



인체 3D 조직모델 기반 환경성 폐질환 독성예측 플랫폼 개발

가천대 길병원 호흡기알레르기내과
손은숙
2026.03.21

Contents



연구개발의 필요성



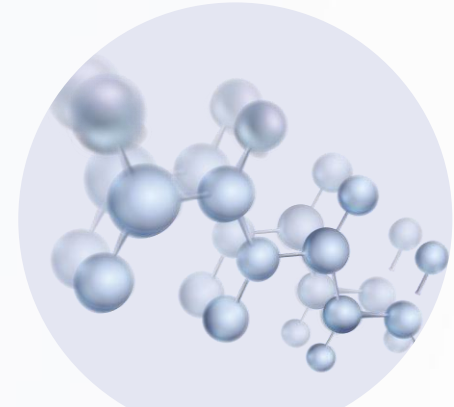
연구개발의 내용 및 결과



호흡기 노출을 위한 장비개발 및 구축



추후 연구 추진 방향



1. 연구개발의 필요성



대기오염에 의한 영향



환경성 폐질환에 대한 연구 부족



인체 3D 조직 모델의 필요성

실내·외 주요 오염물질

실내

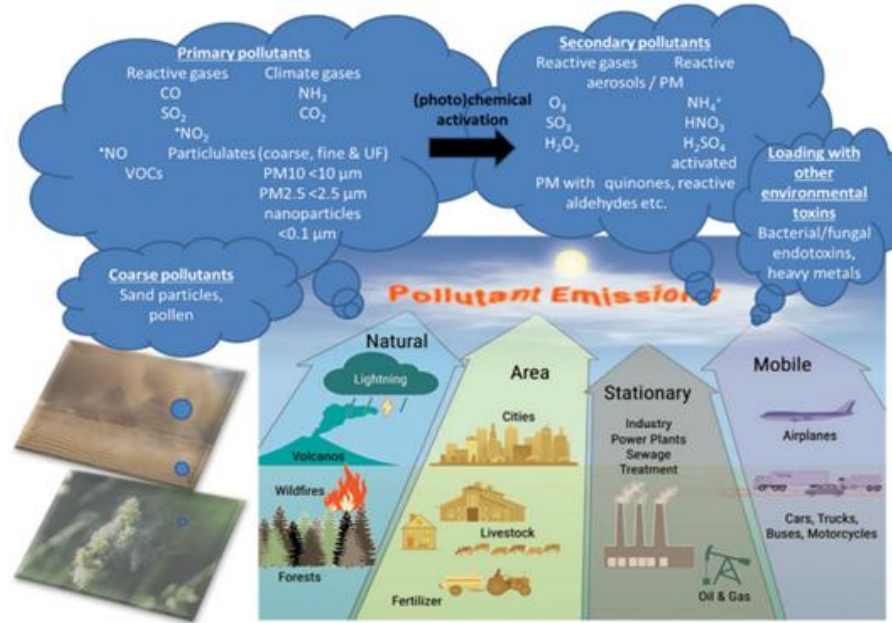
라돈
포름알데히드
이산화탄소
곰팡이·세균

실내·외

미세먼지
(PM10·PM2.5)
VOCs(벤젠·스티렌 등)
이산화질소

실외

이산화황
중금속
오존



환경유해인자?

- 가스상 물질 및 입자상 물질로 나뉨
- 산업화로 주변 환경유해인자의 증가로 위해성이 높아지고 있음
- 흡입·섭취·피부노출 등으로 흡수 또는 축적됨으로써 **환경성질환 유발**



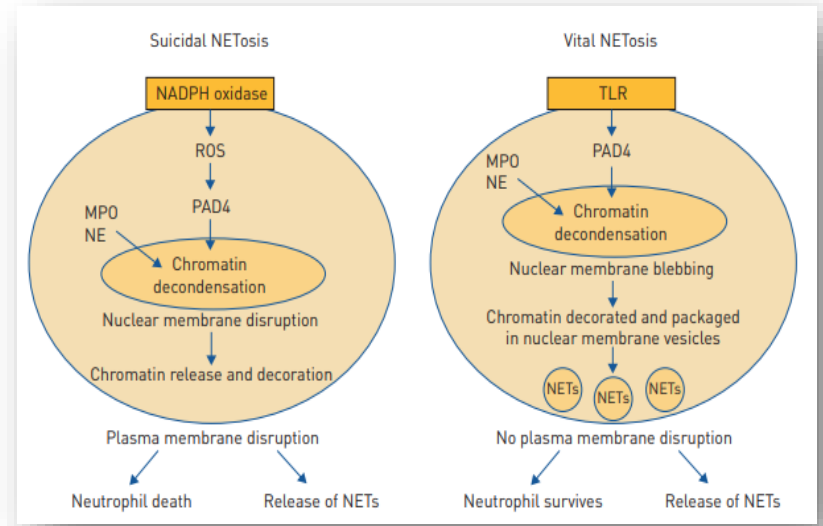
환경성 폐질환?

- 환경유해인자에 관련되어 발생하는 **호흡기질환**
- 천식, 만성폐쇄성폐질환, 폐섬유화증 그리고 폐암 등이 속함
- 환경유해인자에 의한 호흡기 질환의 악화로 연구가 집중 되어 있음

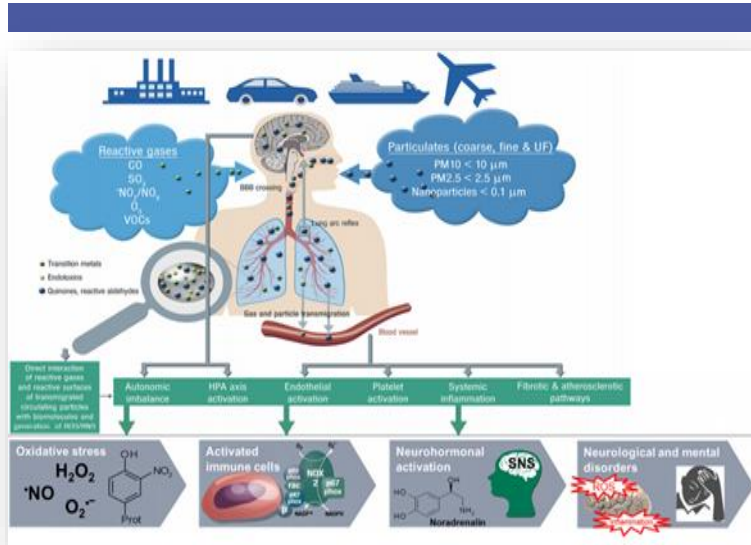


환경유해인자에 의한 환경성 폐질환 연구의 한계

- 천식, 알레르기와 같은 특정 호흡기질환을 대상, 주로 **역학조사 연구가 대부분**
- 6개의 환경성질환 중 **가습기살균제 및 석면**과 같은 특정 물질 노출에 대한 연구에 국한
- 환경유해인자의 **위해성에 대한** 통합적인 영향 **평가의 미흡**
- 환경성 폐질환과 연계된 환경유해인자 노출 특이적 **바이오마커 연구의 미비**



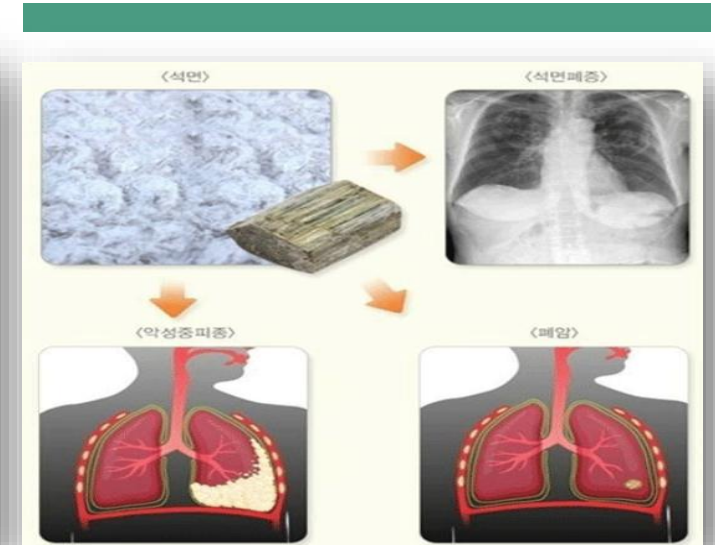
Traffic air pollution과 관련된 NET (ERJ. 2020)



대기오염에 의해 증가된 산화스트레스와 염증 (Int. J. Mol. Sci. 2020)



가습기살균제에 의한 폐질환

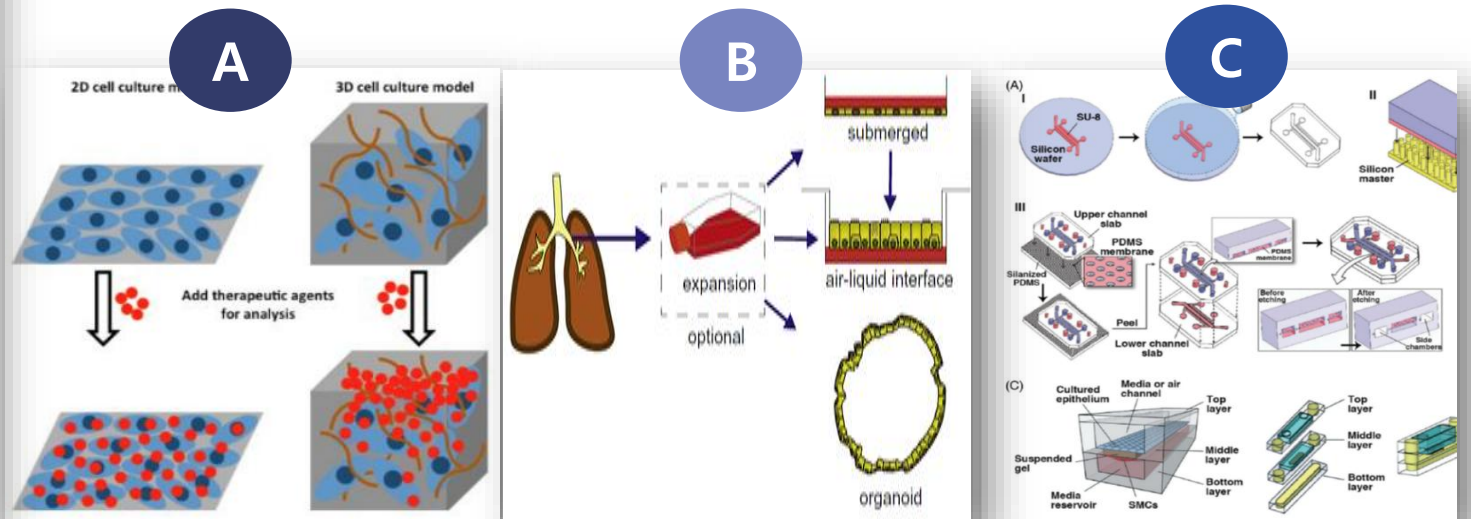
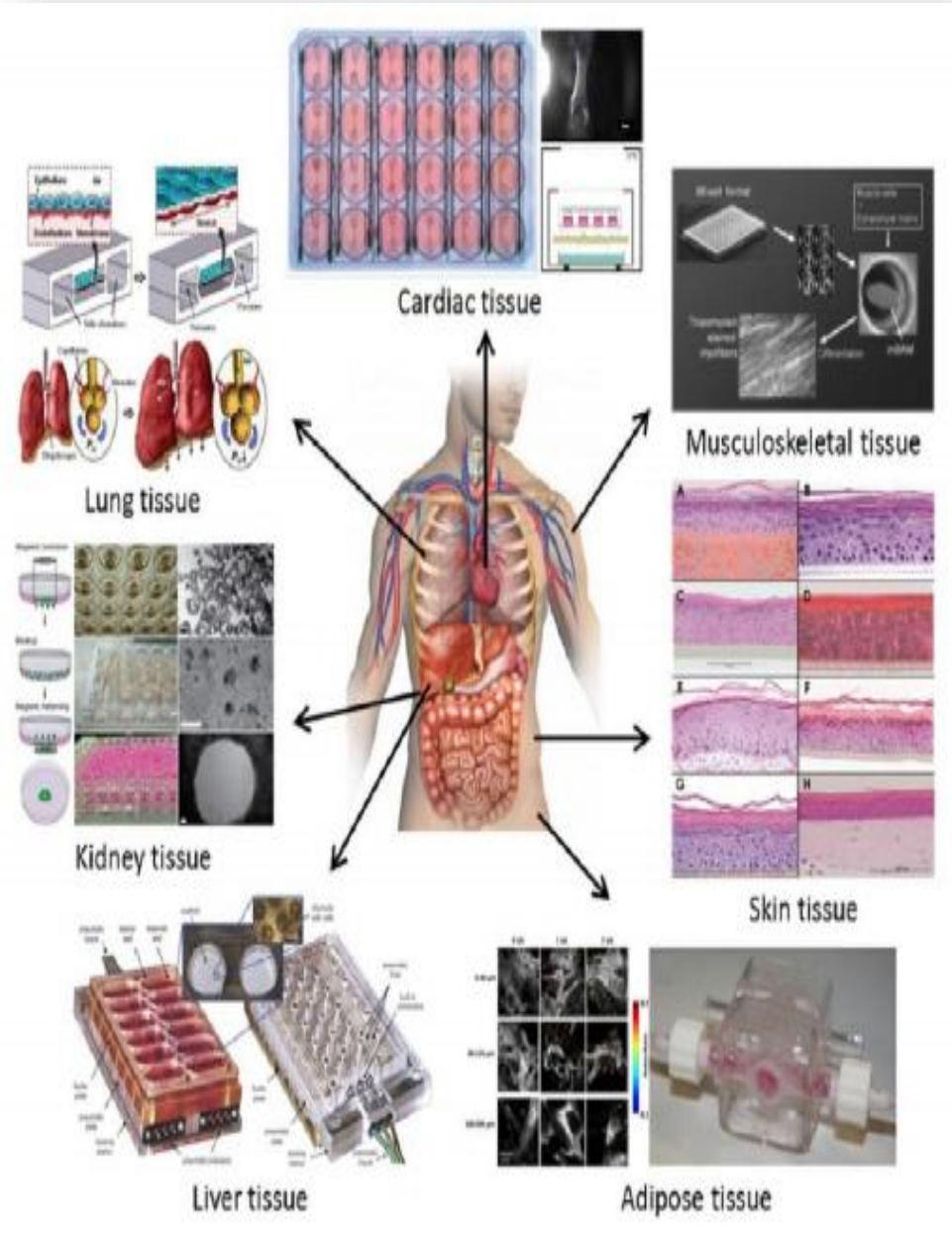


석면 흡입에 의해 폐질환

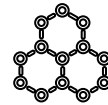


인체 3D 조직 모델의 필요성...

- A** - 기존 환경유해인자에 대한 세포모델은 대부분 2차원 배양
 - 세포간 상호작용, 세포-기질 상호작용, 물질의 흡수, 대사 등 한계점이 있음
- B** - 폐의 경우, - 폐포세포, 섬유아세포, 혈관내피세포 등 다양한 종류의 세포로 구성
 - 들숨 날숨에 따라 지속적으로 폐포가 수축/팽창을 반복한다는 특성
 - **Air liquid interface (ALI) 환경**
 - 오가노이드로 폐포를 모사할 경우 → **ALI 환경, 수축/팽창 등을 모사할 수 없음**
- C** - 위의 단점을 보완하기 위해 **인체 3D 조직을 이용한 장기칩을 활용** 하고자 함
 - 독성평가 뿐만 아니라 효능 연구를 위해 상피조직, 간, 심장, 폐, 신장 조직 등이 개발 중



2. 호흡기 노출을 위한 장비 개발 및 구축

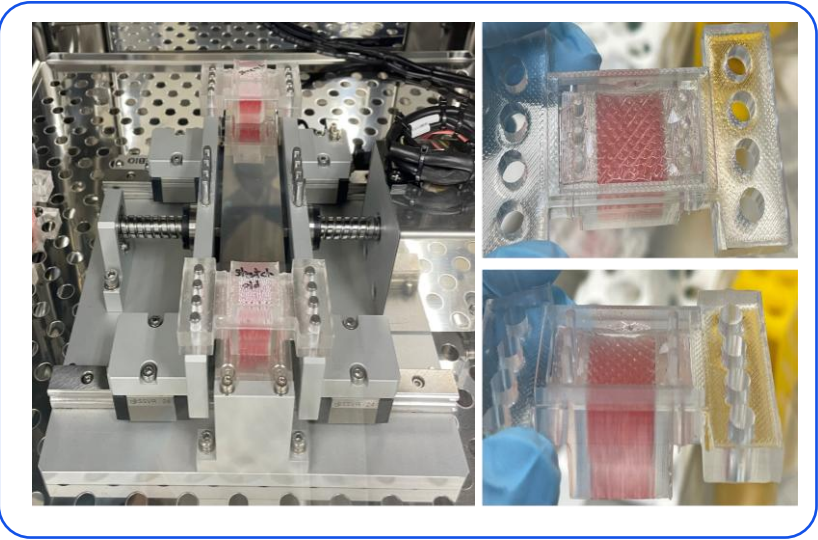
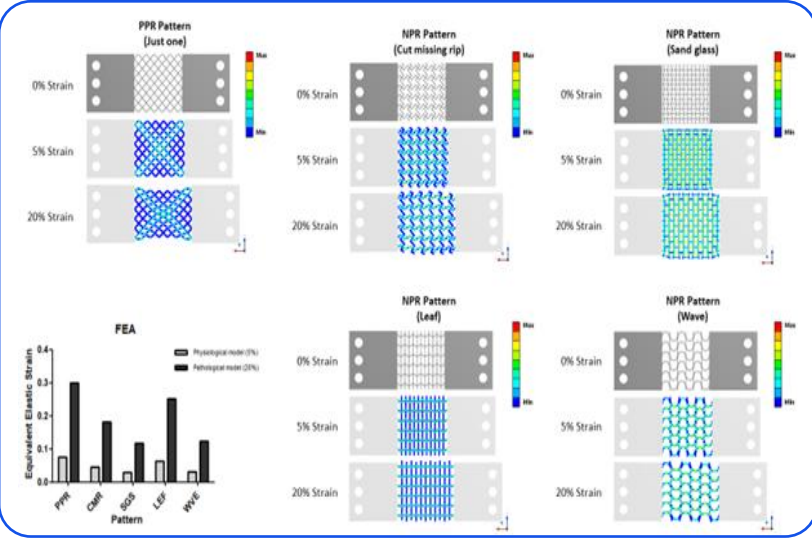
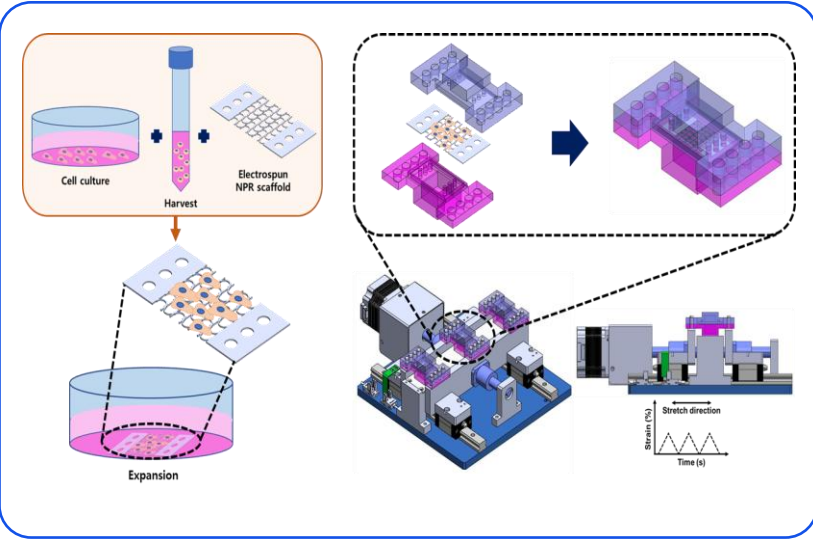


호흡기 독성평가를 위한 인체 3D 폐조직 모델 확립



폐모사칩 호흡기 독성평가를 위한 in vitro 챔버

호흡기 독성 평가를 위한 인체 3D 폐 섬유화 Lung-on-chip 모델 확립



폐섬유화 lung on a chip 모델

- ✓ 호흡하는 동안 strain이 증가하여 microinjury가 폐포에 지속적으로 발생하여 폐섬유화가 증가한다고 알려져 있음
- ✓ 정상 폐조직의 strain은 5%정도이나, 폐섬유화가 발생한 폐조직에 가해지는 strain은 20% 이상임

수축과 이완 가능한 세포배양막 제작

- ✓ 세포배양이 가능하고 수축 이완이 가능한 구조체 패턴 제작
- ✓ Positive Poisson's ratio (PPR), negative Poisson's ratio (NPR) 패턴을 제작하여 수축과 이완 모사

