 최소화 하고, 대퇴동정맥 근처의 박리를 위해서는 전기 소작기의 사용을 최소화 하여 인접하여 주행하는 신경의 손상이 발생하지 않도록 주의 하여야 한다. 대퇴동정맥은 삽관을 위해 혈관의 전면부만 노출시키고, 노출된 혈관에 5-0 prolene으로 1회 쌈지봉합을 시행한다. 심폐기 가동을 위해 300U/Kg 용량의 헤파린을 정주한 후 안내철선을 따라 경식도 초음파의 가이드 하에 Seldinger technique으로 대퇴동정맥의 삽관을 시행한다. 경식도 초음파를 이용하여 우심방내의 정맥 캐뉼라의 위치를 확인하고 동맥관을 통한 혈류 공급시 도관을 통한 압력을 관찰하면서 심폐기를 가동한다.

4. 정맥관 삽관

A. 삽관정맥관의 수 및 삽관 위치

대정맥의 해부학적 구조 및 수술의 종류에 따라 정맥 삽관의 위치 및 수를 결정한다. 술 전 시행한 CT angiography를 이용하여 대정맥 및 삽관을 계획한 정맥의 해부학적 구조를 확인한다. 대퇴정맥이나 내경정맥의 협착 혹은 선천성 하대정맥의 단절 등의 이상소견이 발견될 경우 정맥삽관의 위치를 조정한다. 우심방의 개방이 요하지 않는 승모판막, 대동맥 판막 수술의 경우 환자의 체중이 80Kg 이하인 경우라면 대부분 단일 대퇴정맥을 이용한 삽관으로 수술의 진행이 가능하다. 대퇴정맥을 통한 배액을 위해 사용되는 캐뉼라 중 국내에서 사용 가능한 것은 다음의 3 종류이다. Fem-Flex II (Edwards Lifesciences, Irvine, CA), DLP and Bio-Medicus (Medtronic, Minneapolis, MN)

우심방의 개방이 요하는 삼첨판막 수술과 심방중격 결손증의 수술등에서는 상대정맥의 배액을 위해 추가적인 삽관이 요하는데, 이러한 경우 저자는 경피적 우측 내경정맥을 이용한 삽관 보다는 수술 시야에서 직접 상대정맥에 삽관하는 것을 선호한다.

B. 우측 내경정맥을 이용한 삽관

마취과 의사에 의해 기도 삽관 및 전신마취를 시작한 후 우측 내 경정맥을 이용하여 경피적(Seldinger technique)으로 정맥관을 삽관한다. 환자의 체표면적에 따라 14Fr에서 17Fr 사이의 동맥용 캐뉼라를 사용한다. 삽관 방법은 일반적은 중심정맥 삽관 방법과 동일하나, 캐뉼라의 크기가 굵어 삽관과 관련된 혈관손상의 발생시 그 위험도가 크다. 따라서 경피적 삽관시 항상 혈관 초음파로 확인하며 혈관을 천자 하고, Guide-wire가 정맥내에 위치함을 다시 한번 확인한다. 삽입된 캐뉼라의 끝이 상대정맥-우심방의 경계 부위에 위치할 수 있도록 경식도 초음파로 확인하면서 조절한다. 삽관된 정맥관의 혈전생성을 예방하기 위해 삽관 직전에 20U/Kg용량의 헤파린은 정주하고, 삽관 후에 캐뉼라를 통해 30 U/Kg 용량의 헤파린은 1시간 동안 투여한다. 우측 내 경정맥을 통해 삽관된 캐뉼라는 수술 시야의 밖에 존재하므로, 마취과의가 캐뉼라의 고정 위치 및 꺽임 등을 면밀히 살펴야 한다. 삽관을 위해 사용되는 캐뉼라의 종류는 대퇴동맥을 통해 삽입되는 동맥 캐뉼라와 같고, 15 혹은 17Fr 를 주로 사용한다.

C. 상대정맥 직접 삽관

수술 전 단일 대퇴정맥 삽관 후 수술을 진행하였으나, 정맥혈 배액이 원활하지 않은 경우나, 우심방 절개가 요하는 수술에서 우측 내경정맥 삽관을 대신하여 수술 시야에서 상대정맥에 직접 삽관을 시행할 수 있다. 삽관에 사용되는 정맥 캐뉼라는 14~16Fr의 작은 크기의 캐뉼라이면 충분하고, 수술 창이나, 독립적인 포트를 통해 체외로 배액 한다. 최근 많은 보고에서 최소 침습심장수술을 시행 후 수술장에서 인공 호흡관을 발관하는 경우가 많은데, 상대정맥을 통한 직접 삽관 하는 경우 우측 내경정맥 부위의 지혈을 위한 압박이 불필요하여 수술장내 인공호흡기 발관을 용이하게 한다.

5. 심근보호법

A. 대동맥 겸자

우측 개흉술을 이용한 최소 침습적 개심술의 경우 Chitwood clamp를 이용한 경흉부 대동맥 겸자를 이용하여 차단한다. 경흉부 대동맥 겸자는 3번 늑간의 후방 액와선상으로 삽입하며, 겸자의 한쪽 날은 상행대동맥의 전면이 위치하고 나머지 한쪽 날을 transverse sinus로 진입하여 폐동맥 및 좌심방이의 손상에 유의하면서 상행대동맥을 겸자한다. 최근 다양한 모양의 대동맥 겸자가 개발되어 사용이 가능하므로, 각각의 술자의 선호도에 맞는 겸자를 이용하는 것이 바람직하다.