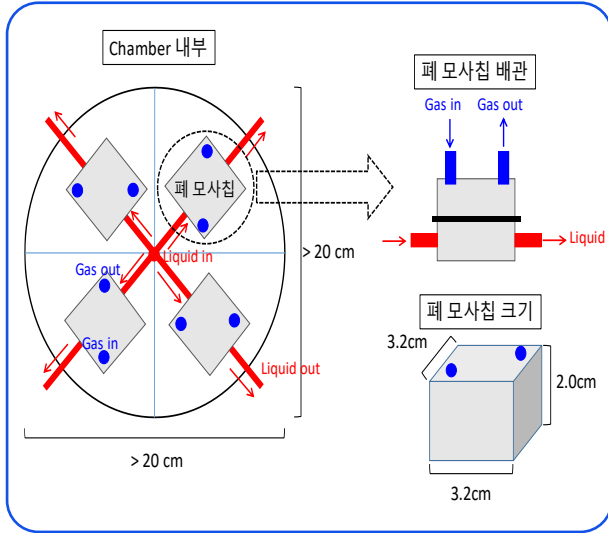
수축과 이완이 가능한 장비 및 chip

- ✓ 정상 및 microinjury 유발 strain을 조절가능 함
- ✓ 기존 장비들과 달리 양방향으로 수축과 이완을 가능하게 하여 인체와 비슷하게 모사함

 폐 모사칩 호흡기 독성 평가를 위한 lung-on-chip용 in vitro 챔버 ①



폐 모사칩 호흡기 독성 평가를 위한 lung-on-chip용 챔버 ①



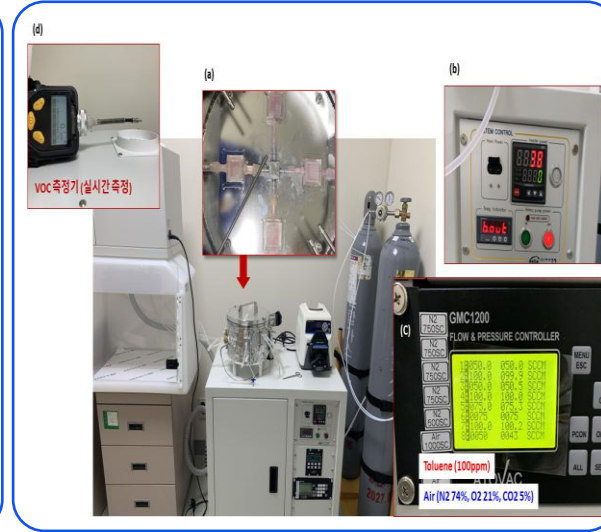
Lung on chip 노출용 장비 설계

- ✓ 자체 lung-on-chip 규격에 맞추어 평가 시스템 설계
- ✓ 2종의 가스 또는 농도별로 조절할 수 있도록 MFC (mass flow controller) 장착
- ✓ 각 라인의 유량 파악을 위해 flow meter 가 장착



Lung on chip 노출용 장비 제작

- ✓ 노출 시 유입된 가스가 나오기 때문에 안전상 흡후드를 장착
- ✓ Air (N2 74%, O2 21%, CO2 5%) 공기를 base로 하여 가스상 물질을 섞어 농도를 조절



Lung on chip 가스 노출 장비 확립

- ✓ 세포모델에 맞는 온도가 유지될 수 있도록 온도센서로 조절
- ✓ 가스유량은 SCCM (Standard Cubic Centimeter per Minute) 단위로 조절
- ✓ 가스상 물질이 외부로 유출되는지 여부를 VOC 측정기로 모니터링

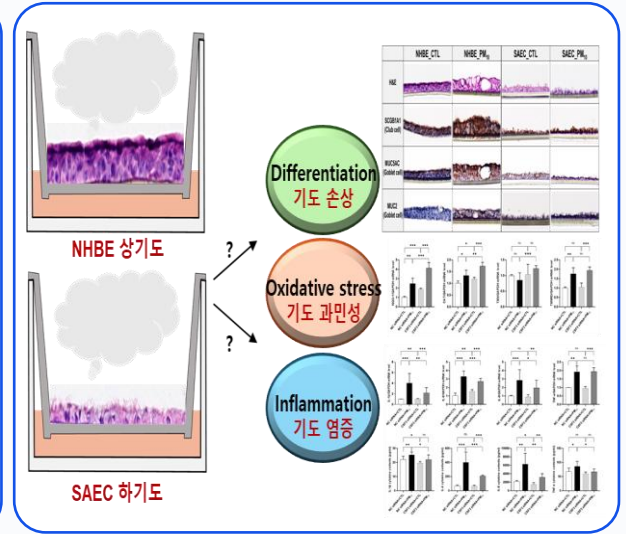
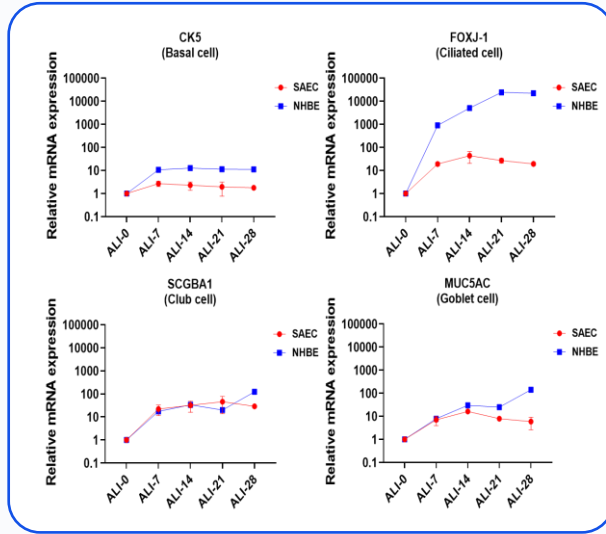
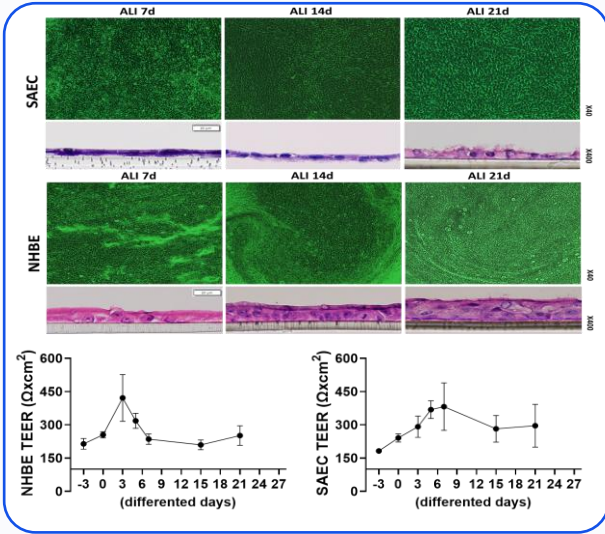
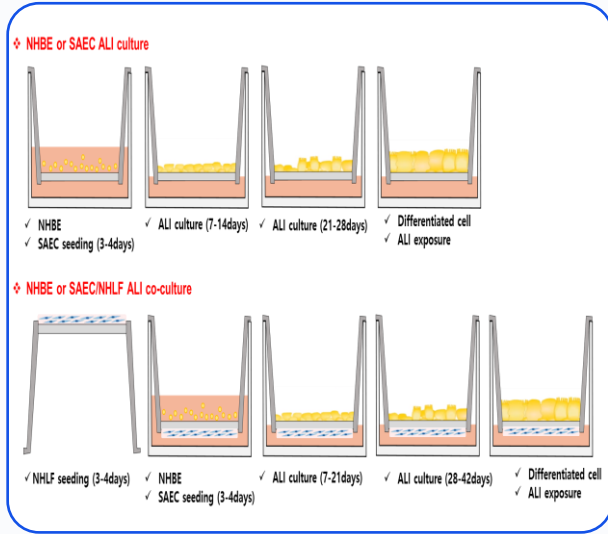


Lung on chip ALI 노출 장비 확립

- ✓ 액상의 물질을 에어로졸화 하여 노출시킬 수 있음
- ✓ 농도별 또는 종류별 노출이 가능
- ✓ Lung on chip 사이즈, 개수는 변경가능



호흡기 독성 평가를 위한 인체 3D 호흡기 ALI 모델 확립



NHBE/SAEC ALI 배양

- ✓ 인체 유래 기관지 상피세포를 이용한 3D ALI 조직모델 확립
- ✓ 폐섬유아세포 NHLF와 co-culture 확립

ALI 배양을 통한 분화 유도

- ✓ TEER 측정을 통해 tight junction 형성 확인
- ✓ 14일 이후부터 Goblet cell, Ciliated cell, Club cell, Basal cell로 분화 진행

3D ALI 세포 기능 검증

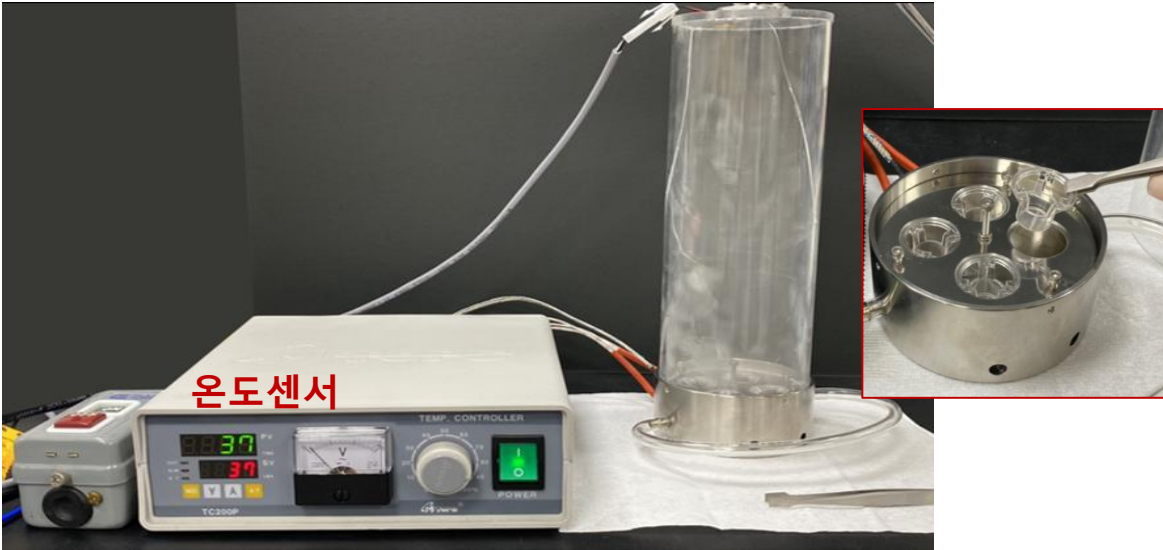
- ✓ Goblet cell: MUC5AC, MUC2 발현
- ✓ Ciliated cell: β-tubulin IV, FOXJ1 발현
- ✓ Club cell: SCGB1A1, SCGB3A2 발현
- ✓ Basal cell: CKRT5 발현 여부 평가

ALI 모델을 활용한 평가 시스템 구축

- ✓ 미세먼지(PM10, PM2.5), 산업가스, 바이러스, 약물 등에 대한 흡입 노출
- ✓ 노출에 대한 반응성을 연구 목적에 따라 평가

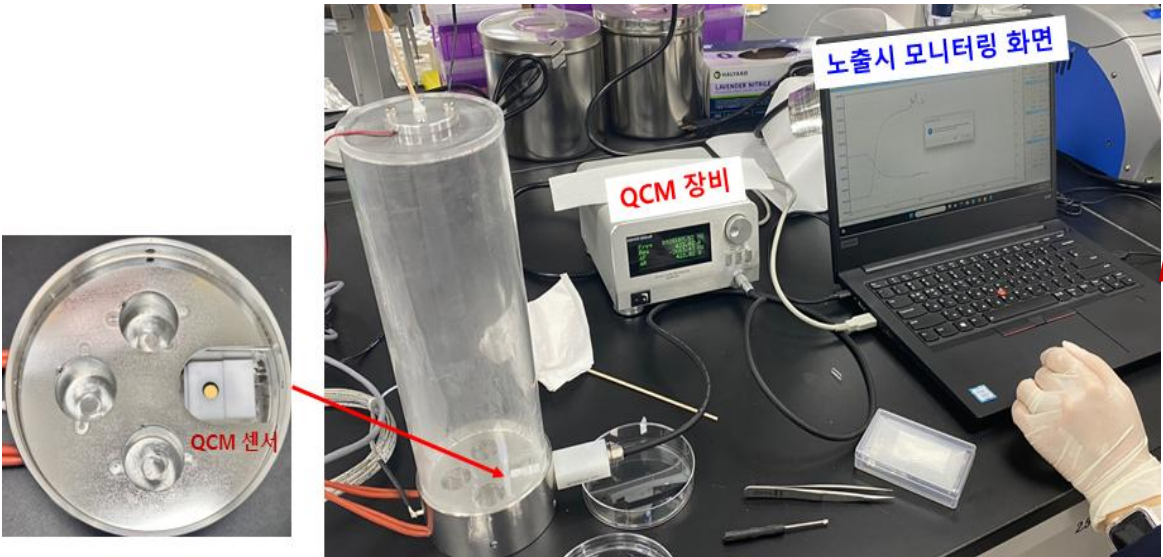


폐 모사칩 호흡기 독성 평가를 위한 ALI용 in vitro 챔버 ②



온도센서

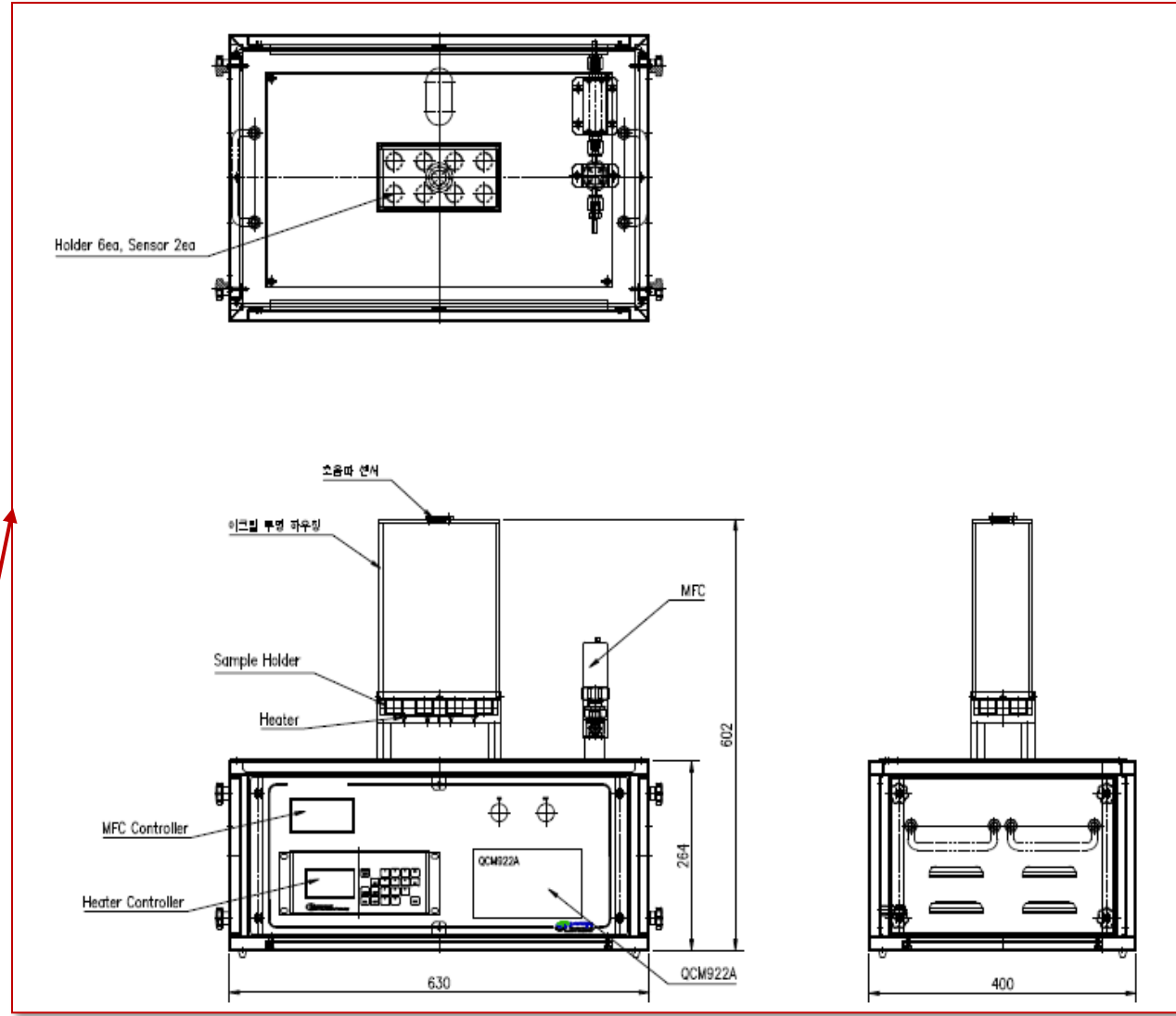
Aerosol 발생 on/off



노출시 모니터링 화면

QCM 장비

QCM 센서



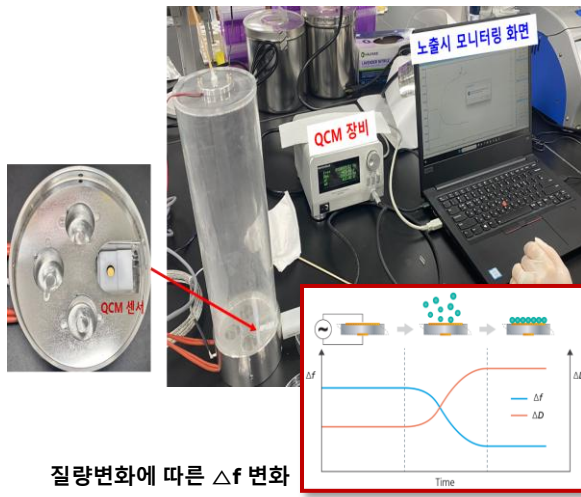


폐 모사칩 호흡기 독성 평가를 위한 ALI용 in vitro 챔버 ②



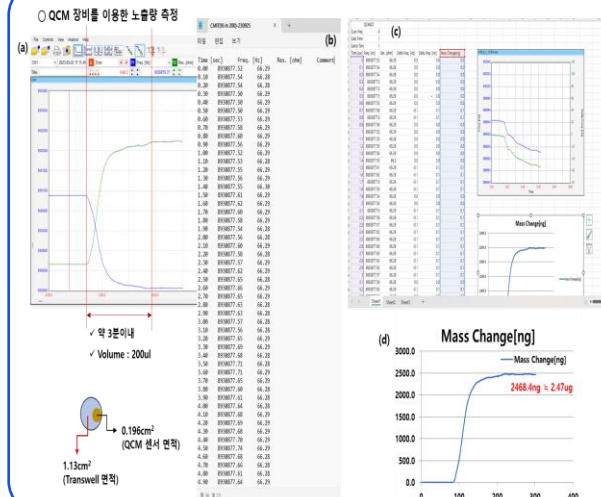
ALI 노출을 위한 예비 장비

- ✓ 세포배양 온도에 맞도록 온도센서 장착
- ✓ 외부물질을 에어로졸화 시킬 수 있는 단자를 상부에 부착
- ✓ Transwell 사이즈에 맞도록 단독으로 제작



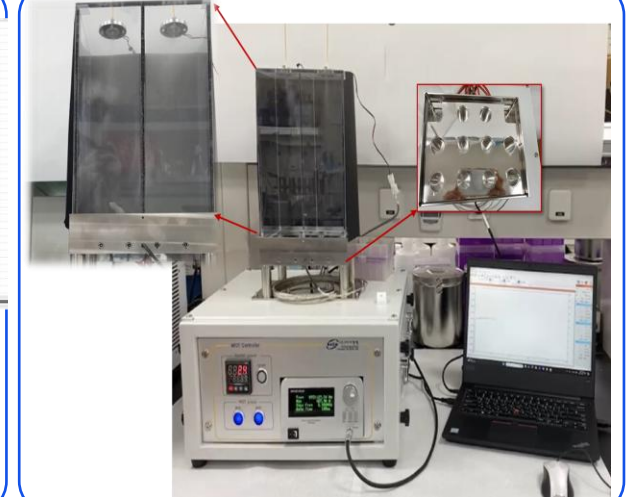
실시간 노출 모니터링

- ✓ 미세질량분석이 가능한 Quartz Crystal Microbalance (QCM, Seiko EG&G) 장비를 도입
- ✓ 세포모델에 노출되는 외부물질을 실시간으로 모니터링



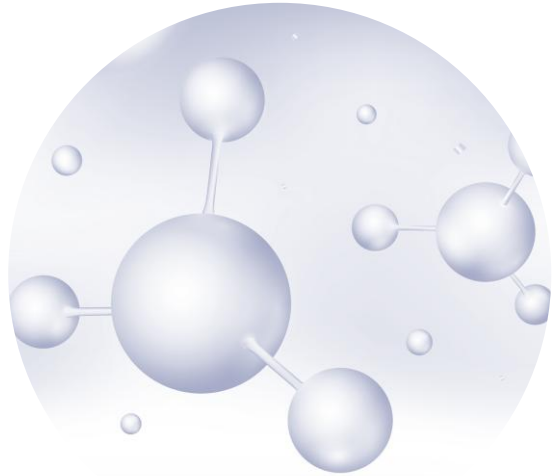
노출시킨 물질을 정량화

- ✓ QCM 센서표면에 물질의 흡착 또는 결합으로 인한 나노 규모의 질량 변화 감지
- ✓ 소프트웨어 프로그램을 통하여 노출량을 산출
- ✓ 반복 노출 실험을 통하여 오차범위가 매우 적음을 검증