B. 심정지액의 주입 방향

국내에서는 최소침습 심장수술 중 역행성 심정지액의 주입을 위해 개발된 ProPlege sinus catheter (Edwards Lifesciences, Irvine, CA)의 이용이 불가능한 실정이다. 따라서 우측개흉술 및 제한적 흉골절개술을 통한 최소침습 심장수술시 대동맥 근부에

캐뉼라를 직접 삽입하고 전향적 심정지액을 주입하는 것이 유일한 심정지액 투여 방법이다.

C. 심근 보호액의 선택:

최소침습 심장 수술 시 심근 보호액의 선택은 수술자의 선호에 따라 결정된다. 최소 침습 심장수술을 일반적으로 수술 중 대동맥 차단시간이 길고, 수술 중 추가적인 심근 보호액의 투여가 곤란한 경우가 많아 Custodiol 심정지액이 가장 널리 사용되고 있다. 하지만 Custodiol 심정지액의 경우 다량의(2L) 세포 내액성 수액이 비교적 빠른 속도로 주입됨에 따라 혈액희석, 응고장애, 전해질 불균형 등의 부작용을 초래한다. 이에 저자들은 Custodiol 심 정지액을 투입하는 경우 관상정맥동으로 배출되는 심 정지액을 흡입하여 제거하고 있다. 또한 저자들은 대동맥 겸자 시간이 50분이내로 예상되는 비교적 간단한 수술의 경우 저제온 법(29° C)과 동반하여 혈성 심 정지액을 사용하고 심방중격 결손증의 교정수술의 경우 심근 보호액의 투여 없이 중등도의 저 체온 하에서 심실세동을 유발하여 수술을 시행한다. 이전에 심장수수을 받은 과거력이 있는 환자에서 최소침습 삼첨판막에 재수술을 시행하는 경우 박리를 최소화 하기 위하여 말초 삽관으로 심폐기를 가동 후 정상 체온을 유지하면서 심 박동하에서 판막수술을 시행한다. 이러한 최소침습 삼첨판막 재수술의 장점은 아래와 같다. 첫째, 박리를 최소화 하여 수술이 간단하다. 둘째, 심비대가 심한 환자의 경우 정중흉골의 재진입시 발생가능한 심장손상을 피할 수 있다. 셋째, 수술 중 심방전도 차단의 발생을 즉시 알 수 있으므로 수술 중 이러한 합병증을 피할 수 있다. 넷째, 심정지를 유도하지 않아 수술 후 가장 어려운 합병증인 우심실 기능부전을 최소화 할 수 있다.

6. 심폐기 가동 원칙

A. 음압 보조 정맥환류법

최소침습적 심장수술에 사용되는 정맥관들은 고식적인 개심술시 사용되는 캐뉼라에 비해 작은 내경을 가지고 있다. 따라서 다양한 방법으로 정맥환류를 최대화 하기 위해 노력한다.

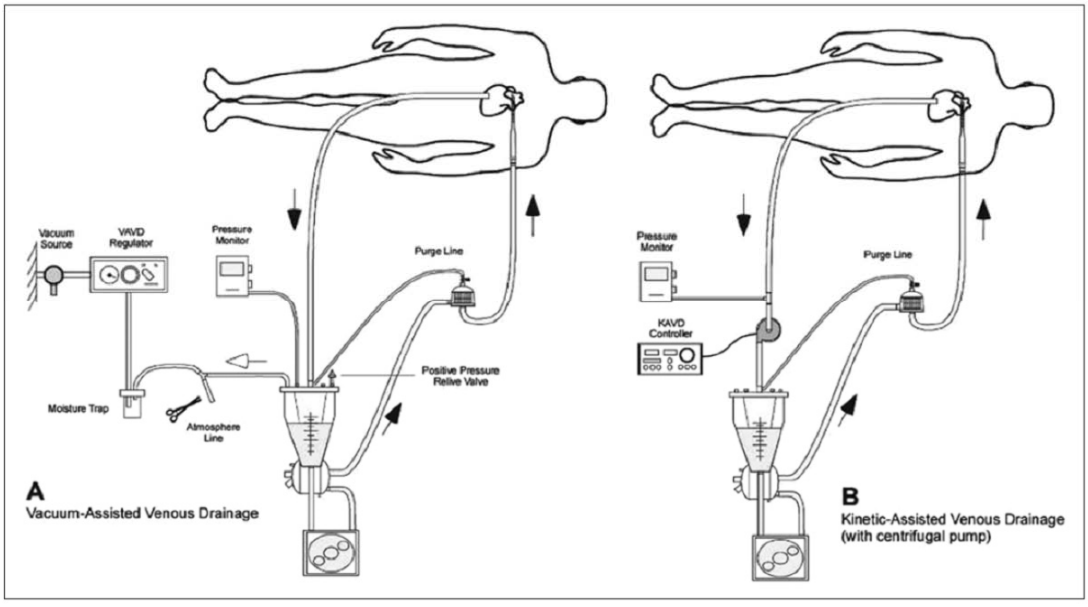

Fig 1. Schematic of vacuum assisted-venous drainage (VAVD) and centrifugal-assisted venous drainage (CAVD).