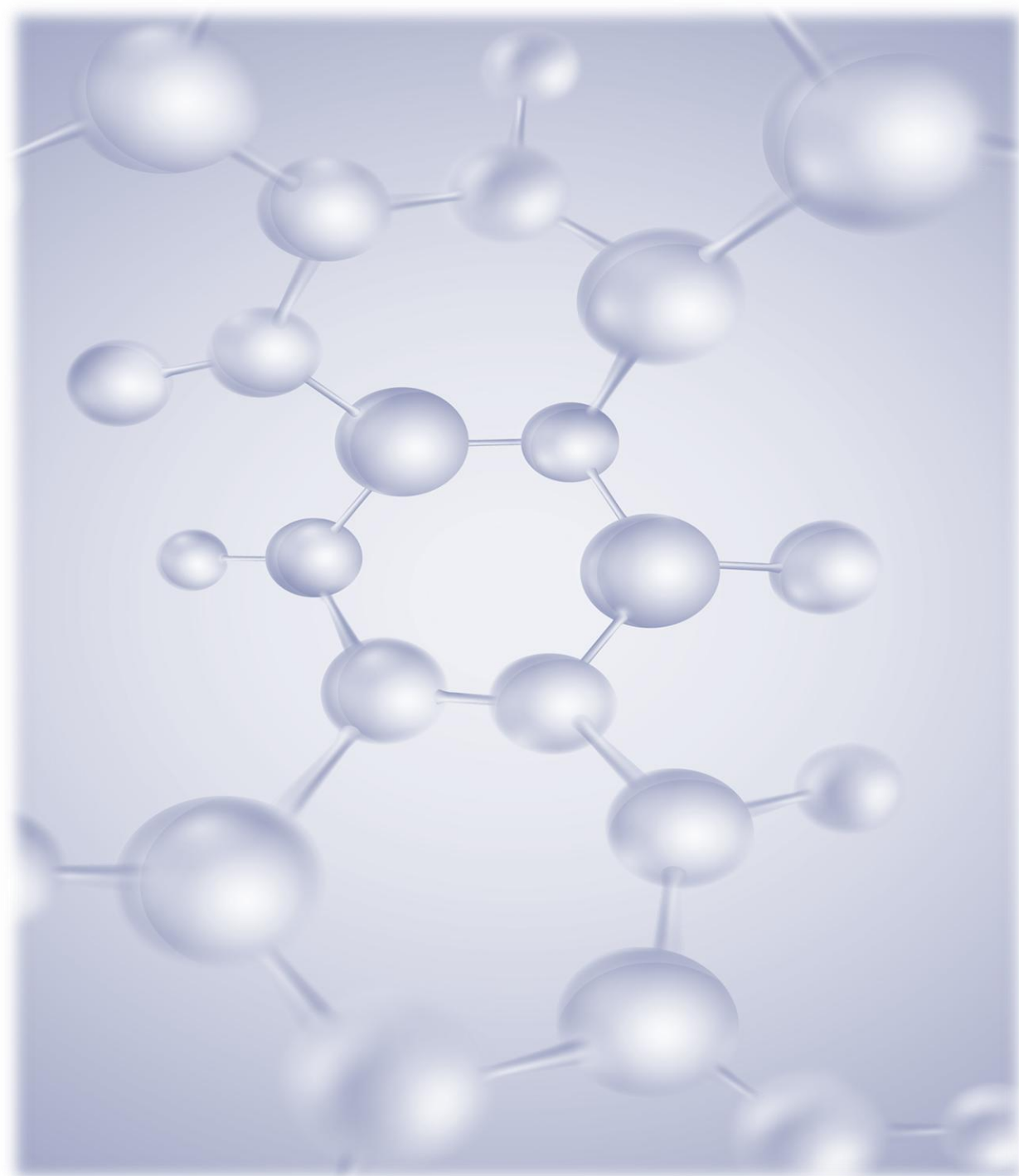


ALI 노출을 위한 평가시스템 장비 확립

- ✓ 가스상, 액상의 물질을 에어로졸화 하여 노출시킬 수 있음
- ✓ 동시 1-10개까지 노출이 가능
- ✓ 농도별 또는 종류별 노출이 가능
- ✓ Transwell 사이즈나 개수는 변경가능

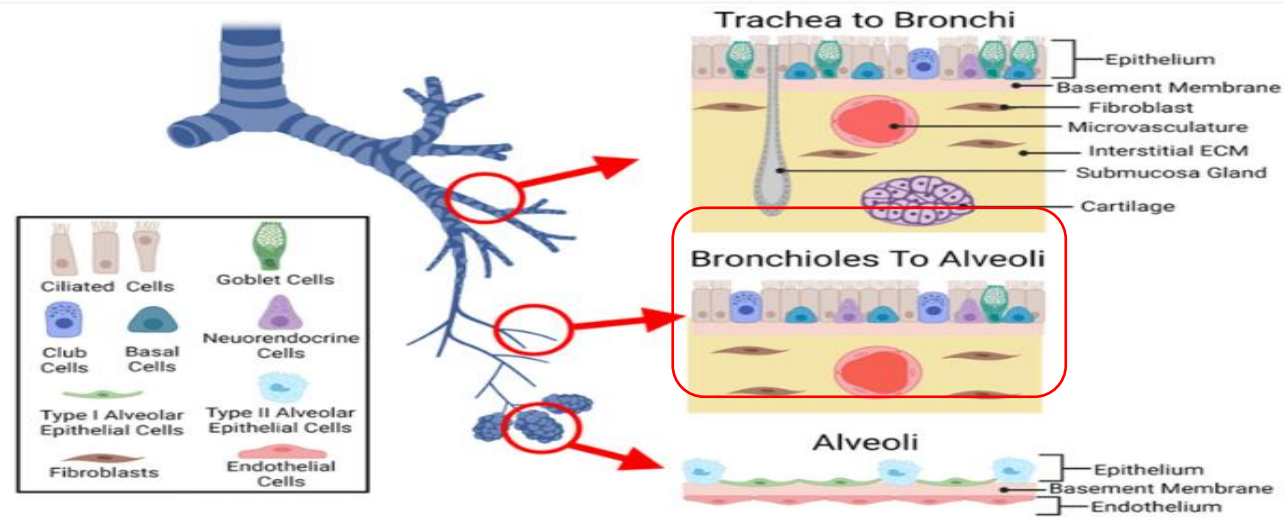


3. 연구개발의 내용 및 결과





ALI 노출에 적합한 in vitro 호흡기계 세포모델



Cells of the Lung. The conducting airways are lined with a pseudostratified epithelium, including mucus producing goblet cells, ciliated cells, neuroendocrine cells, and basal cells. The alveolar epithelium is composed of type 1 flattened epithelial cells and cuboidal type 2 epithelial cells.

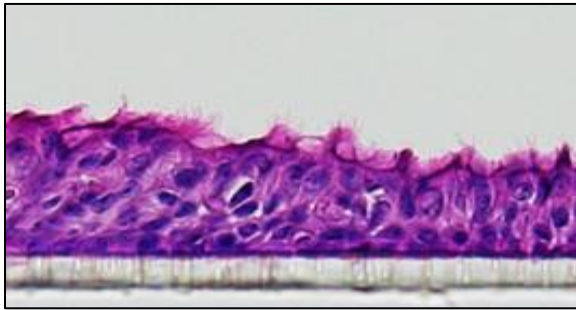
<Ref. 2021, Cells 10(7):1602>

모델	상피세포	섬유아세포	총괄	협동	ALI 배양 성능 실험
상기도 모델	NHBE	MRC-5 or NHLF	PET membrane (12well transwell)	PCL membrane (12 or 24well insert)	<Tight junction 확인> -TEER 측정: 세포의 tight junction에 의해 형성된 저항을 측정 -Zo-1과 E-cadherin 단백질의 IF 확인 <점액 및 분비액 확인> -MUC5AC에 대한 IF 확인: goblet세포에서 분비되어지는 물질로 점액 분비 여부를 확인 -Surfactant 측정: 폐포에서 분비되어 지는 계면활성제
하기도 모델	SAEC	MRC-5 or NHLF			<분화되는 특정 세포 분포 확인> -β-tubulin IV 단백질 IF 확인: ciliated 세포 -SCGBA1 단백질 IF 확인: club 세포 -CKRT5 단백질 IF 확인: basal 세포

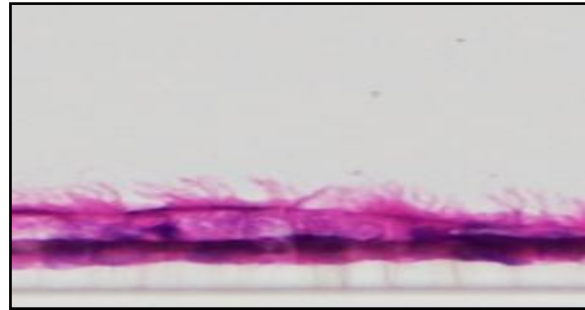


In vitro 에어로졸 세포노출을 위한 ALI 배양

✓ NHBE 상기도 ALI 모델

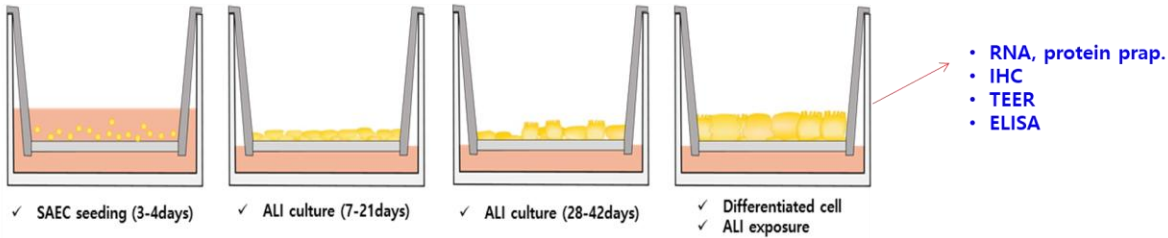


✓ SAEC 하기도 ALI 모델

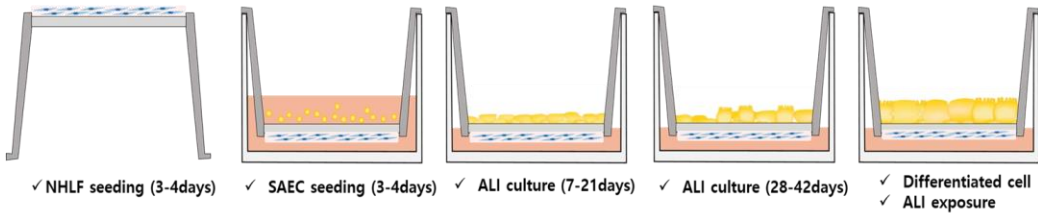


X200

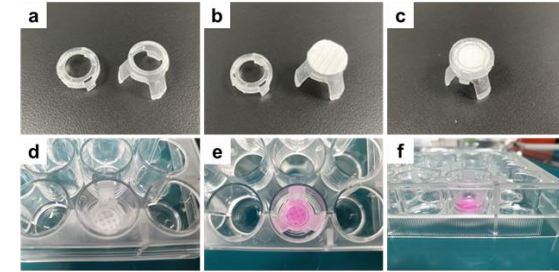
❖ 폐상피세포인 SAEC or NHBE 단독 ALI 배양 in 0.4 pore transmembrane 12well + 0.1mg/ml collagen type 1 coating



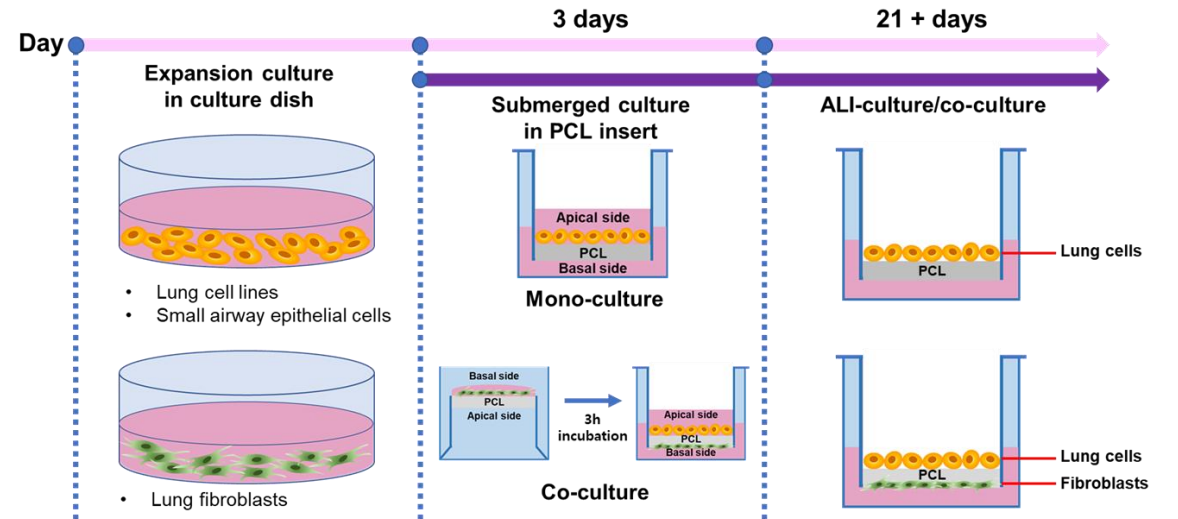
❖ 폐섬유아 NHLF와 폐상피세포의 co-culture ALI 배양 in 0.4 pore transmembrane 12well + 0.1mg/ml collagen type 1 coating



Transwell PET membrane (총괄)



ALI 배양을 위해 나노 섬유를 insert에 결착

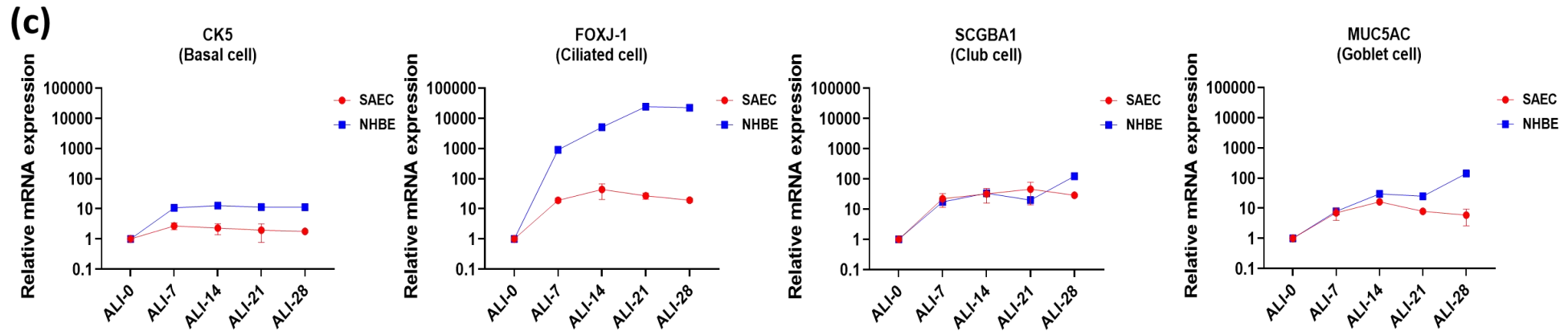
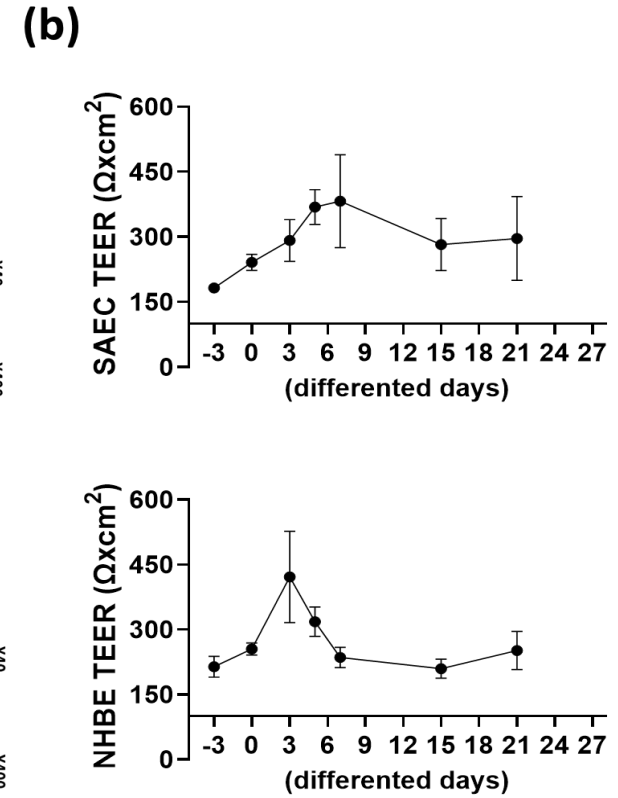
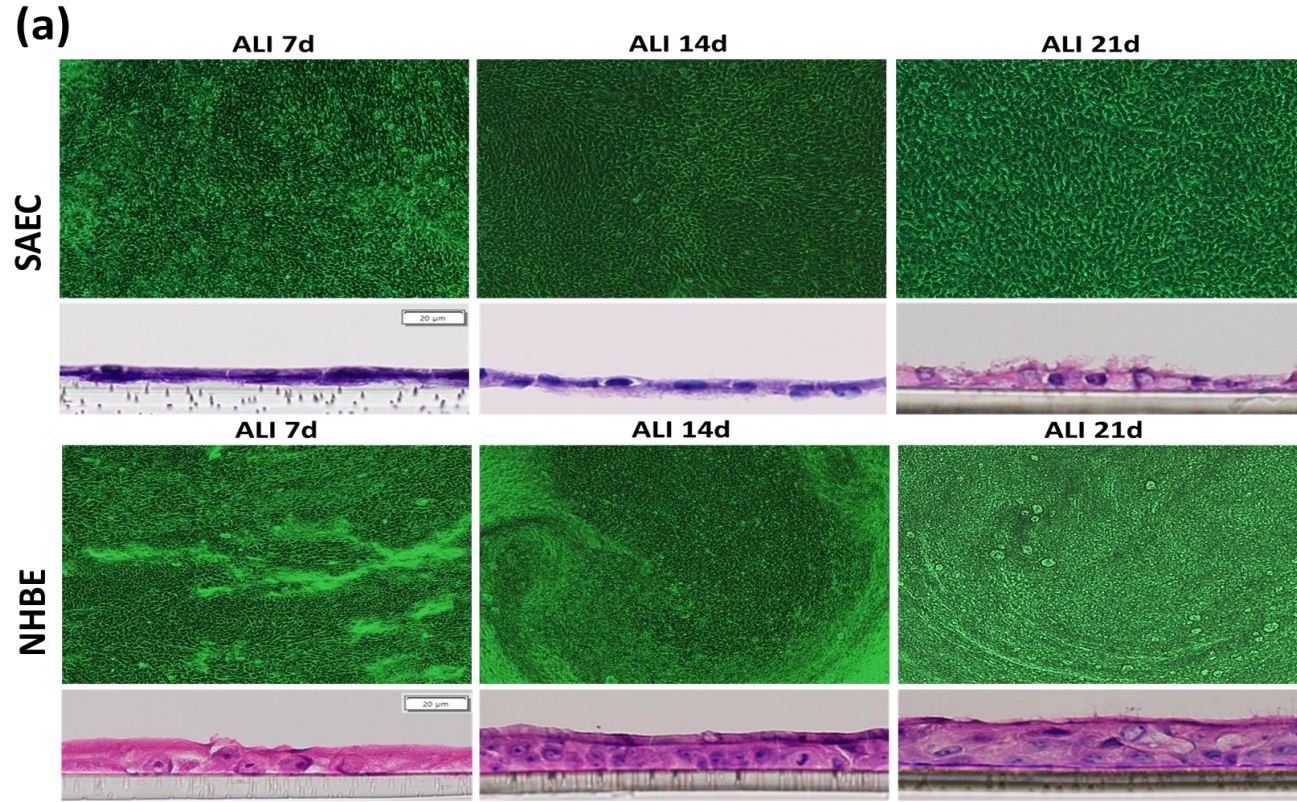


Insert에 결착된 나노 섬유막층에 두 종류 세포 공배양의 최적 ALI를 구축

Nanofiber PCL membrane (협동)



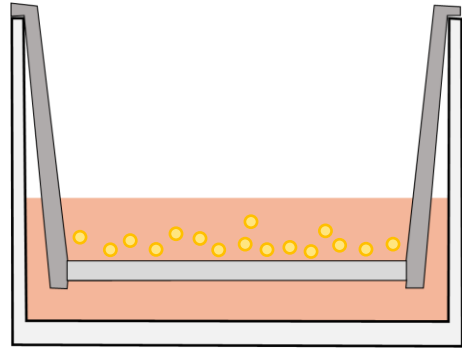
In vitro 에어로졸 세포노출을 위한 ALI 배양



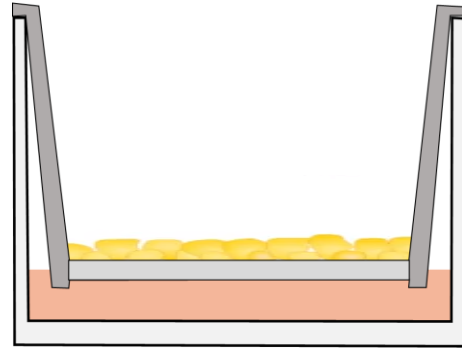


선별된 환경유해인자의 노출방법에 따른 in vitro 호흡기 독성 평가

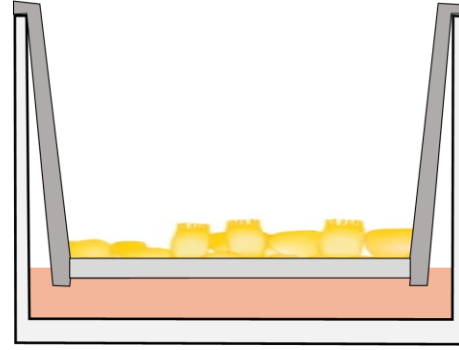
❖ NHBE or SAEC ALI culture



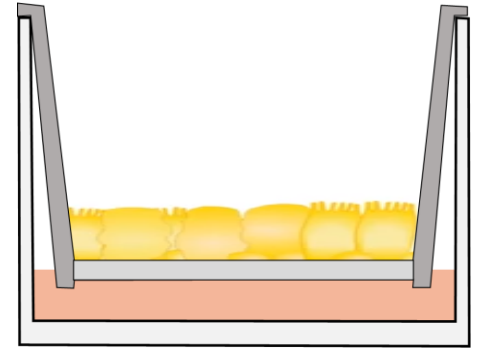
- ✓ NHBE
- ✓ SAEC seeding (3-4days)



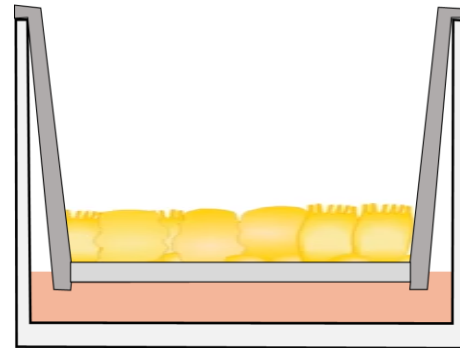
- ✓ ALI culture (7-14days)



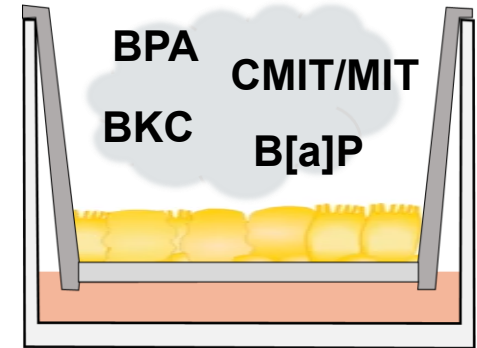
- ✓ ALI culture (21-28days)



- ✓ Differentiated cell
- ✓ ALI exposure



- ✓ Incubated for 24-120h



- ✓ ALI exposure (4min/회)

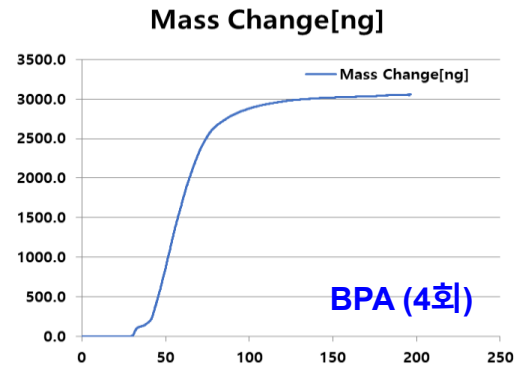
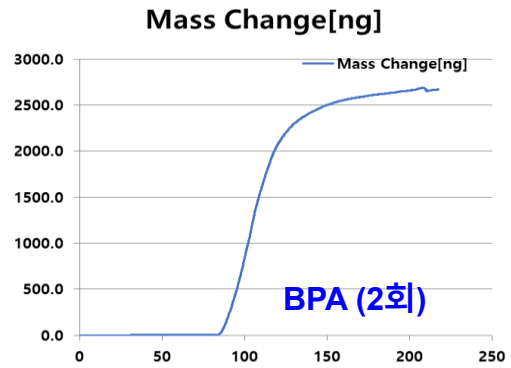




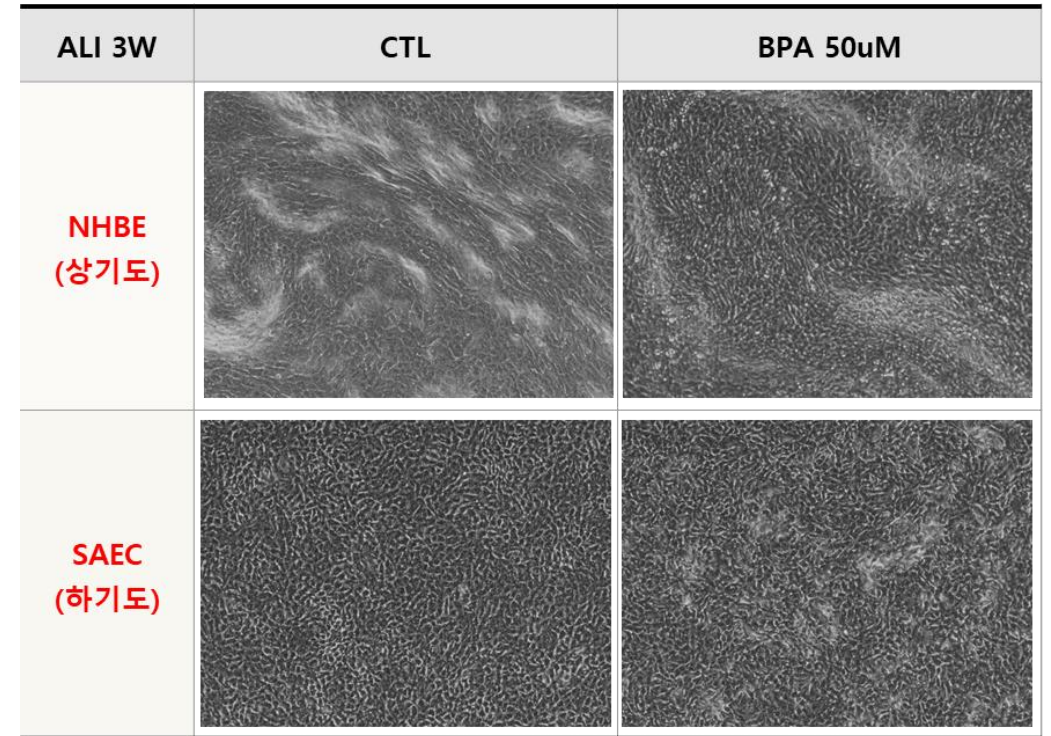
In vitro 에어로졸 노출에 의한 호흡기 독성평가 : EDC (비스페놀 A, BPA)

(a)

환경유해인자	ALI exposure (200ul)		submerged
	2회	4회	
BPA	7.33ng	16.11ng	50nM (11.4ng)

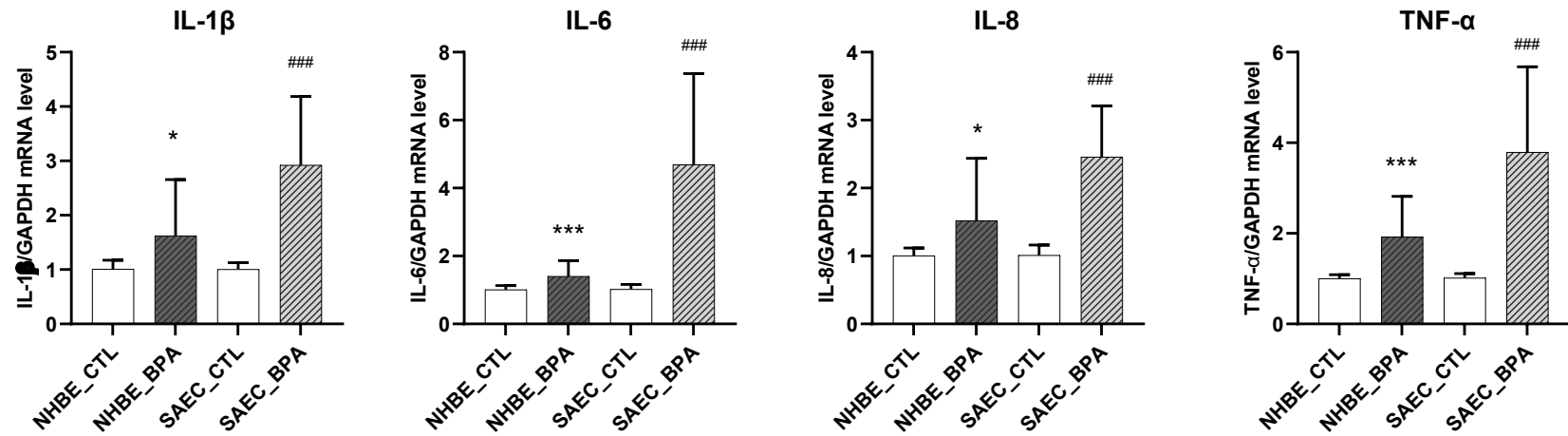


(b)

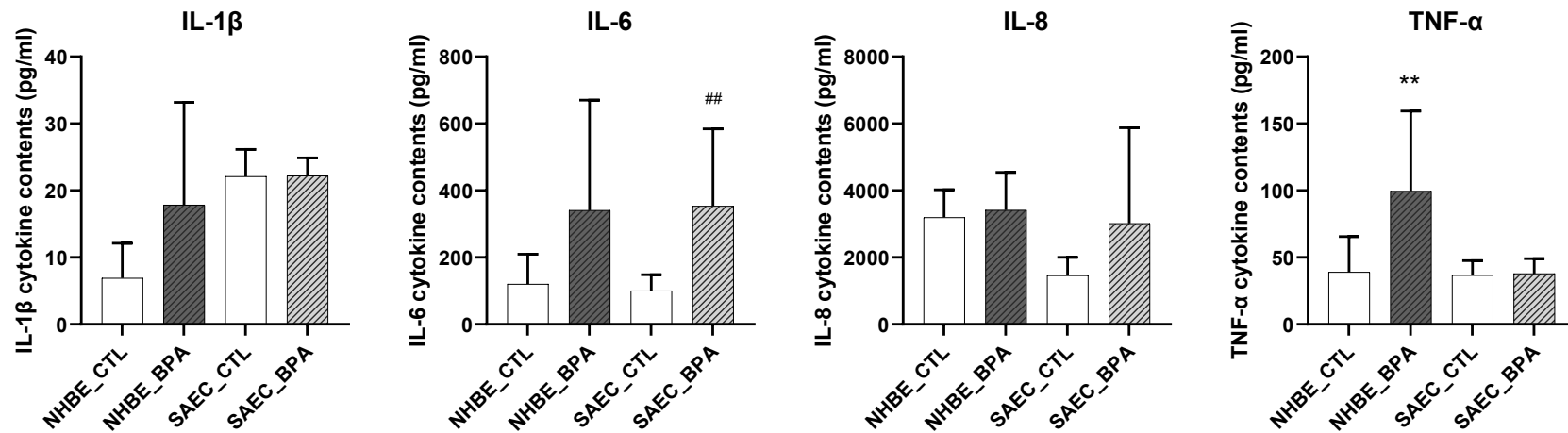


➤ ALI 세포모델에서 BPA 노출에 의한 호흡기 영향 _ Inflammatory response

(a)

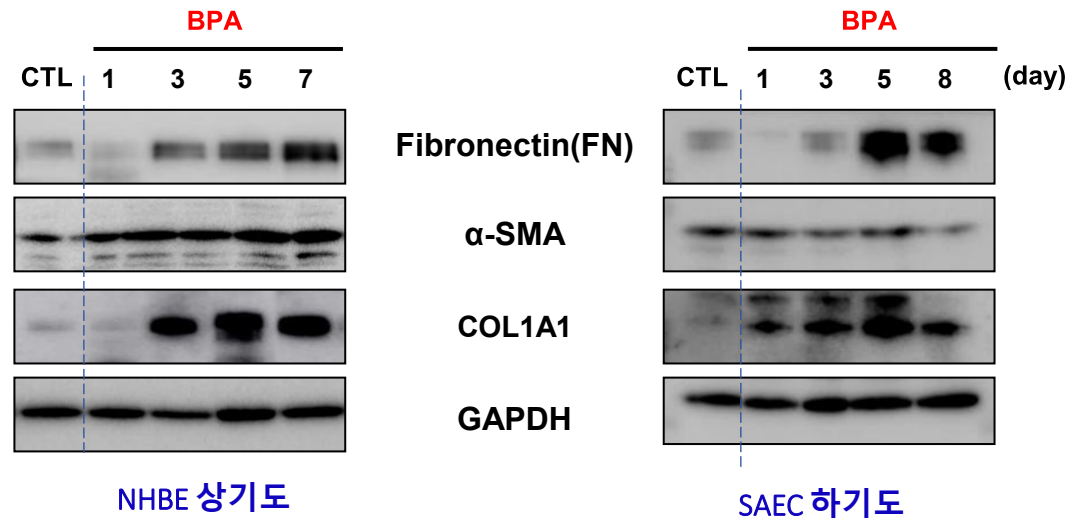
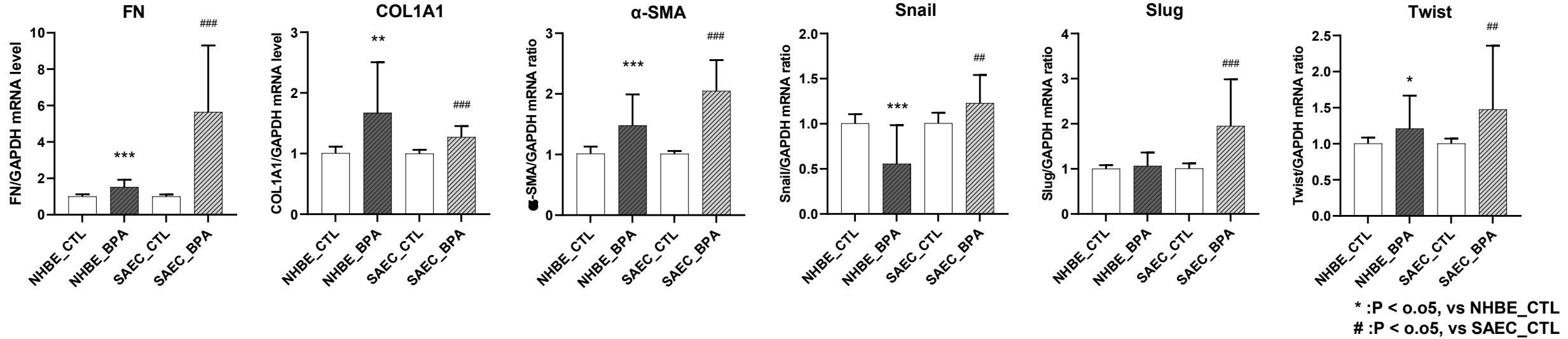


(b)



* :P < 0.05, vs NHBE_CTL
:P < 0.05, vs SAEC_CTL

➤ ALI 세포모델에서 BPA 노출에 의한 호흡기 영향 _ Fibrosis response

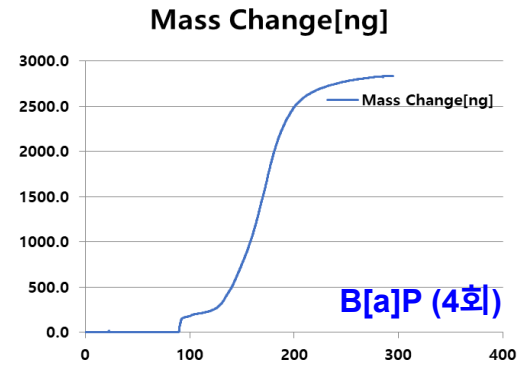
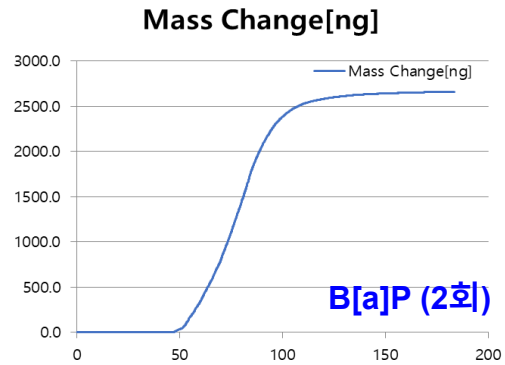




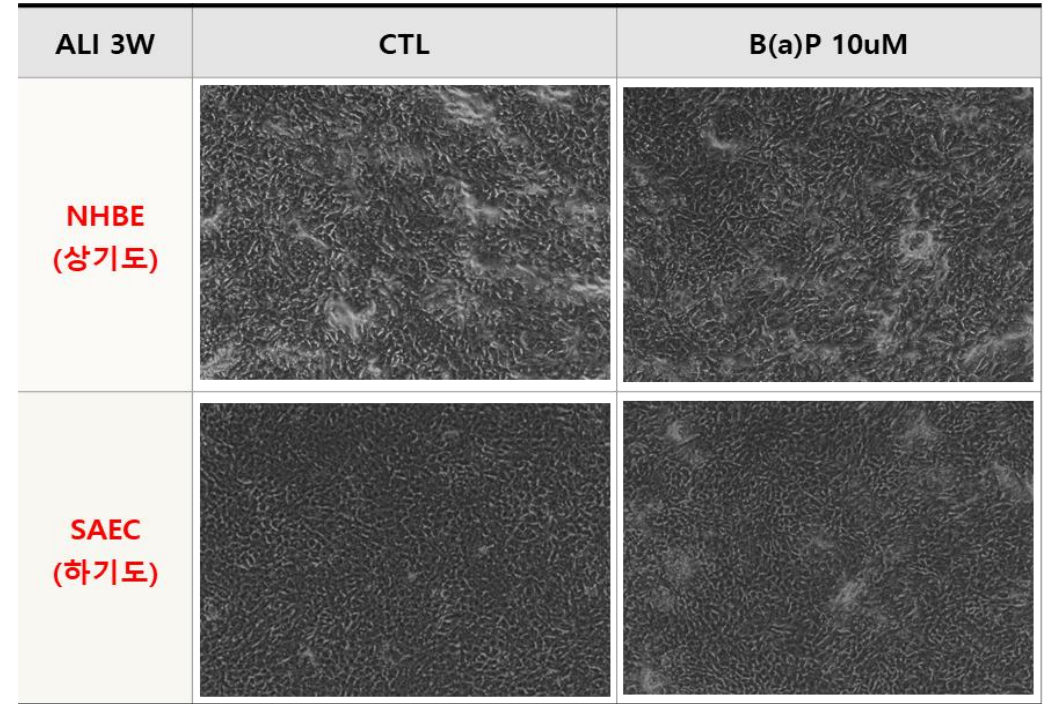
In vitro 에어로졸 노출에 의한 호흡기 독성평가 : PAHs (벤조피렌, B[a]P)

(a)

환경유해인자	ALI exposure (200ul)		submerged
	2회	4회	
B(a)P	1.55ug	3.30ug	10uM (2.52ug)

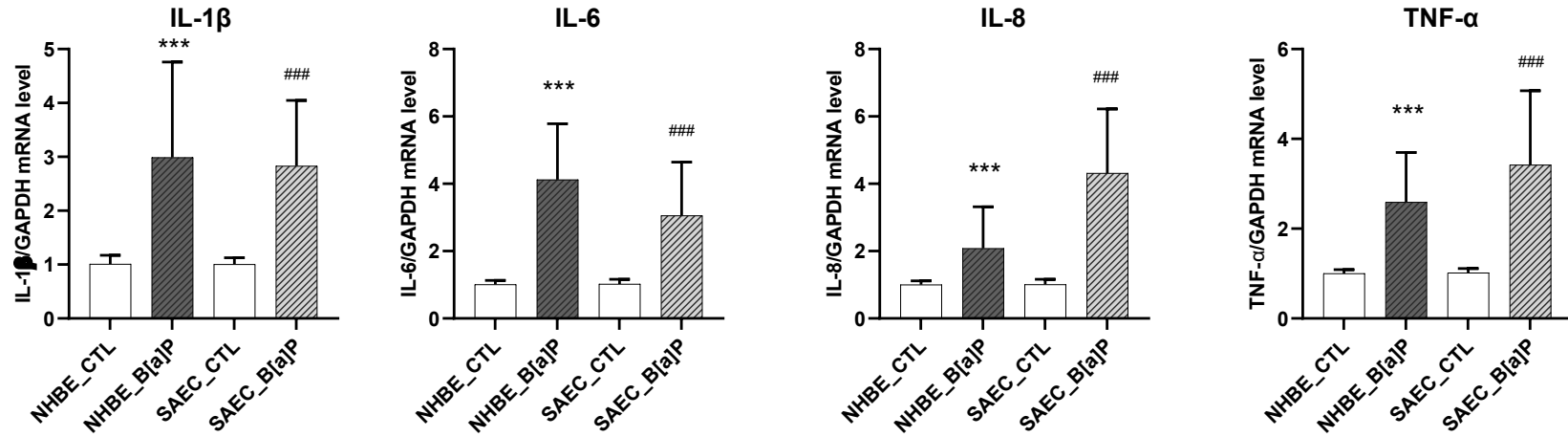


(b)