이를 위해 가장 흔하게 사용되는 방법은 음압 보조 정맥환류법(Fig. 1A)이며, 외국의 일부 병원에서는 원심성펌프 보조 정맥환류법(Fig. 1B)을 사용한다. 국내에서는 비용적인 측면과 연질재질의 정맥 저혈소(soft reservoir)의 사용이 불가능한 관계로 원심성펌프

보조 정맥환류법을 사용하는 기관이 없다. 음압 보조 정맥환류법은 공인된 음압 조절기를 이용하여 적절한 음압을 저혈소에 형성하여 정맥환류를 증대시키는 방법으로, 정수압에 추가하여 20-60 mmHg 정도의 음압 보조를 통해 정맥환류를 극대화 한다(Fig. 1A). 이는 15년 이상의 임상경험이 보고된 비교적 안전한 방법이지만, 몇몇 주의점이 있는데, 저혈조 및 정맥도관에 100 mmHg 이상의 음압이 걸리게 되면 혈구 손상으로 용혈을 유발하며, 심한 경우 정맥 저혈조의 균열을 유발할 수도 있다. 따라서 최소한의 음압을 적용하는 것이 권장된다. 또한 심폐기 가동 초기에 적절하게 음압이 적용되지 않은 상태에서 pump sucker 와 vent를 가동하면, nonvented-reservoir 내부에 갑작스런 양압이 발생하여, 정맥도관을 통한 air-lock이 발생할 수 있다. 이를 예방하기 위해서 5 mmHg를 초과하는 양압이나 -150 mmHg 이하의 음압이 발생시 작동하는 감압밸브가 설치 되어있는 저혈조를 사용하여야 한다. 음압보조 정맥환류법에서 주의할 점은 아래와 같다.

가) 공인된 음압 조절기를 이용한다.
나) 정수압과 합한 음압의 최대가 −100 mm Hg을 초과하지 않게 조절한다.
다) 적절한 정맥배액이 가능한 최소한의 음압을 적용한다.
라) 저혈조에 음압 및 양압 알람을 모니터 한다.
마) 심폐기 가동 직후 정맥도관 내에 air-lock의 발생에 주의한다.

B. 이산화 탄소

우측 개흉술을 이용한 최소침습 심장수술 시 수술의 후반부에 대동맥 근부 캐뉼라를 이용하여 심장 내부의 잔존 공기를 제거함에 어려움을 겪을 수 있다. 이는 대동맥 근부의 캐뉼라를 최적의 위치에 삽입하기 어렵고, 잔존공기의 배출을 위한 심장 마사지를 적용 하기 어렵기 때문이다. 이에 산소 및 질소에 비해 혈액에 용해도가 높은 이산화 탄소를 수술 중 지속적으로 수술 부위에 분사함으로써 공기 색전증의 빈도를 줄일 수 있다. 이산화 탄소 분사를 위해서는 특별한 장치가 추가적으로 필요하지 않으며, 원해 사용하는 포트의 side port를 이용하거나, 정맥 주사용 18 게이지 카테터를 이용한다.

C. 저 체온 법

저자들은 최소침습 심장수술 중 일상적으로 중등도의 저 체온증을 유도하고 있다. 이는 심근보호에 유리하고, 주요 수술 술기를 시행하는 도중 심폐기의 혈류를 낮게 유지하여 수술 시야의 확보에 도움을 준다. 비교적 긴 심폐기 가동시간이 요하는 수술에서 저체온의 유도 및 정상체온으로의 회복은 혈액응고 기전에 장애를 초래할 수 있으므로 수술 진행 중 심폐기사와 밀접한 대화를 통해 심폐기 가동시간을 최소화 하기 위한 체온 조절 전략이 필요하다.

D. 수혈 최소화를 위한 노력

최소침습 심장수술시 절개를 최소화함으로써 실혈량을 줄이는 점은 수혈을 최소화하는데 도움이 되지만, 비교적 긴 심폐기 가동시간은 오히려 수혈의 요구량을 증가시킨다. 최근 여러 문헌을 살펴보면 낮은 수혈 빈도는 최소침습 심장수술의 장점 중 하나로 꼽히고 있다. 이를 위해 저자들이 시도하고 있는 처치로는 다음과 같다.