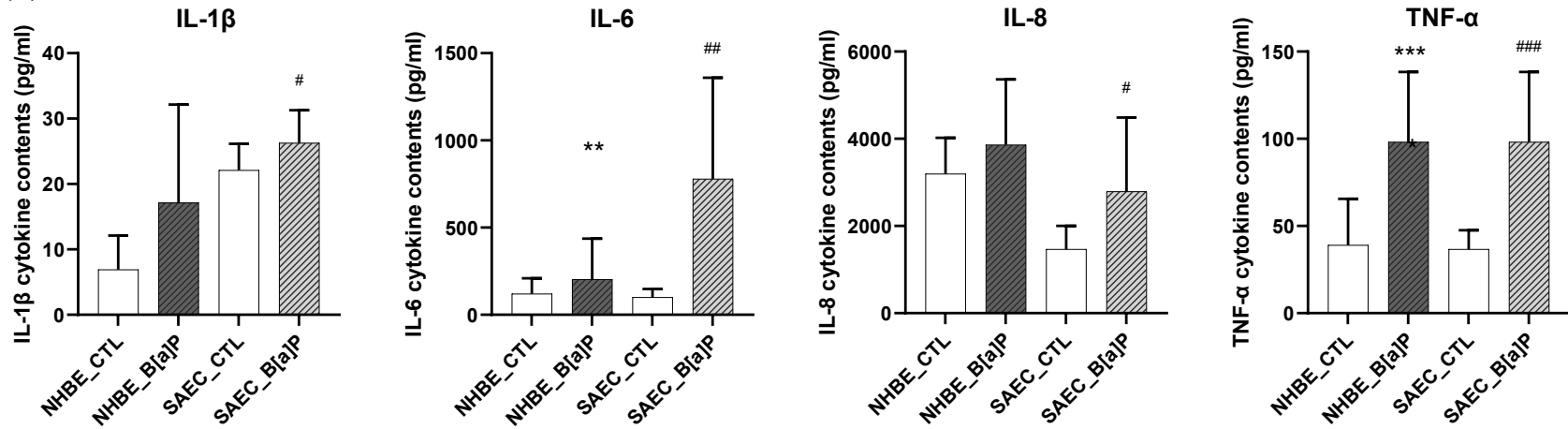


➤ ALI 세포모델에서 B[a]P 노출에 의한 호흡기 영향 _ Inflammatory response

(a)

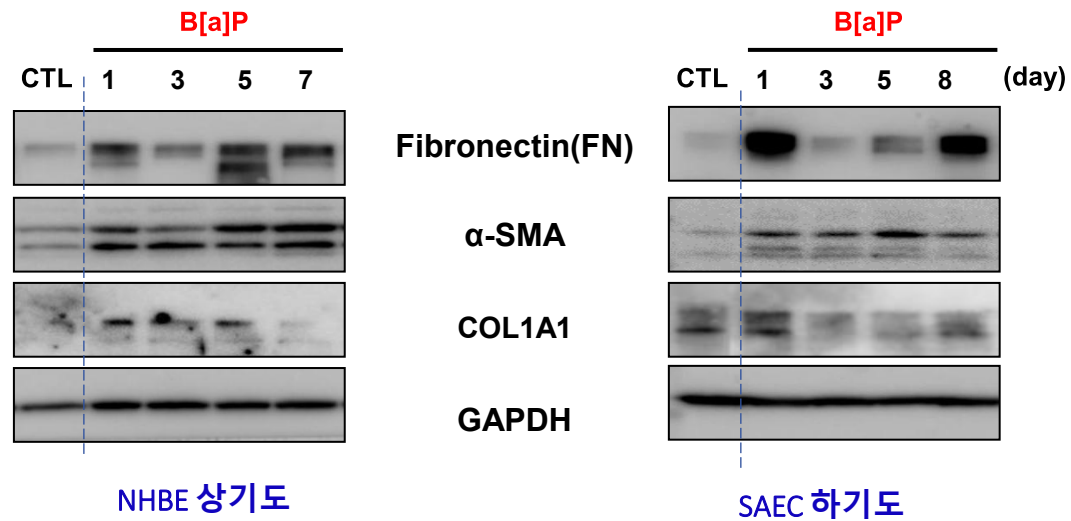
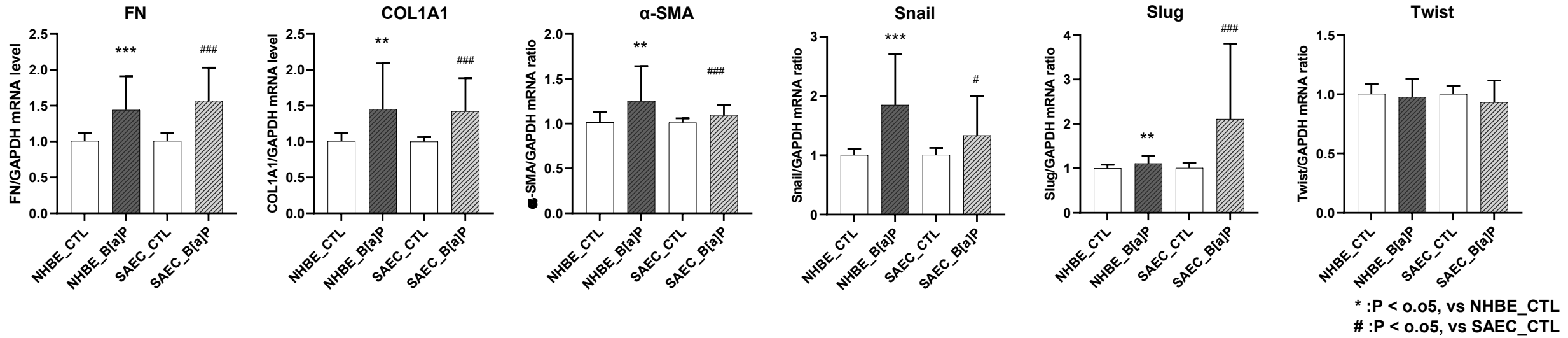


(b)



* :P < 0.05, vs NHBE_CTL
:P < 0.05, vs SAEC_CTL

➤ ALI 세포모델에서 B[a]P 노출에 의한 호흡기 영향 _ Fibrosis response

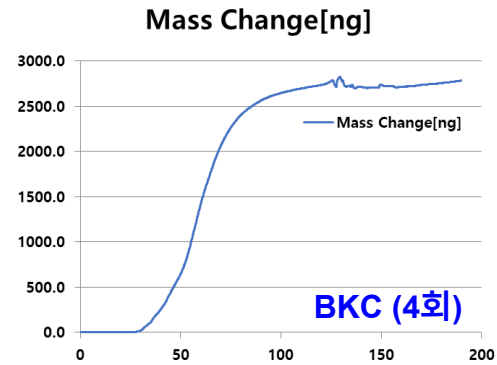
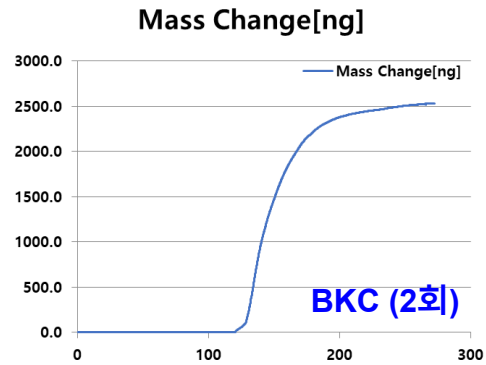




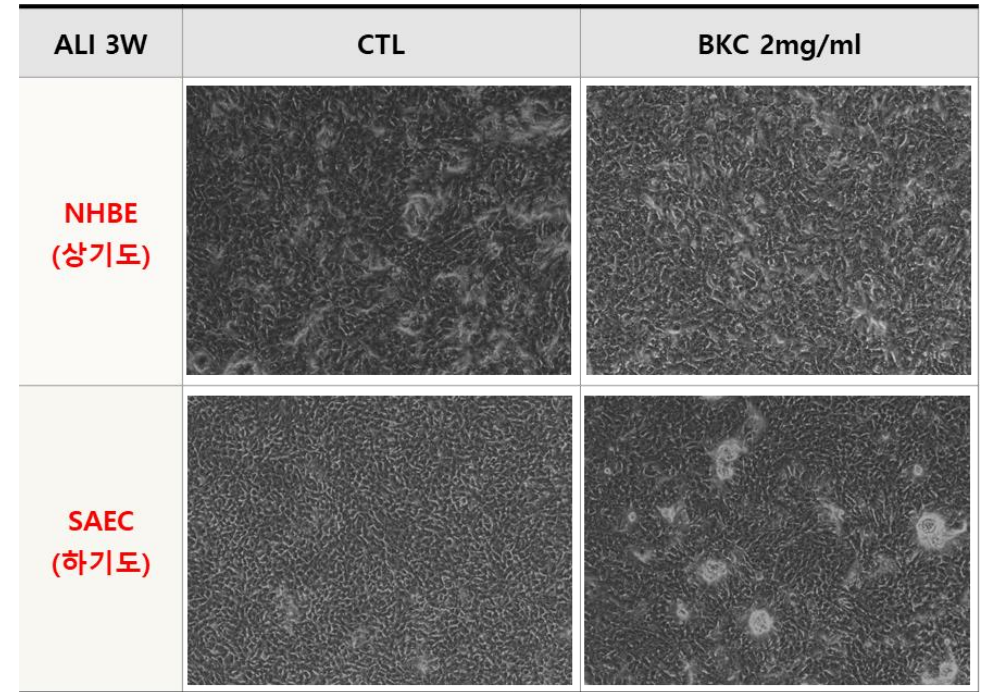
In vitro 에어로졸 노출에 의한 호흡기 독성평가 : 기타 (벤젤코덤, BKC)

(a)

환경유해인자	ALI exposure (200ul)		submerged
	2회	4회	
BKC	1.17ug	2.57ug	2ug/ml (2ug)

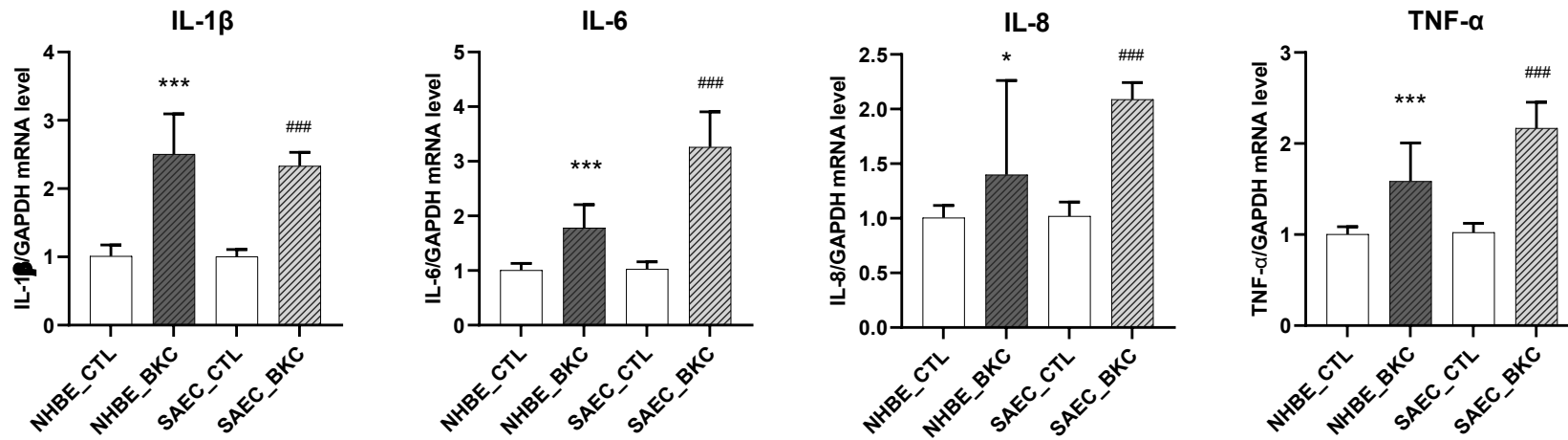


(b)

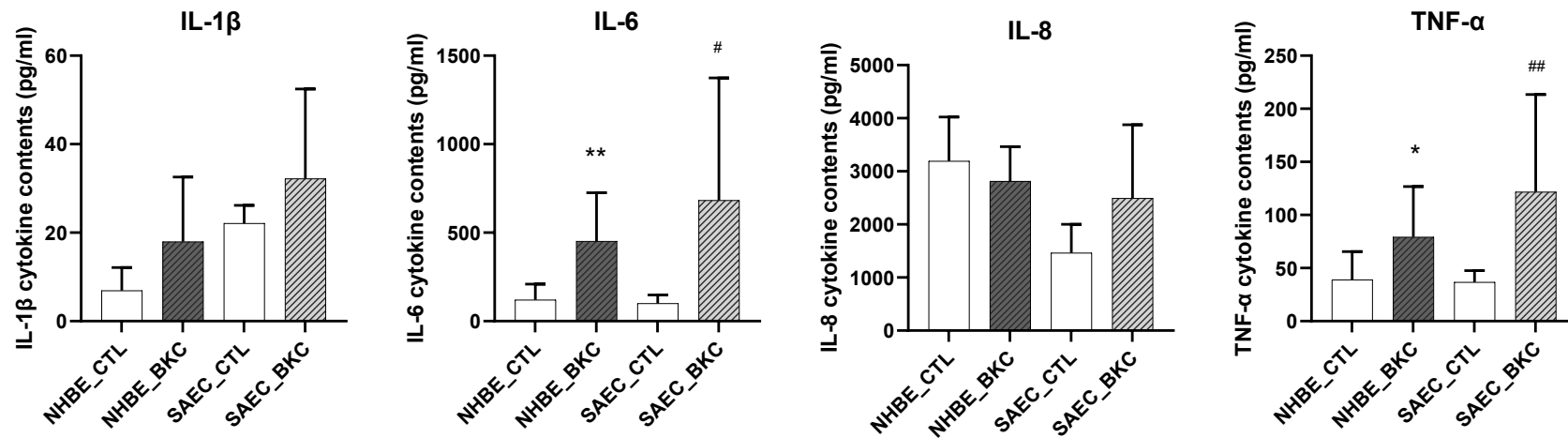


➤ ALI 세포모델에서 BKC 노출에 의한 호흡기 영향 _ Inflammatory response

(a)



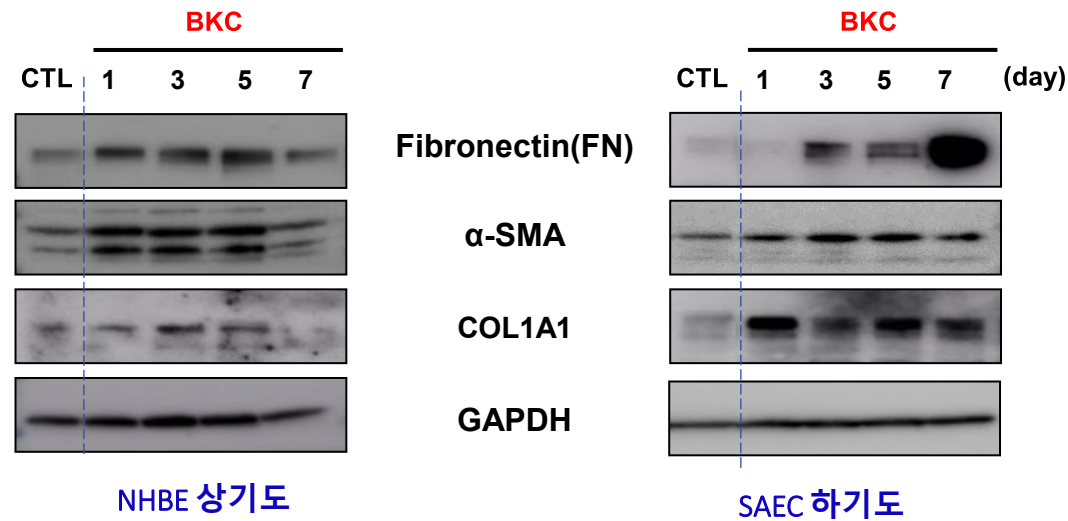
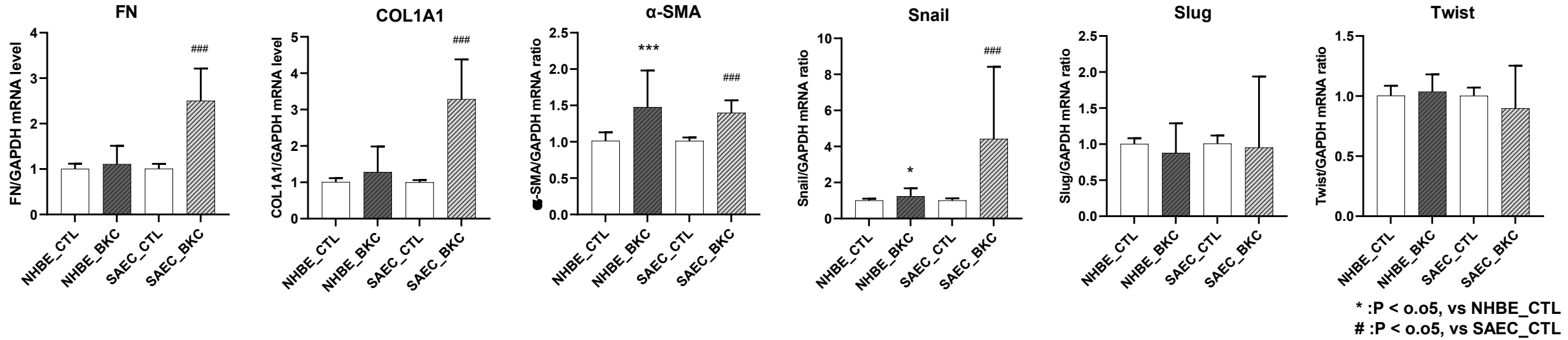
(b)



* :P < 0.05, vs NHBE_CTL

:P < 0.05, vs SAEC_CTL

➤ ALI 세포모델에서 BKC 노출에 의한 호흡기 영향 _ Fibrosis response

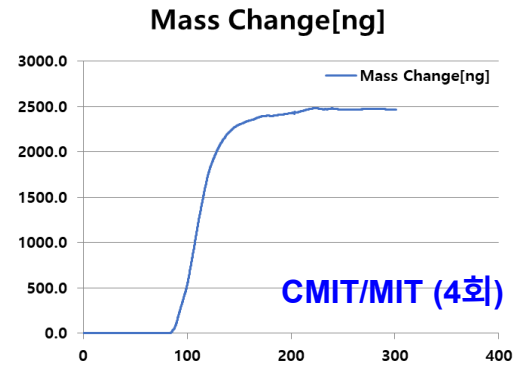
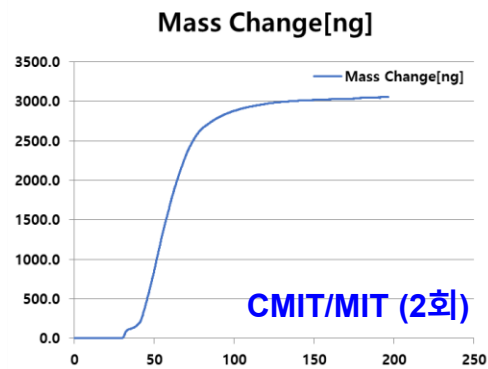




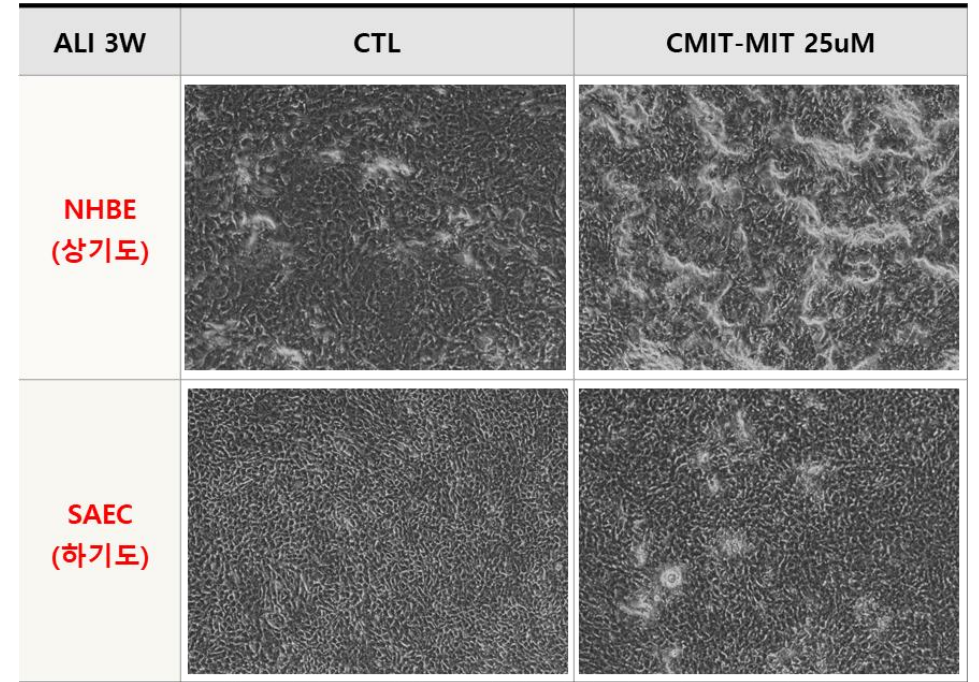
In vitro 에어로졸 노출에 의한 호흡기 독성평가 : 기타 (CMIT-MIT)