가) Priming 용액을 줄여 혈액희석을 최소화
  A. 환자의 체표면적에 적합한 산화기의 선택
  B. 심폐기의 위치를 대퇴동정맥 근처로 이동하여 동정맥 튜브의 길이를 최소화
  C. 3/8 inch 정맥 튜브 사용
  D. Retrograde autologous priming
나) Autologus blood donation:
  A. Intraoperative: 동정맥 캐뉼라 삽관 후 시행
  B. Preoperative: 수술 3주전부터 1주 간격으로 시행 최대 2-3 unit의 전혈

수술 전 환자의 혈액검사를 바탕으로 Priming 후 예상되는 Hct이 25%를 초과할 경우, 적절한 자가 헌혈의 양을 계산하고 삽관된 동맥 캐뉼라 이용하여 자가 헌혈을 시행한다. 자가 헌혈된 혈액은 심폐기 가동을 완료하고 헤파린을 중화하는 시기에 환자에게 재 주입한다. 최근에는 대동맥 협착증과 불안정성 협심증을 제외한 정규 심장수술이 예정되어 있는 환자에서 수술 2-3주 전부터 자가헌혈을 적극적으로 시행하여, 동종 수혈을 최소화하기 위해 노력하고 있다.

다) 수술 중 혈액여과 필터의 사용:

최소침습 심장수술시 이용되는 Custodiol solution 심정지액, 판막 검사와 메이즈 술식시 냉동절제를 위해 사용된 카테터를 녹이기 위해 사용되는 생리식염수가 정맥혈 저혈조로 배액됨에 따라 일시적인 혈압강하와 혈액희석이 발생할 수 있다. 이를 극복하기 위하여 심폐기 가동을 시작함과 동시에 지속적으로 혈액투과를 실시한다.

맺음말

최근 최소침습 심장수술을 보다 활발하게 적용할 수 있게 만든 가장 큰 변화는 수술 기법의 변화나 수술 로봇의 발전이 아니라 말초 삽관을 비롯한 다양한 심폐기 가동방법의 변화라고 생각한다. 흉골을 절개하지 않고도 심폐기의 가동 및 안정적인 심근보호가 가능해진 체외순환 방법의 발전은 최소침습 심장수술의 결과를 예측 및 재현이 가능하게 만들고 있다. 본 강의에서 다룬 최소침습 심장수술의 체외순환법은 다양한 임상상황에서 적용이 가능하며, 새로운 대동맥 판막 치환술(Rapid deployment AVR) 등의 최근 빠르게 발전하는 심장수술의 여러 영역에서 유용하게 적용하고 있다. 최근 진일보한 다양한 장비의 국내 도입과, 이를 이용한 보다 안전하고 효율적인 심폐기 가동이 가까운 미래에 가능하리라 기대해 본다.

Pediatric Cardiopulmonary Bypass

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김 형 태

Introduction

- Pediatric patients are not small adult patients, and require different management strategies from the adult
  - Smaller blood volume
  - Higher oxygen consumption
  - Compensatory shunting
  - Significant levels of hemodilution
  - Reduced clotting factors and plasma proteins
  - Wider fluctuation of perfusion flow rates and temperatures per procedure

Introduction

- The aorta is cannulated with a wire-wound, thin walled cannula

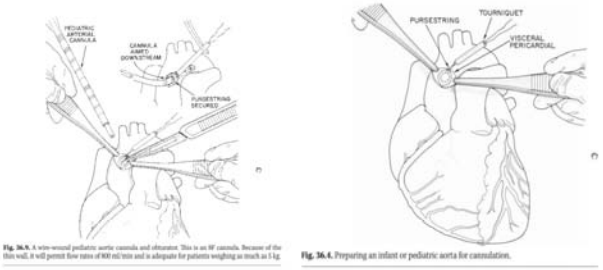
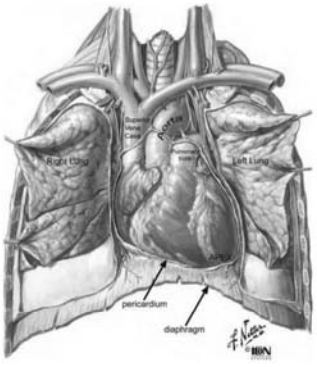


Fig. 36.4. Preparing an infant or pediatric aorta for cannulation.

Introduction

- Aortic cannula has not entered the innominate artery and that the tip lies on the **inner curve of the aortic arch** just distal to the pericardial reflection
- Secured to the draps to avoid undue tension



Introduction

- Often a right-angled cannula with a metal or plastic tip is inserted directly into the SVC, rather than into the right atrium, when using two venous cannulae

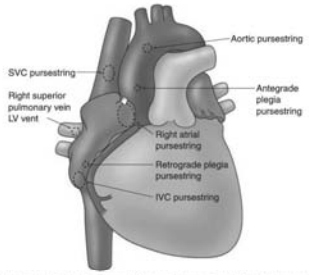


Fig. 36.1. Sites on the heart and great vessels for cannulation sutures. IVC, inferior vena cava; LV, left ventricle; SVC, superior vena cava.

Left ventricular venting technique

- If an LV vent is needed, it is inserted before commencing CPB (anesthesiologist performing a Valsalva maneuver to elevate the LA pressure)
- An incision is made in the purse-string suture at the junction of the RUPV and LA
- Some surgeons prefer to insert the LA vent while on CPB (perfusionist filling the heart by occluding the venous line, translocating blood volume from the bypass circuit to elevate LA pressure)

Cardiopulmonary bypass circuit

- The foremost principle of CPB management
  - To minimize the patient's metabolic adaptation to a non physiologic state, a state of "controlled shock" and nonpulsatile perfusion

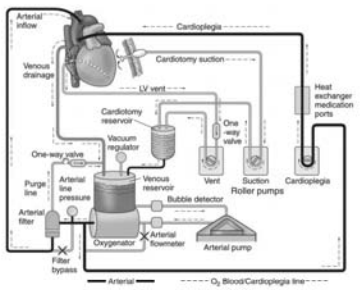


Fig. 36.10. Example of a complete cardiopulmonary bypass circuit. LV, left ventricle; P, pressure transducer.

Cardiopulmonary bypass circuit

- The circuit design and the selection of the arterial and venous cannula are based on the calculated blood flow rates necessary to provide adequate hemodynamic support and gas exchange

Table 36.2 Two Methods for Calculating "Full" Blood Flow Rates

Age (y)	1. Blood flow rate (BFR; L/min/m²) from body surface area (BSA; m²)	Body weight (kg)	2. Blood flow rate (ml/min/kg) from body weight (in kg)
0–2	BSA × 2.6	0–5	150
2–4	BSA × 2.5	6–10	125
4–6	BSA × 2.4	11–15	100
6–9	BSA × 2.3	16–25	90
>9	BSA × 2.2	>25	70

Cardiopulmonary bypass circuit

- The cannulae are described by either French size or in millimeters, which reflects only the **external dimensions**, without regard to the internal diameter or performance characteristics (ratio of internal diameter to external diameter (ID/ OD) need to be considered)

Table 36.3 Required Inside Tubing Diameter for Different Patient Weights

Patient weight (kg)	Arterial line (in.)	Venous line (in.)	Vacuum-assisted venous line (in.)
<8	1/4	1/4	1/4
>8–17	1/4	3/8	3/8
17–50	3/8	3/8	3/8
>50	3/8	1/2	3/8

Cardiopulmonary bypass circuit

- A pressure gradient not exceeding 100 mmHg at "full flows" is recommended for an arterial cannula
- The performance characteristics of venous cannula are more vital than those of the arterial cannula since blood flow through the extracorporeal circuit is dependent upon the venous return

Cardiopulmonary bypass circuit

- Passive venous return
  - More traditional method
  - Dependent upon gravity
  - The level of the heart above the venous reservoir (40 to 70 cm)
  - Large-bore tubing

Cardiopulmonary bypass circuit

- "Assisted" venous return
  - Achieved with the aid of vacuum being applied to the venous line or reservoir
- Advantages
  - Smaller-diameter venous lines and cannulae
  - Smaller incisions
  - Lowering the extracorporeal circuit priming volume
- Disadvantages
  - An increase in gaseous microemboli if the vacuum is too great
  - the reservoir volume is too low to allow proper dissociation of gaseous microemboli from the blood
  - An increase of hemolysis if the vacuum rate is too great

Cardiopulmonary bypass circuit

- "Assisted" venous return
  - Limit the amount of vacuum to less than -60 mmHg
  - Prefer to maintain a venous reservoir volume sufficient enough to provide a 10-second reaction time

Cardiopulmonary bypass circuit

- Venous drainage
  - Reduced if the side ports of an oversized venous cannula are obstructed by an overstretched cava
  - Or if the internal diameter of the venous line and/or cannula is too small to accommodate the expected venous return
- Results
  - Overdistension of the right heart
  - Flooding of the operative field
- A pressure gradient of less than 30 mmHg at the rated blood flow
- Not allow an excessive negative pressure to develop (the ideal venous pressure should range between 0 to 5 mmHg)

Cardiopulmonary bypass circuit

- If the expected priming volume would cause an "unacceptable" anemia, occasionally packed red blood cells may be added to the extracorporeal circuit before commencing CPB

Table 36.4 Patient Blood Volume

Age	Blood volume (ml/kg)
Premature	100
Newborns	90
1–12 mo	80–85
1–10 y	75–80
Adult	70–75

Table 36.5 Priming Volume per Length of Tubing of Given Diameter

Tubing diameter (in.)	Priming volume (ml/ft)
3/16	5.00
1/4	9.65
3/8	21.71
1/2	38.61

Table 36.6

$$\text{Hemodilutional hematocrit (hct) (\%)} = \frac{\text{Patient blood volume} \times \text{wk (kg)} \times \text{hct (\%)}}{(\text{Patient blood volume} \times \text{wt [kg]}) + \text{priming volume (ml)}}$$

Cardiopulmonary bypass circuit

- Hemodilution
  - Advantageous effect for perfusion
    - Decreasing fluid viscosity -> augmenting blood flow
  - Side effect
    - The reduction of oncotic pressure -> tissue edema
  - When albumin or mannitol is added to the extracorporeal circuit to obtain an oncotic pressure of 16 mmHg, extracellular fluid accumulation is reduced

Cardiopulmonary bypass circuit

- Hemodilution
  - Diminishing blood's viscosity and resistance to flow
  - Promotes increased microcirculatory flow and tissue perfusion
- Hypothermia
  - Direct vasoconstriction
  - Increases viscosity, creating sludging and stasis at the capillary level, resulting in reduced blood flow