(a)

환경유해인자	ALI exposure (200ul)		submerged
	2회	4회	
CMIT/MIT	2.03ug	3.28ug	25uM (2.88ug)

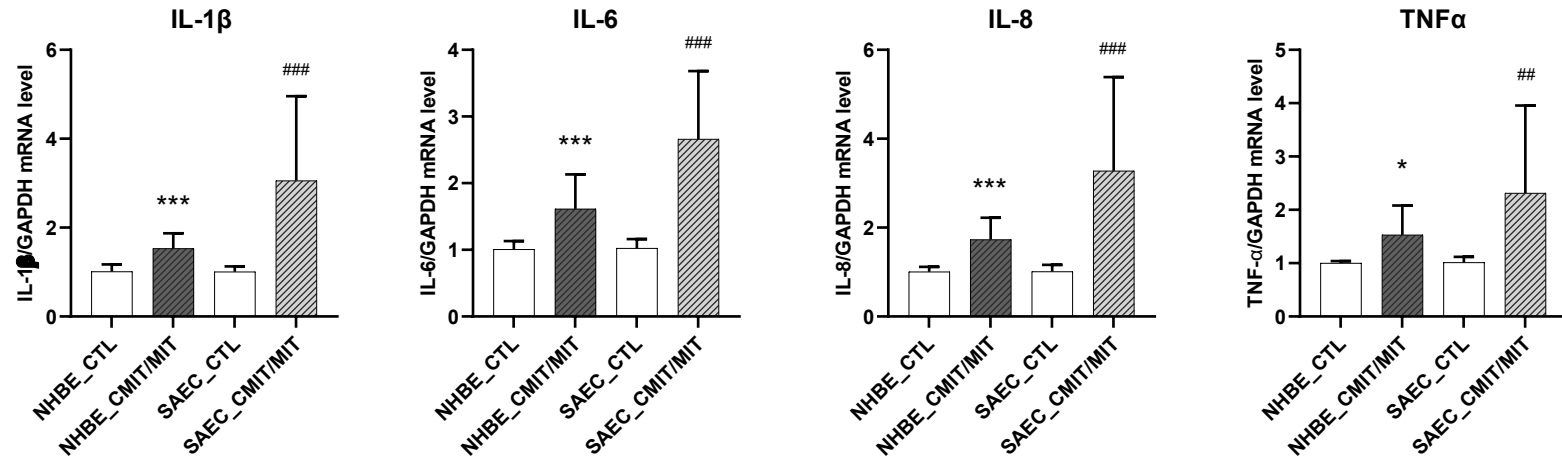


(b)

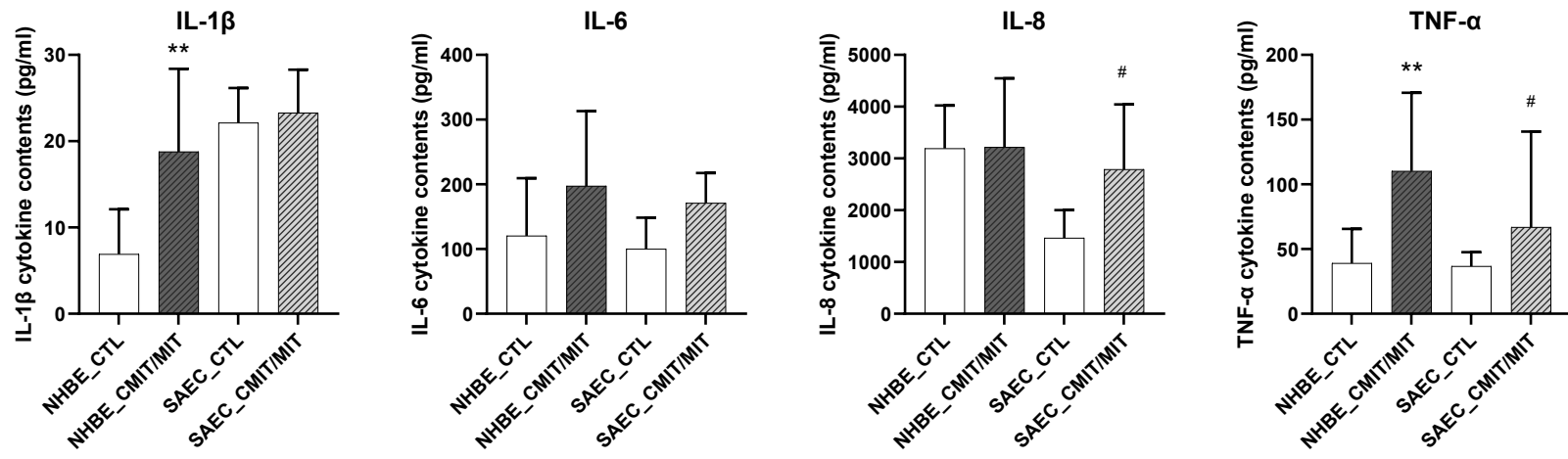


➤ ALI 세포모델에서 **CMIT/MIT** 노출에 의한 호흡기 영향 _ **Inflammatory response**

(a)

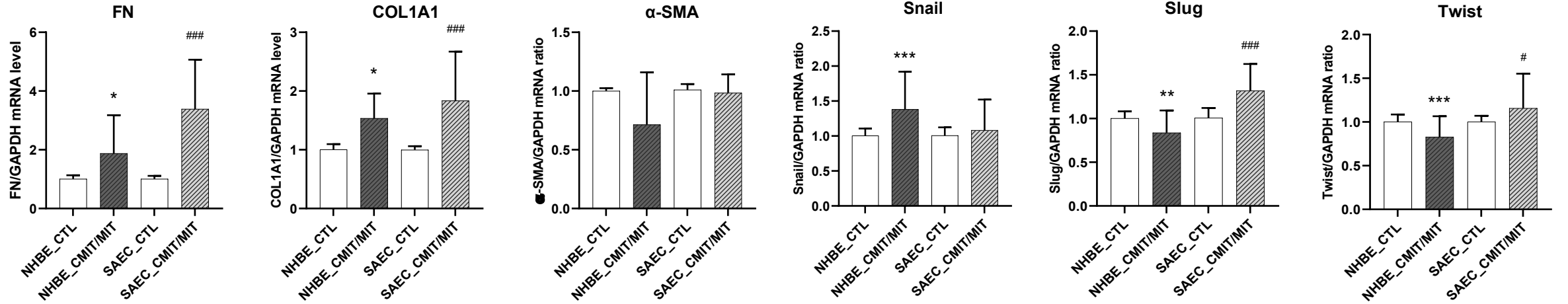


(b)

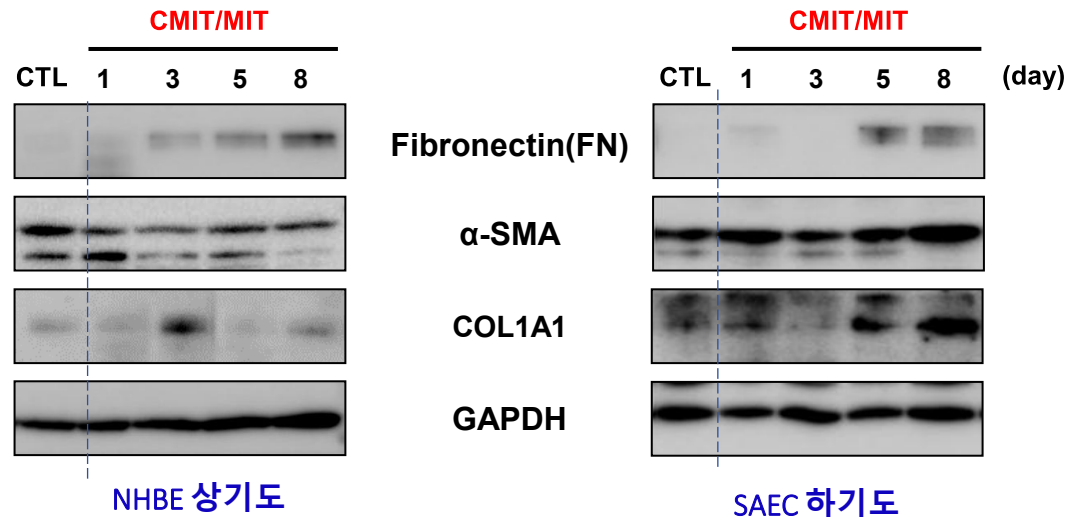


* :P < 0.05, vs NHBE_CTL
:P < 0.05, vs SAEC_CTL

➤ ALI 세포모델에서 **CMIT/MIT** 노출에 의한 호흡기 영향 _ **Fibrosis response**



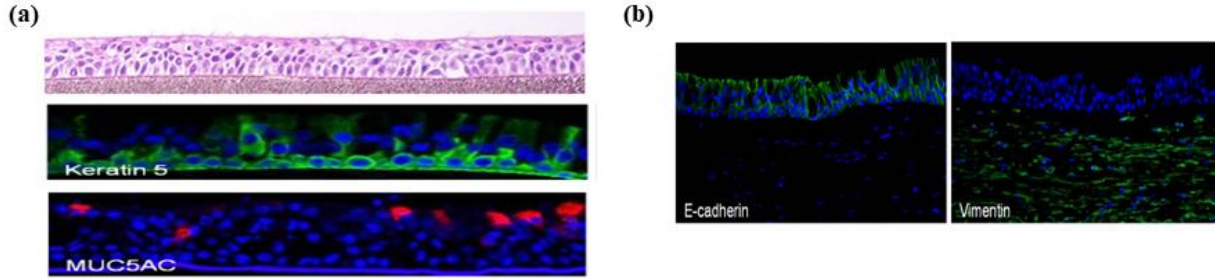
* :P < 0.05, vs NHBE_CTL
:P < 0.05, vs SAEC_CTL



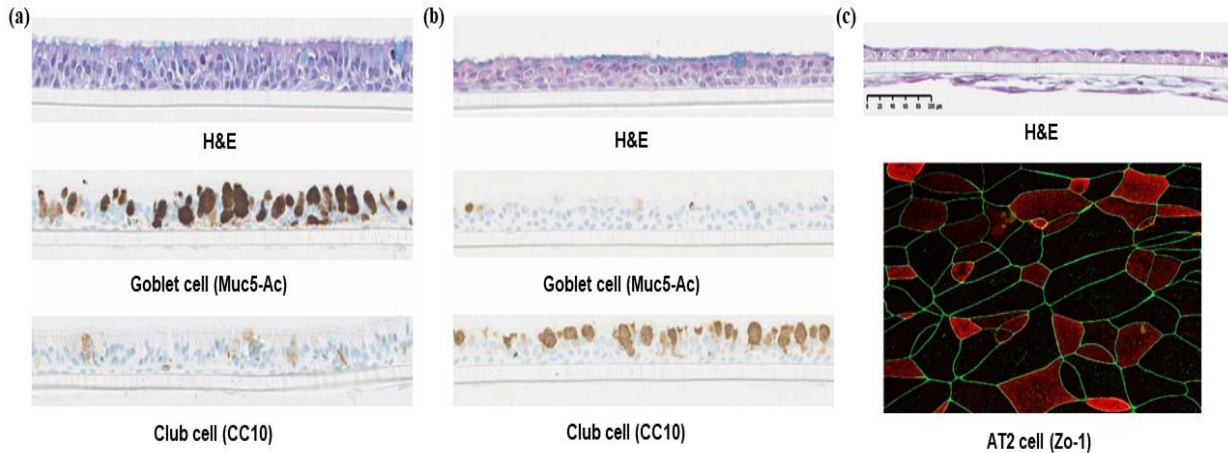


외산 3D 조직모델에서 환경유해인자가 미치는 호흡기 독성 영향 평가비교

[MarTeck사, 미국] - (a) Epiarway, (b) EpiarwayFT



[Epithelix사, 스위스] - (a) MucilAir, (b) SmallAir, (c) AlveolAir

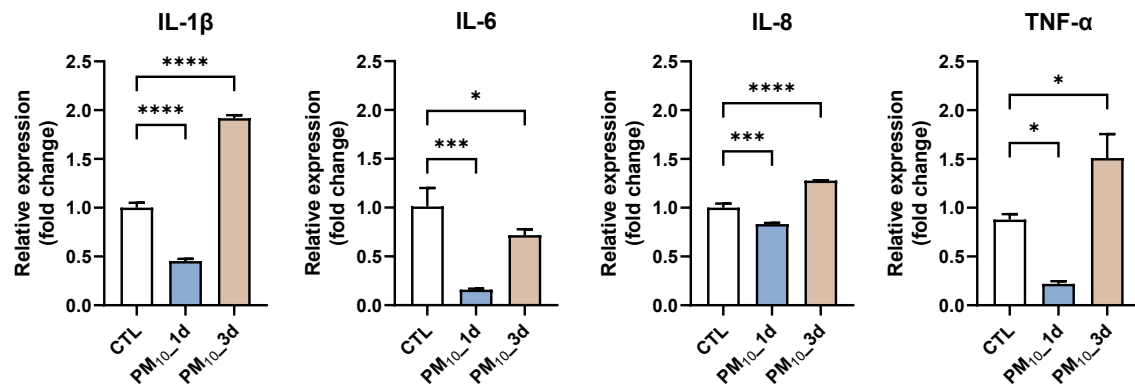


vs. SAEC ALI

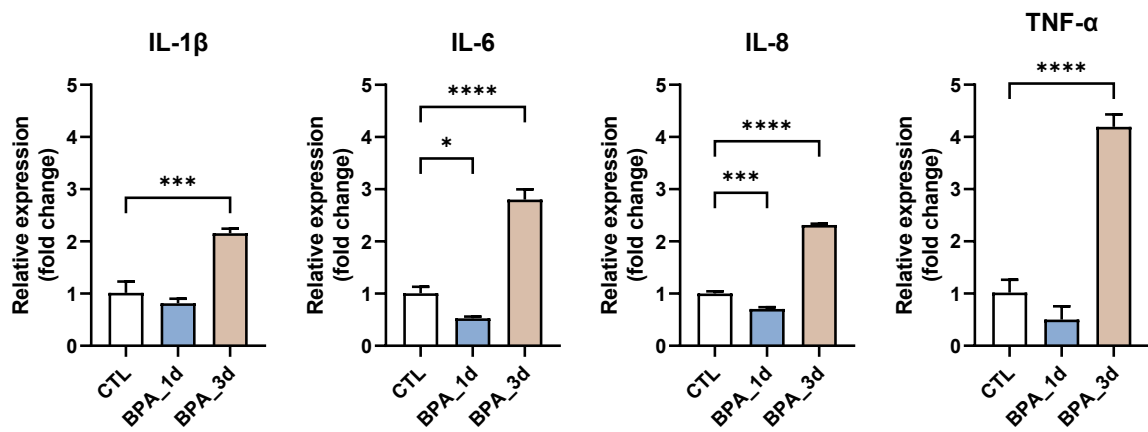
[외산 3D 조직모델과의 성능비교]

- 환경유해인자 노출에 의한 **염증 반응** : qRT-PCR, ELISA
- 환경유해인자 노출에 의한 **섬유화 반응** : western blot
- 환경유해인자 노출에 의한 **분화 반응** : qRT-PCR, IHC, ELISA