Cardiopulmonary bypass circuit

- Is there an "acceptable" degree of hemodilution?
  - A general rule of thumb is that the hematocrit in percent should not exceed the desired level of hypothermia in degrees Celsius
- Utilizing low-prime and mini-extracorporeal bypass circuits

Instituting cardiopulmonary bypass and decompressing the left heart

- Visual inspection of the op. field, monitors, and bypass lines as the perfusionist initiates CPB will provide an immediate assessment of effectiveness of the conversion to artificial cardiopulmonary support

Instituting cardiopulmonary bypass and decompressing the left heart

- Sudden spike in the extracorporeal line pressure
  - An occluded arterial line
  - A malpositioned aortic cannula
  - An aortic dissection
- CPB should be terminated immediately and the cause identified and corrected

Instituting cardiopulmonary bypass and decompressing the left heart

- right heart should be decompressed and central venous pressure should be <5 mmHg
- A high central venous pressure and poor venous drainage at the initiation of CPB
  - A malpositioned venous cannula
  - A kinked venous line
  - An "air lock"
  - Venous cannulae that are too large or small
  - An inappropriate height between the operating table and the venous reservoir
  - An inappropriate amount of vacuum, or vacuum leak

Instituting cardiopulmonary bypass and decompressing the left heart

- LV distension
  - Aortic valvular insufficiency
  - Excessive bronchial venous return or collateral vessels
  - Incomplete drainage of the systemic venous return
- An acute, transient state of systemic arterial hypotension, resulting from hemodilution and vasoactive substance release -> not necessary to treat with alpha agonists (the mean arterial pressure will generally increase with the initiation of systemic cooling and increased levels of endogenous catecholines and angiotensin

Instituting cardiopulmonary bypass and decompressing the left heart

- In children and infants with congenital heart disease, the right heart should not be opened until the aorta is cross-clamped or ventricular fibrillation has occurred

Table 36.2 Two Methods for Calculating "Full" Blood Flow Rates

Age (y)	1. Blood flow rate (BFR; L/min/m²) from body surface area (BSA; m²)	Body weight (kg)	2. Blood flow rate (ml/min/kg) from body weight (in kg)
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4–6	BSA × 2.4	11–15	100
6–9	BSA × 2.3	16–25	90
>9	BSA × 2.2	>25	70

Instituting cardiopulmonary bypass and decompressing the left heart

- Decompression of the LV is best achieved in infants and small children by tightening the vena cava tapes, opening the right atrium, and passing a small suction line through the patent foramen ovale into the LV

Instituting cardiopulmonary bypass and decompressing the left heart

- **Cooling the patient**
  - Hypothermic CPB
  - The reduced metabolic rate and oxygen consumption
  - Approximately 5% to 7% per degree Celsius that the body temperature is lowered

Table 36.7 Definition of Levels of Hypothermia and Approximate "Safe" Circulatory Arrest Times

Hypothermia level	Patient temperature (°C)	Circulatory arrest times (min)
Mild	37–32	5–10
Moderate	32–28	10–15
Deep	28–18	15–60
Profound	>18	60–90

Instituting cardiopulmonary bypass and decompressing the left heart

- **Cooling the patient**
  - Induced by surface cooling using cooling blankets and ice packs applied directly to the patient
  - By core cooling with cold perfusate from the extracorporeal circuit
  - Tissues and organs have varying blood flows -> systemic cooling is not a uniform process
    - Maintain high perfusion flow rates of 2.2 to 2.5 L/min/m2
    - Limit the rate of the cooling to <1 degree Celsius/minute until the desired temperature is reached
  - Perfusion flow rates are adjusted to maintain "normal" mixed venous blood gases

Instituting cardiopulmonary bypass and decompressing the left heart

- **Rewarming**
  - During rewarming, the warming blanket is set to 40 degrees Celsius
  - The perfusion flow rates are increased to 2.5 to 3.0 L/min/m2
  - Pressure permitting, pharmacologic vasodilation is used
  - the bladder temperature reaches 32 degrees Celsius, the patient begins to vasodilate spontaneously and the pharmacologic vasodilator may be terminated

Instituting cardiopulmonary bypass and decompressing the left heart

- **Removal of air from the heart**
  - The patient is placed in a 30-degree head-down position
  - The caval tourniquets are loosened
  - The perfusionist restricts venous return to the pump
  - The right heart begins to fill
  - The anesthesiologist ventilates the lungs
  - The heart is gently massaged while the vent in the LV continues to drain

Instituting cardiopulmonary bypass and decompressing the left heart

- **Removal of air from the heart**
  - The antegrade cardioplegic cannula is placed on suction
  - More blood is massaged through the left heart
  - Some air is removed via the antegrade cardioplegic cannula
  - Pump flow is reduced to one-half of calculated flow
  - Arterial pressure is reduced to 50 mmHg
  - The aortic cross-clamp is removed while suction is maintained on the antegrade cardioplegic cannula

Instituting cardiopulmonary bypass and decompressing the left heart

- **Removal of air from the heart**
  - Transesophageal echocardiography is used to determine if there is residual air whithin the heart
  - If there is, the operating table is rocked side to side
  - The left atrial appendage is inverted
  - Gentle massage of the heart
  - The sternum and sternal retractor can be shaken
  - Venous return is restricted intermittently to allow the heart to eject
  - Suction on the intracardiac vent is discontinued
  - Suction is maintained on the aortic cardioplegia/vent cannula as the heart continues to eject
  - Confirm the left heart is free of air by TEE

Discontinuing cardiopulmonary bypass

- Termination of CPB is performed gradually, with **constant communication between surgeon, perfusionist, and anesthesiologist**
- Always check to be sure the **LUNGS are being VENTILATED** before weaning the patient from CPB
- The ventilation, blood gases, cardiac output, and blood pressure are watched carefully over the next 5 to 10 minutes to ensure stable hemodynamic function of the heart, and good oxygenation by the lungs

Reversal of heparin

- All pump suckers are turned off, and administering protamine
- A **"protamine reaction"** with vasodilatation and profound hypotension may ensue

Removal of the arterial cannula

Sternal closure

References

- Mastery of Cardiothoracic Surgery, Larry R. Kaiser, et al., Third edition

ECMO Support in Adult Cardiac Patients

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김 근 직

ECMO Support in Respiratory Patients

제주한라병원 흉부외과

이 길 수

ECMO Support in Pediatric Patients

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장 우 성

ECMO Case in Different Clinical Settings

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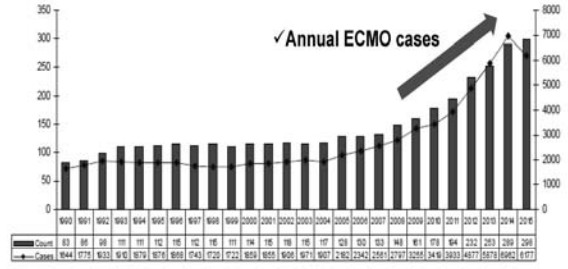
김 관 식

2016 January ELSO Report

Centers by Year



3 Issues of ECMO Management

1. ECMO initiation
2. ECMO maintenance
3. ECMO weaning

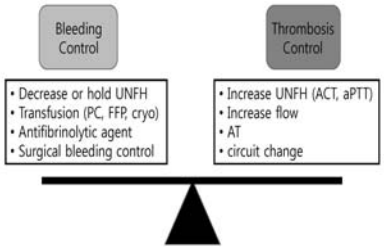
ECMO initiation

- Indication/Guideline
- ECMO modes/Cannular strategies

ECMO maintenance

- Anticoagulation
- Infection/Sepsis control
- Cerebral monitoring
- ECMO related complications

Anticoagulation



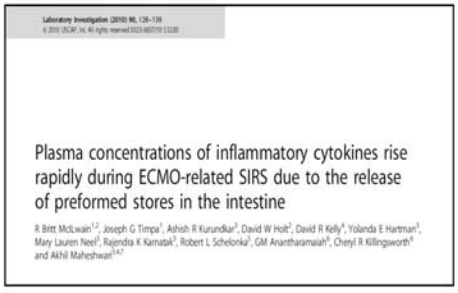
Infection/Sepsis Control

Infection and Sepsis

- Infections in patients receiving ECMO are common
- sites of infection (most commonly bloodstream, lower respiratory tract, urinary tract, and wound)
- causative microorganisms (typically gram-negative bacilli and staphylococci)
- similar to other intensive care unit patients.

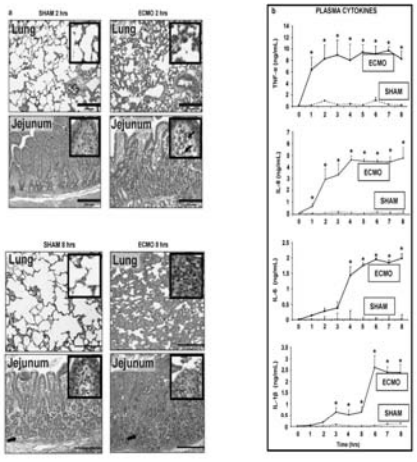
- Signs of sepsis: ambiguous in patients on EMCO
- fever may be absent
  - because of the servo control of body temperature by the heat exchanger.
- even subtle signs of infection warrant an aggressive search for a septic cause.
  - (ex, deteriorating hemodynamics or leukocytosis)
- Broad spectrum empiric antimicrobial therapy
  - (ex. carbapenem, vancomycin)

Effects of CRRT on inflammatory cytokines during ECMO


Laboratory Investigation (2010) 90, 128–139

Plasma concentrations of inflammatory cytokines rise rapidly during ECMO-related SIRS due to the release of preformed stores in the intestine

R Britt McLwain[1,2], Joseph G Timpa[1], Ashish R Kurundkar[2], David W Holt[2], David R Kelly[4], Yolanda E Hartman[3], Mary Lauren Neel[3], Rajendra K Karnatak[3], Robert L Schelonka[3], GM Anantharamaiah[5], Cheryl R Killingsworth[6] and Akhil Maheshwari[3,4,7]



CRRT on ECMO: Potential Benefits

- Management of fluid balance
- Control of electrolyte abnormalities
- Removal of inflammatory mediators
- Enhanced nutritional support

Cerebral Monitoring

aEEG monitoring

It is well known that the aEEG provides the useful information for neonatal encephalopathy.