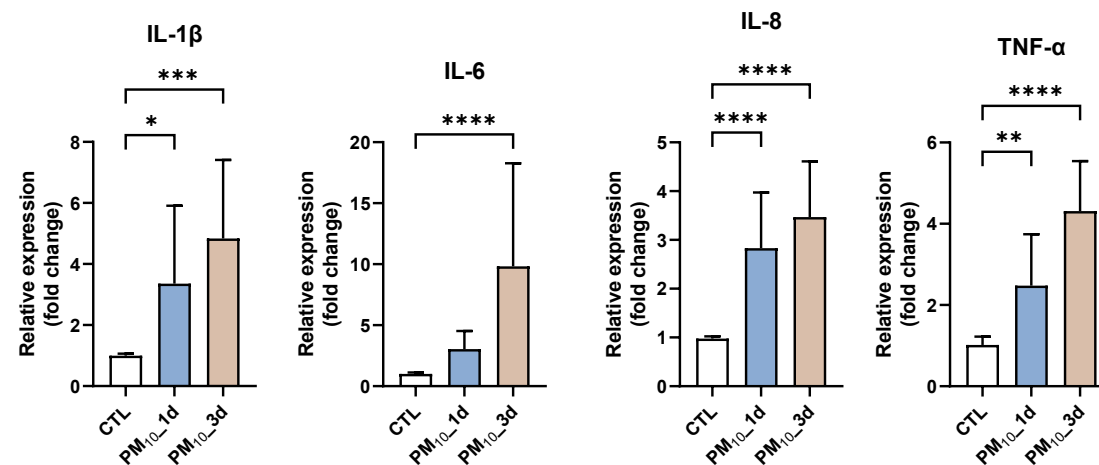
PM₁₀_SmallAir



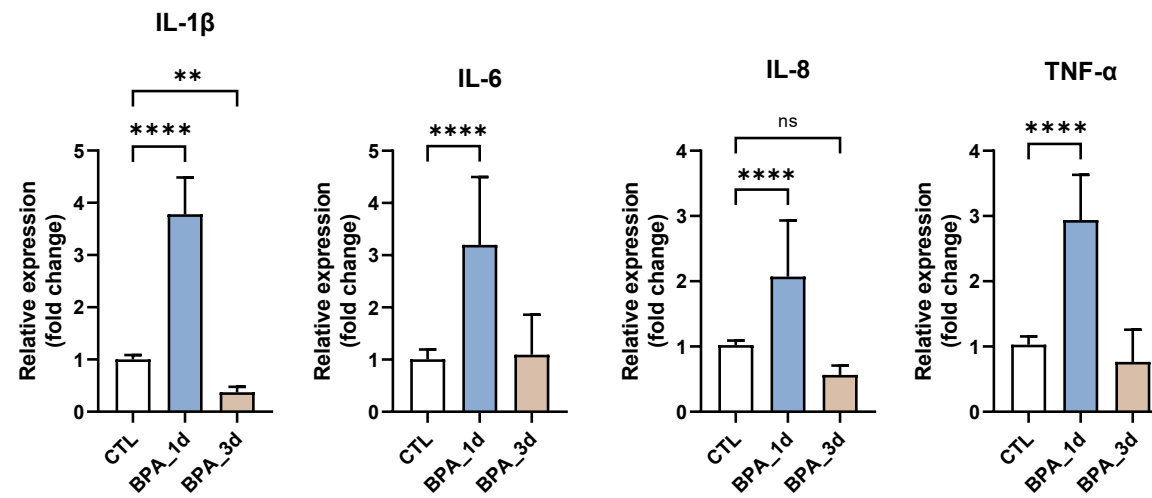
BPA_SmallAir



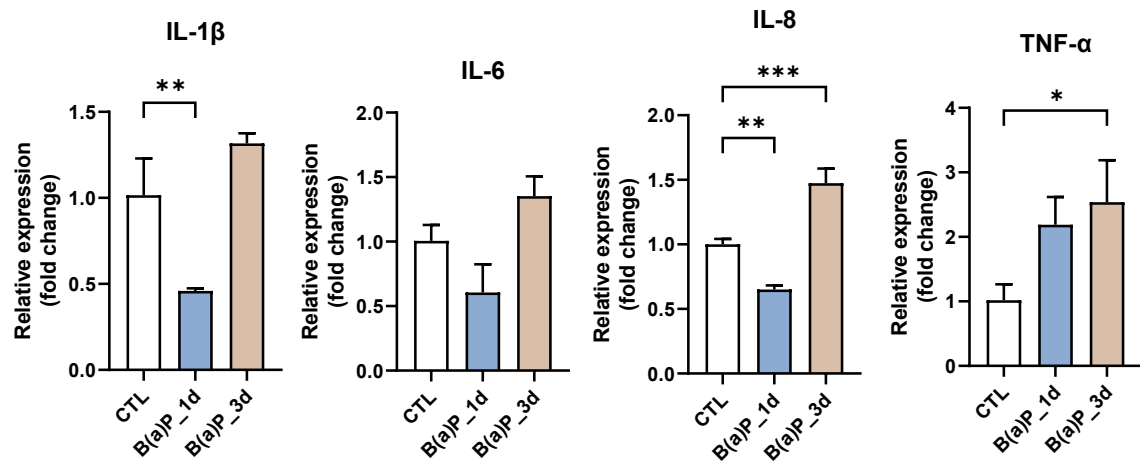
PM₁₀_SAEC



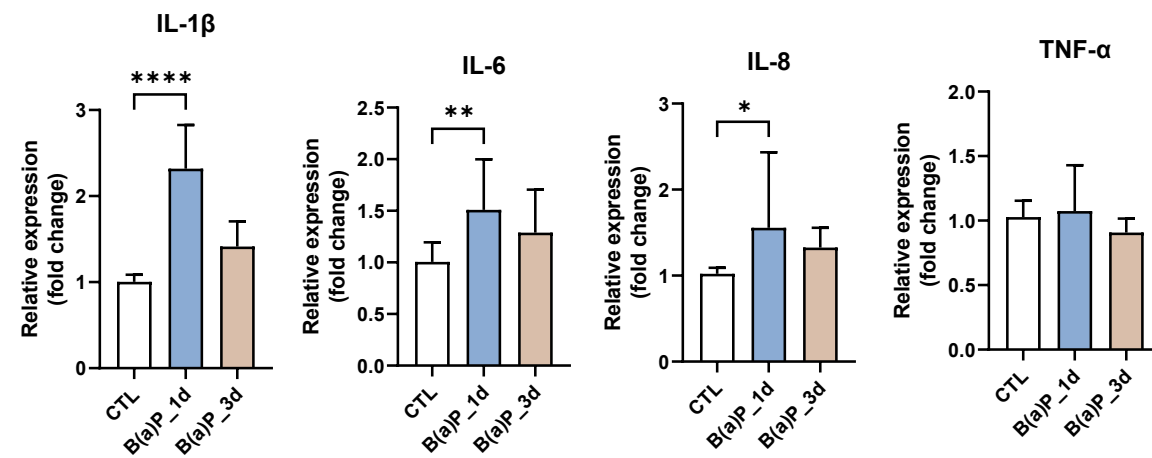
BPA_SAEC



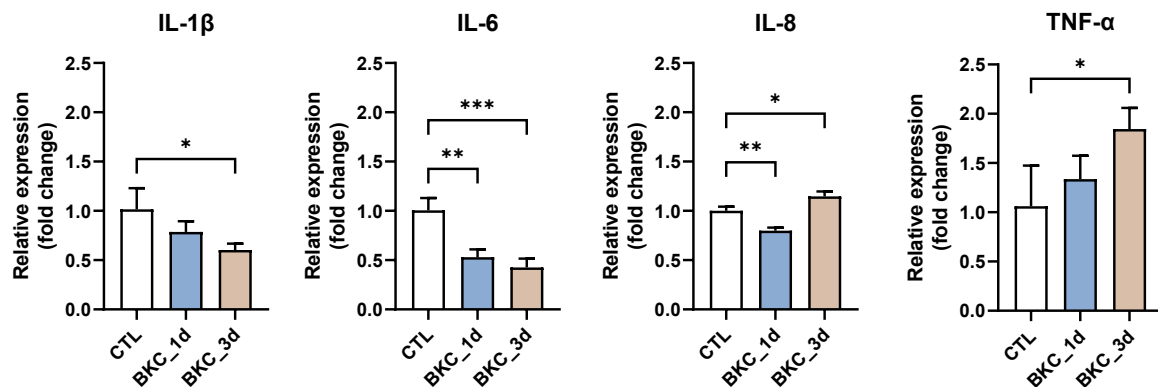
B[a]P_SmallAir



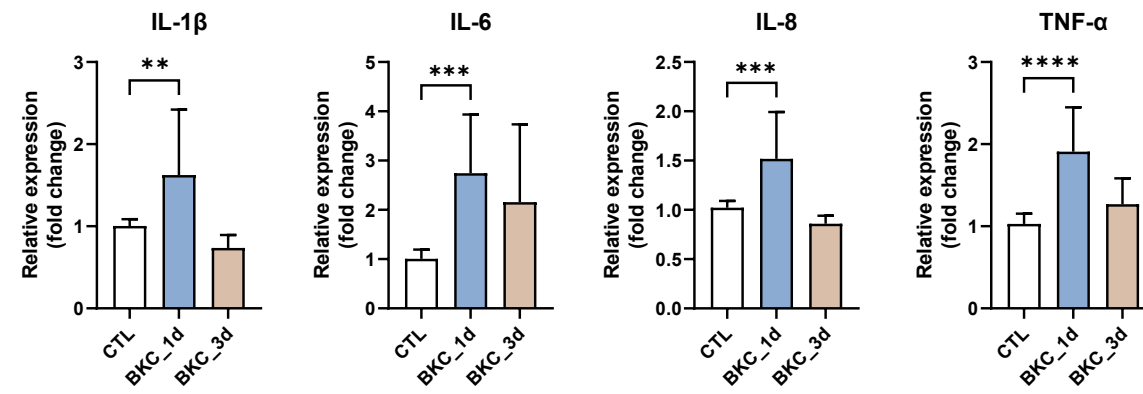
B[a]P_SAEC



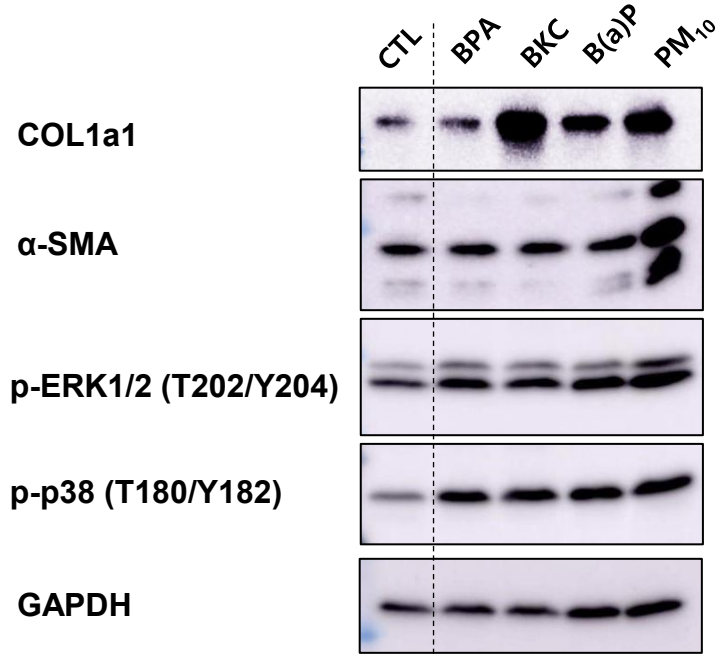
BKC_SmallAir



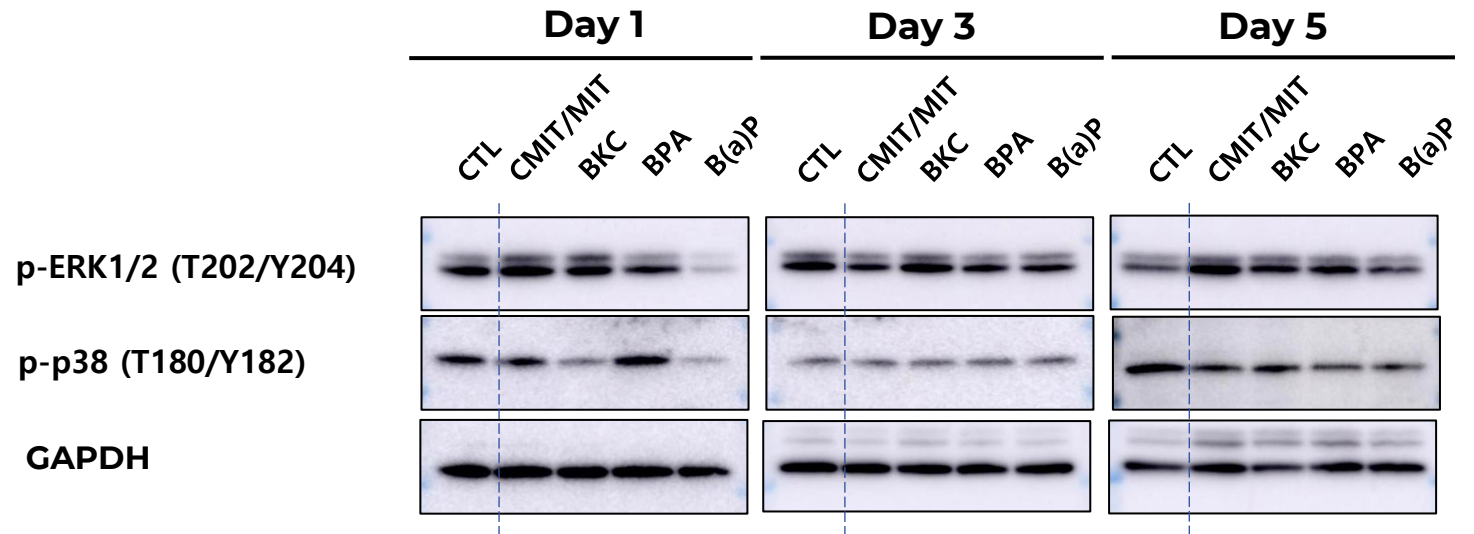
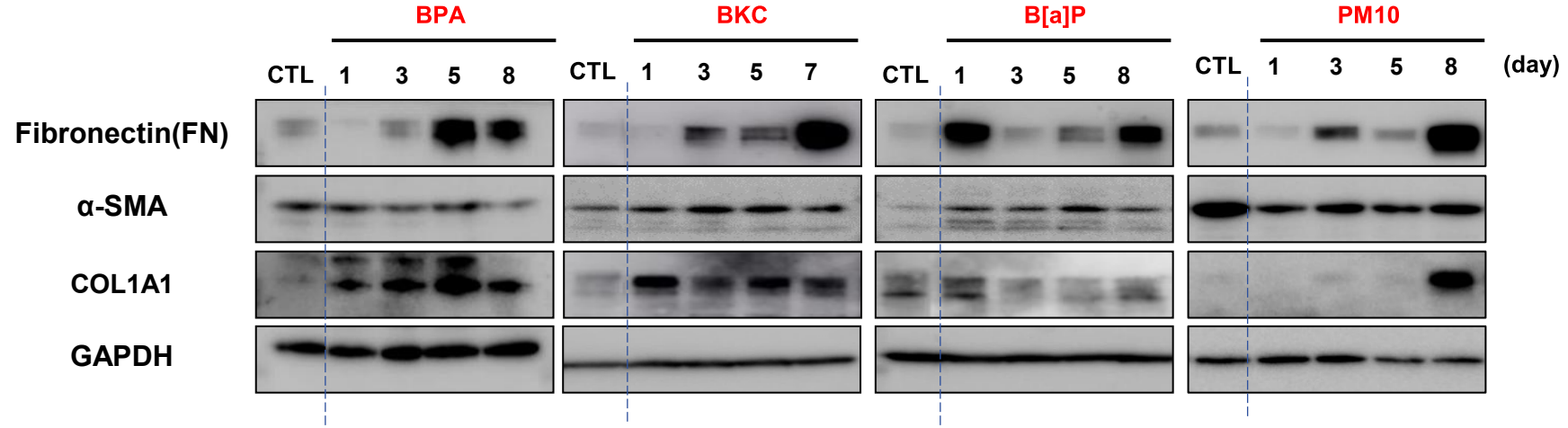
BKC_SAEC



SmallAir



SAEC

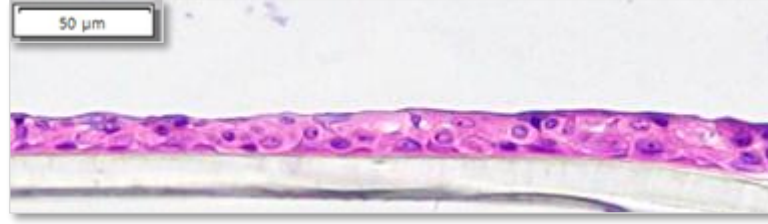


SmallAir

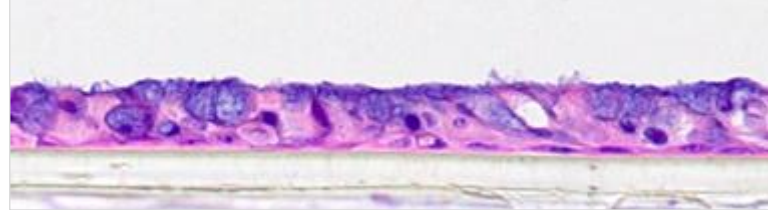
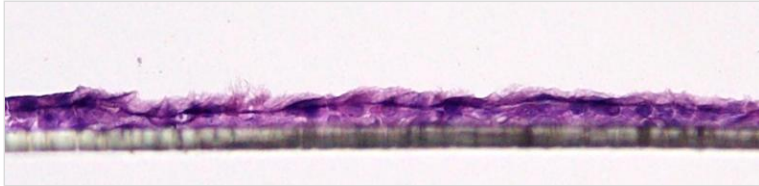
SAEC_ALI

NHBE_ALI

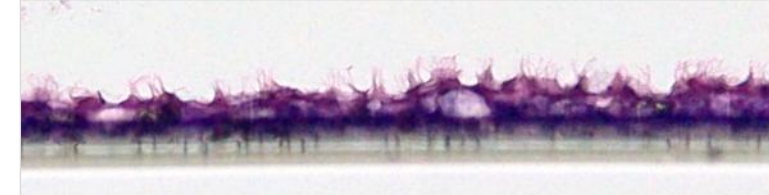
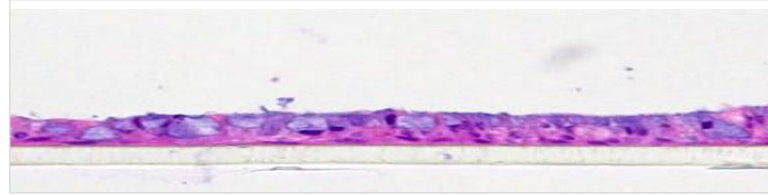
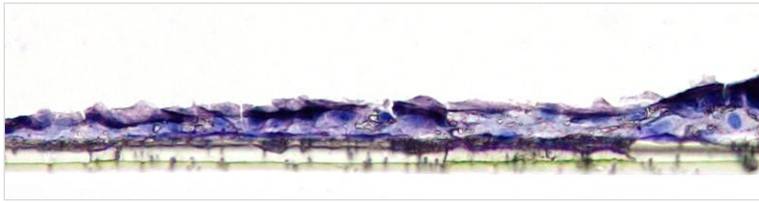
CTL



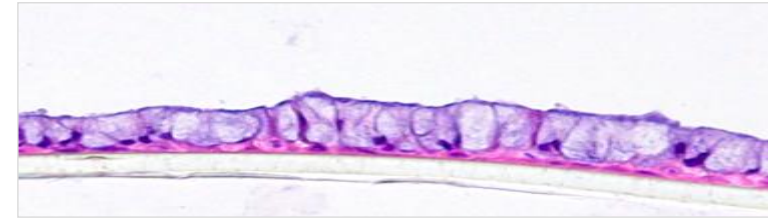
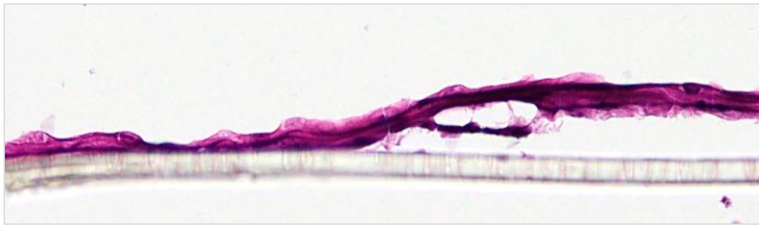
PM



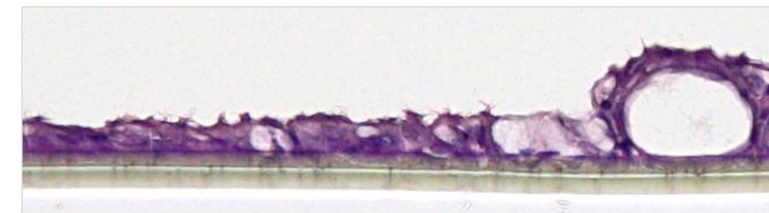
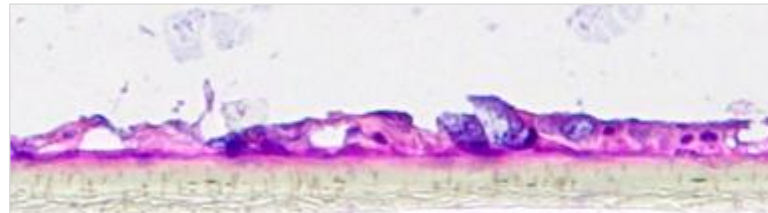
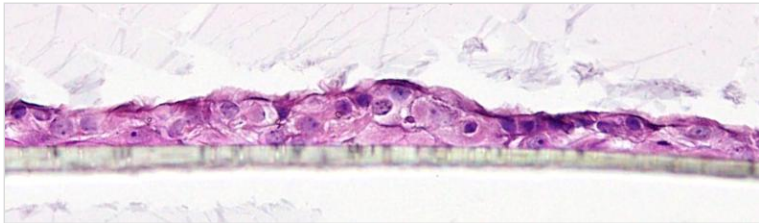
BPA



BKC



B[a]P





각 환경유해인자별 후보 바이오마커 탐색 : NGS 및 IPA 분석

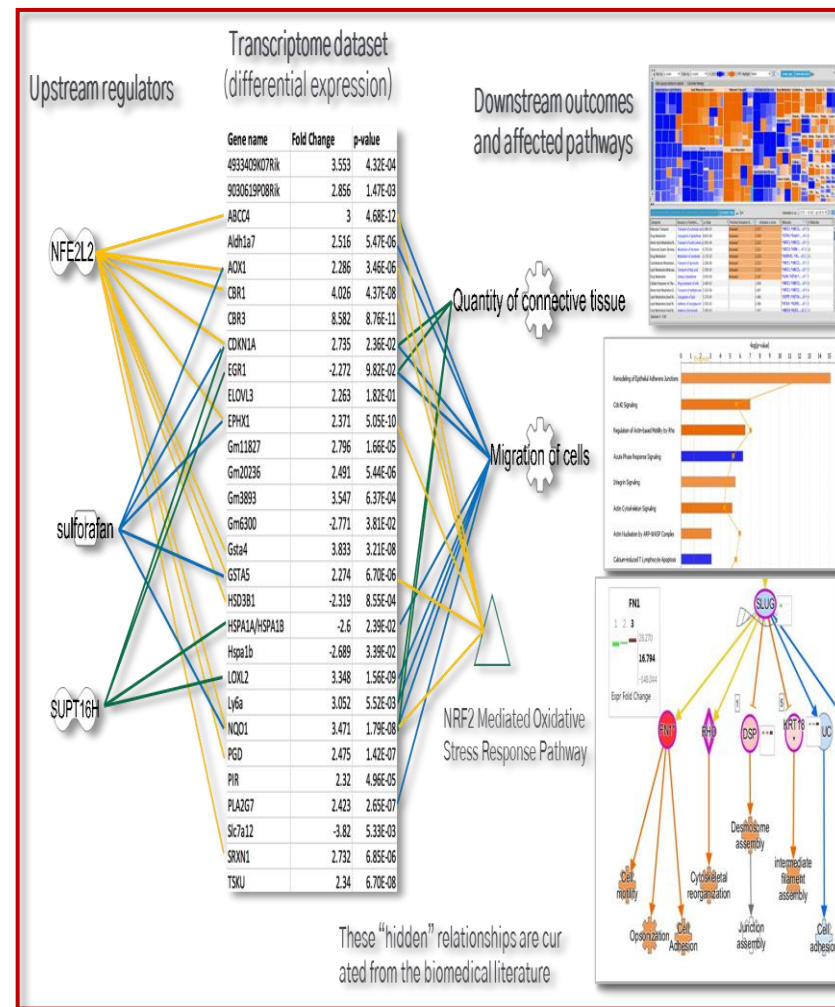
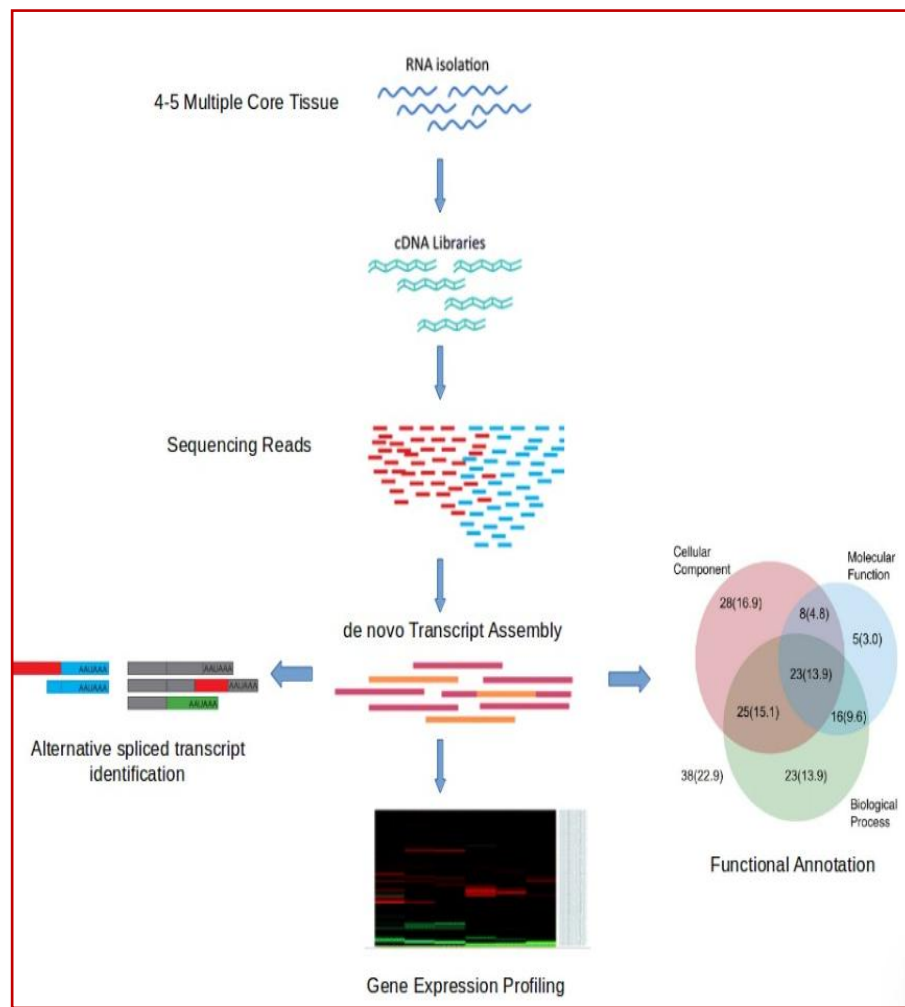
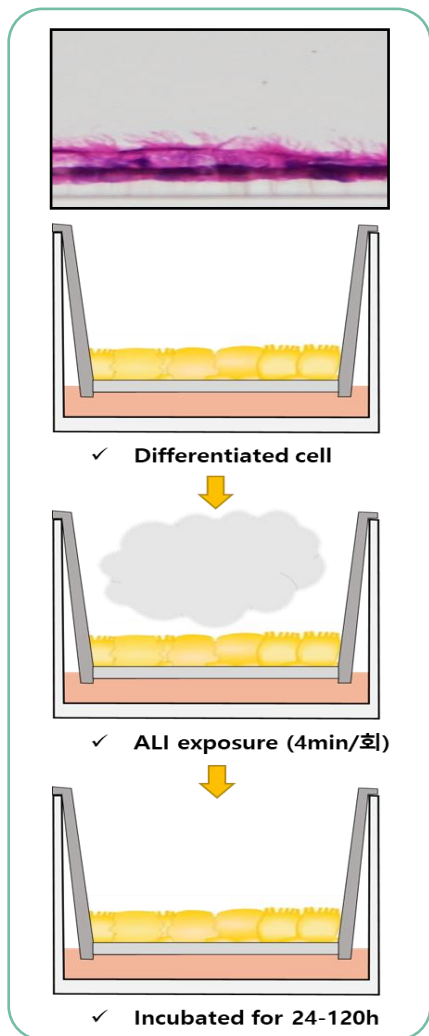
✓ SAEC 하기도 ALI 모델