PEDIATRICS

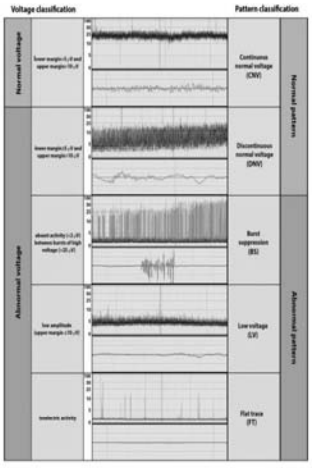
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Assessment of Neonatal Encephalopathy by Amplitude-integrated Electroencephalography

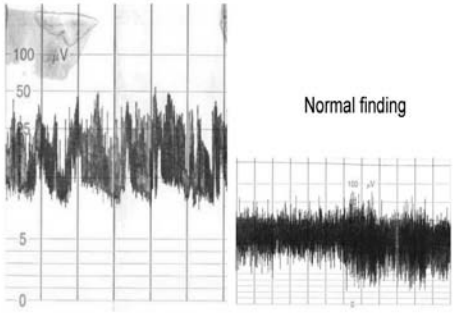
H. Eken Ebrahim, Frances M. Cowan and Denis Azzopardi

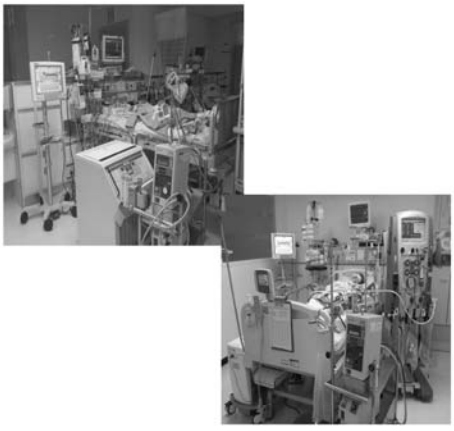
Pediatrics 1999;103;1263

Conclusion. The aEEG is a simple but accurate and reproducible clinical tool that could be useful in the assessment of infants with encephalopathy. *Pediatrics* 1999;103:1263–1271; *cerebral function monitor, neonatal encephalopathy, outcome.*



Seizure in aEEG





ECMO related Complications

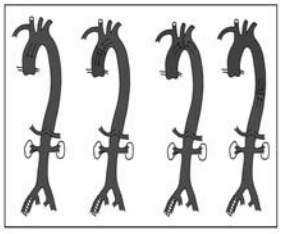
- Two circulaltion/competition
- Recirculation
- Lower body ischemia

Two circulaltion

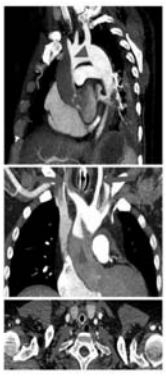
Upper body hypoxemia in VA ECMO

Differential cyanosis, 2-Pump circulation

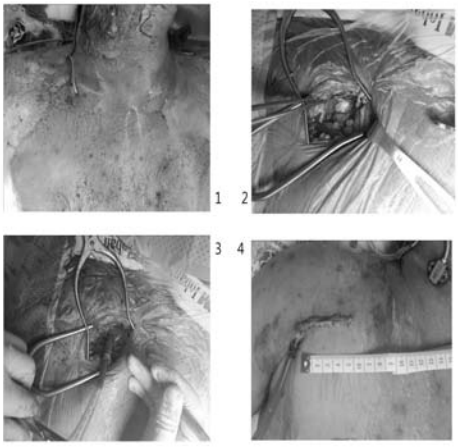
- ↑ SaO2 in upper body / ↓ SaO2 in lower body
- marginal myocardial function and respiratory failure in VA



Watershed Phenomenon



Potential solutions
- increasing ECMO flows to reduce LV ejection
- changing to VV / VAV ECMO (IJV)
- central cannulation (axillary artery)



Recirculation

hypoxemia with VV ECMO (SaO2 85%)
- inadequate ECMO flow (m.c.)
- other cause despite adequate circuit flows
  - significant recirculation
    - a low SaO2 and high SDO2 (typically 75%),
  - inadequate sedation, sepsis, iatrogenic overheating, overfeeding and seizures.
    - increased oxygen consumption and pathologically increased CO
    - a low SaO2 low SDO2.

high SvO2 or SdO2 (>80%)
- recirculation in VV

Lower body ischemia

pph. VA ECMO

- early sign: cool, pale
- in progress: color change
- late phase:
  - compartment syndrome
  - rhabdomyolysis

action

- smaller bore cannula
- additional cannulation for distal perfusion
  - if, possible. US guided puncture
  - retrograde perfusion through DPA (micropuncture needle)
- axillary artery cannulation

ECMO weaning

- Recovery of underlying disease
  - Optimal demand of inotropics and vasoconstrictors
  - lung protective ventilator setting
  - Maintenance of U/O
  - CXR, Echo
  - Lab: ABGA, EtCO2, lactate....
- Gradual decrease of ECMO flow and increase of native cardiopulmonary function.
- Continuation of anticoagulation during weaning period and after decannulation