✓ RNA seq. based NGS analysis

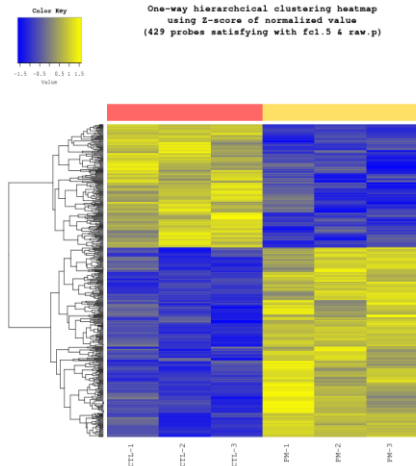


✓ IPA (core analysis, Iso/BioProfiler etc.)

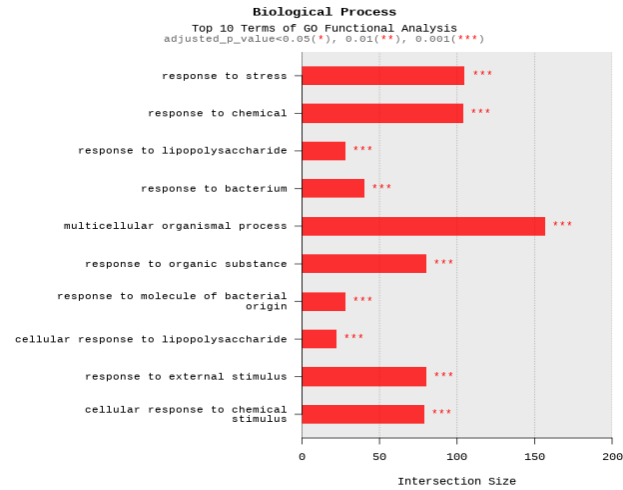


➤ SAEC ALI 세포모델에서 **PM** 노출에 의한 호흡기질환 관련 바이오마커 탐색

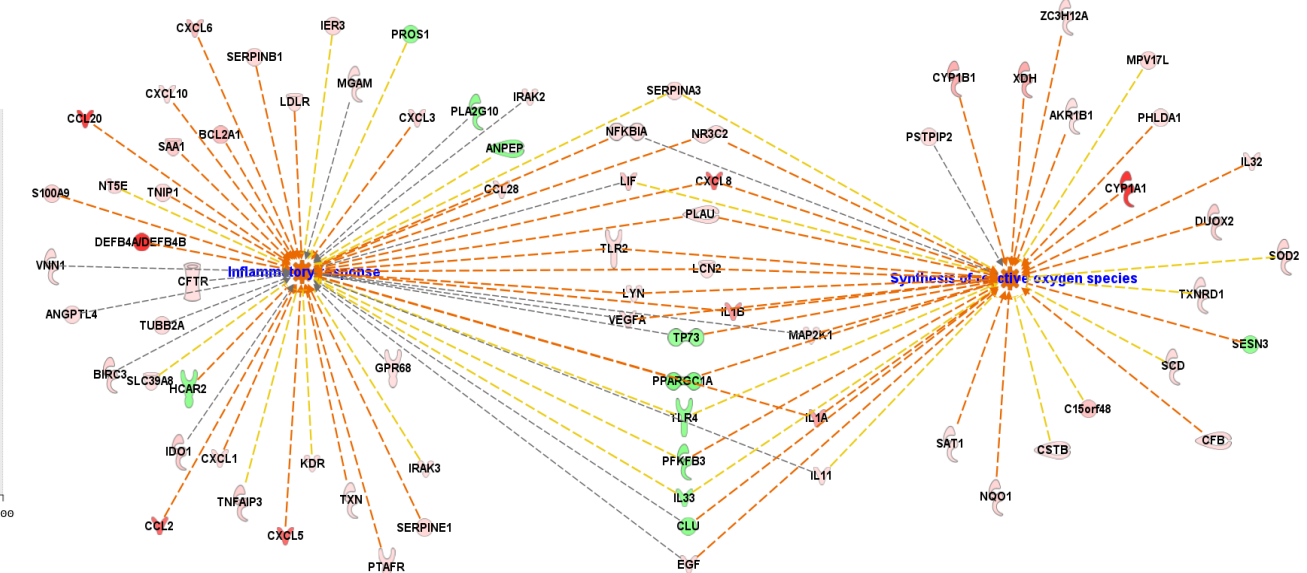
(a) Hierarchical clustering



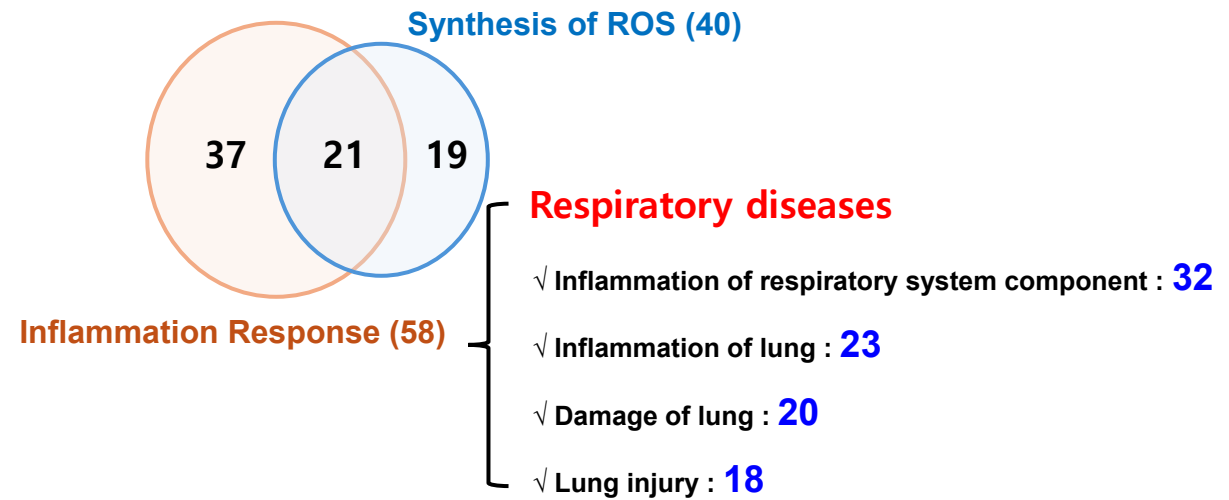
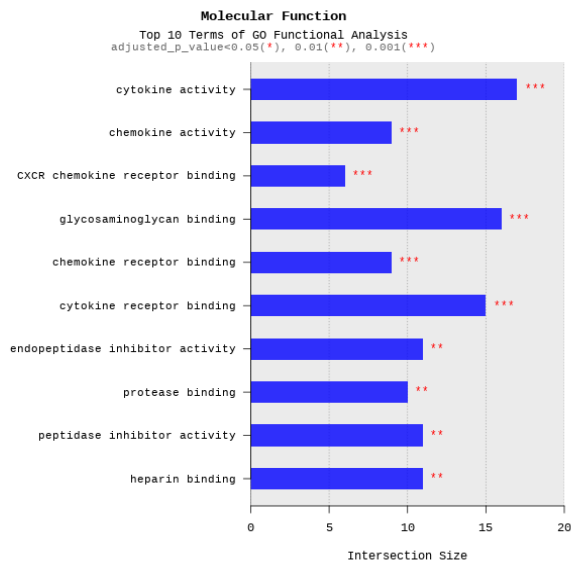
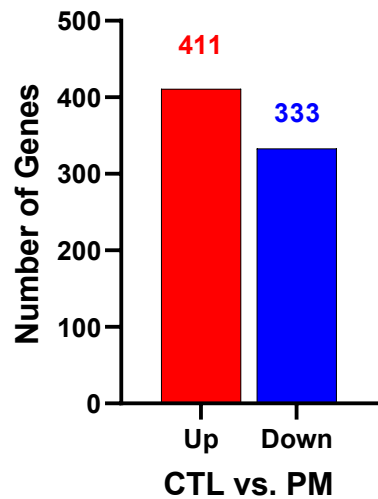
(b) Histogram of GO analysis



(c) IPA analysis

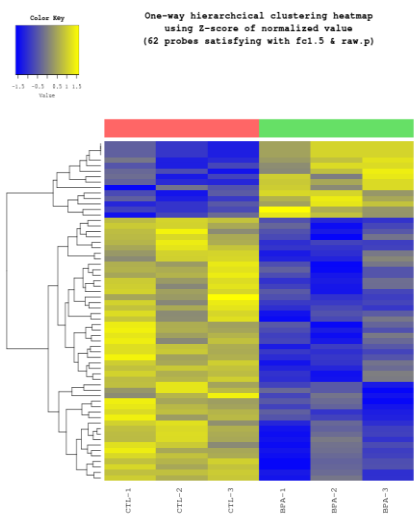


DiffExp Gene Statistics

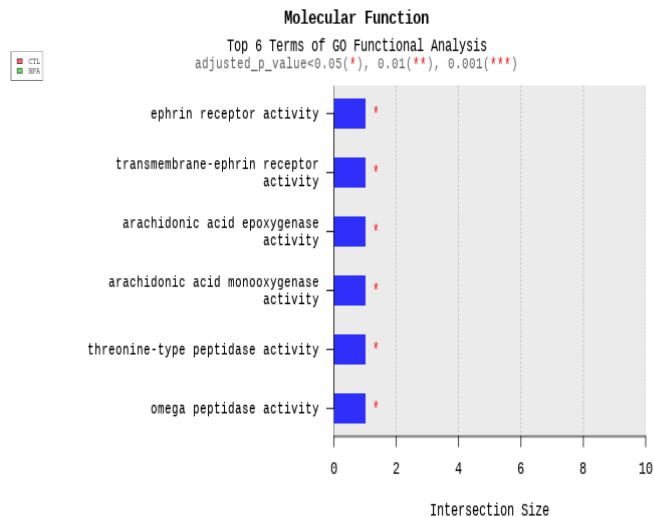


➤ SAEC ALI 세포모델에서 BPA 노출에 의한 호흡기질환 관련 바이오마커 탐색

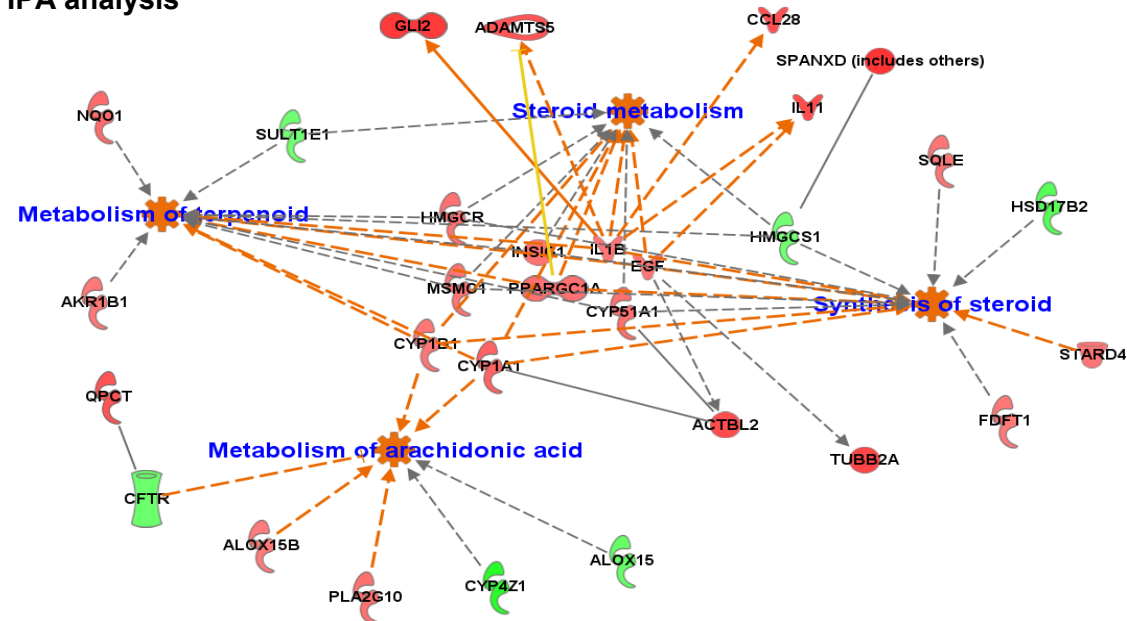
(a) Hierarchical clustering



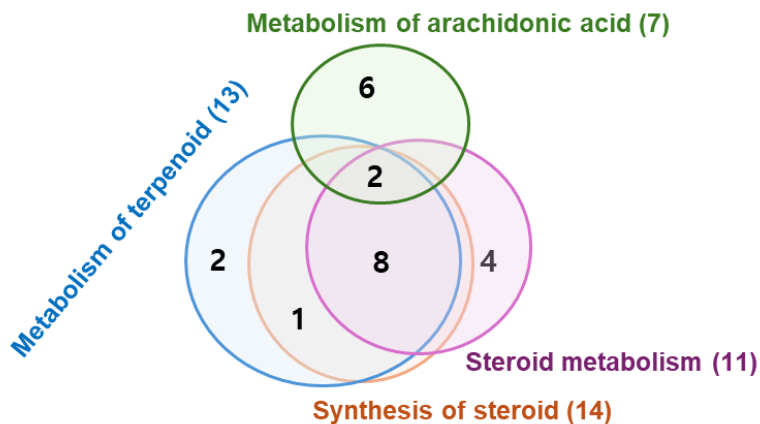
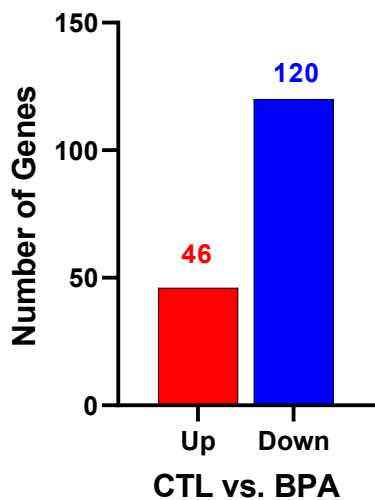
(b) Histogram of GO analysis



(c) IPA analysis



DiffExp Gene Statistics

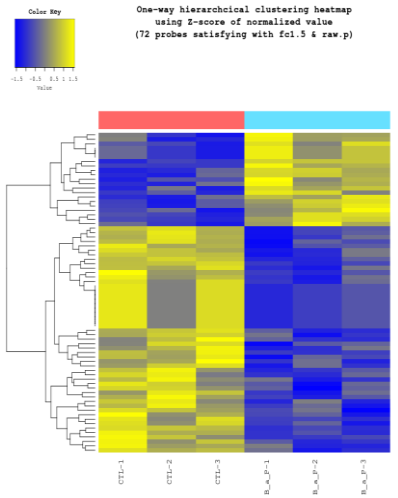


Respiratory diseases

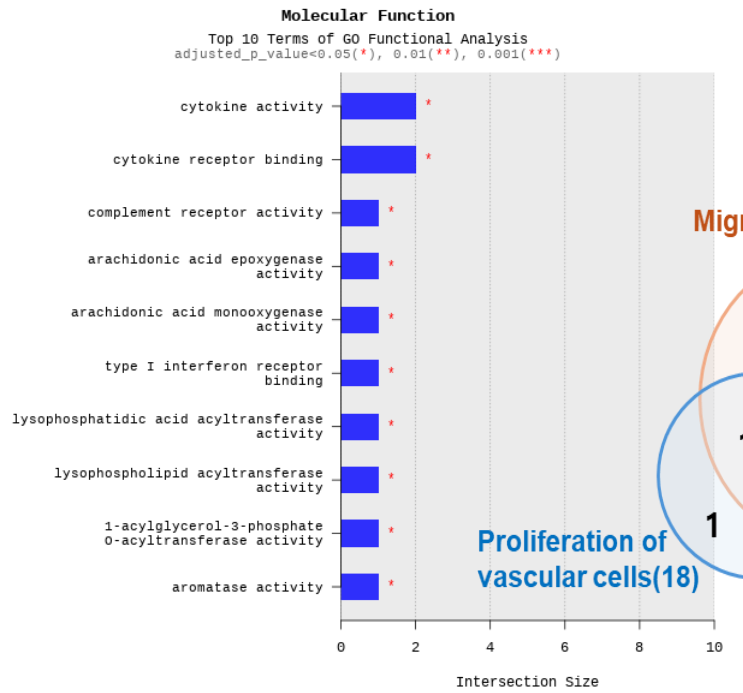
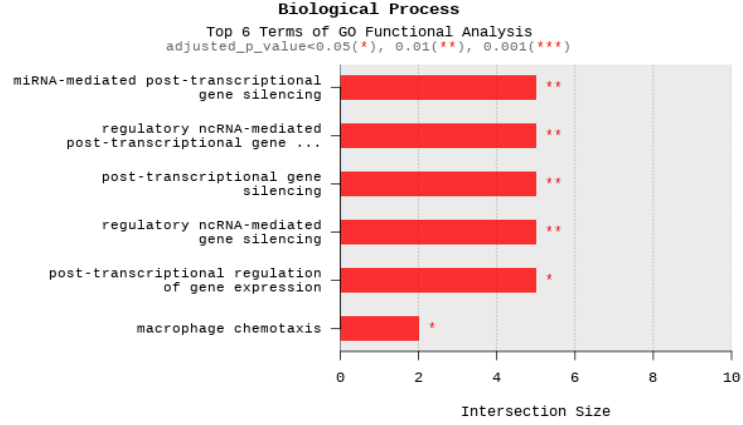
- ✓ Lung cancer : 13
- ✓ Inflammation of respiratory system component : 12
- ✓ Inflammation of lung : 8
- ✓ Inflammation of airway, Damage of lung : 6
- ✓ Lung injury, COPD : 5
- ✓ Acute lung injury, fibrosis : 4

➤ SAEC ALI 세포모델에서 B(a)P 노출에 의한 호흡기질환 관련 바이오마커 탐색

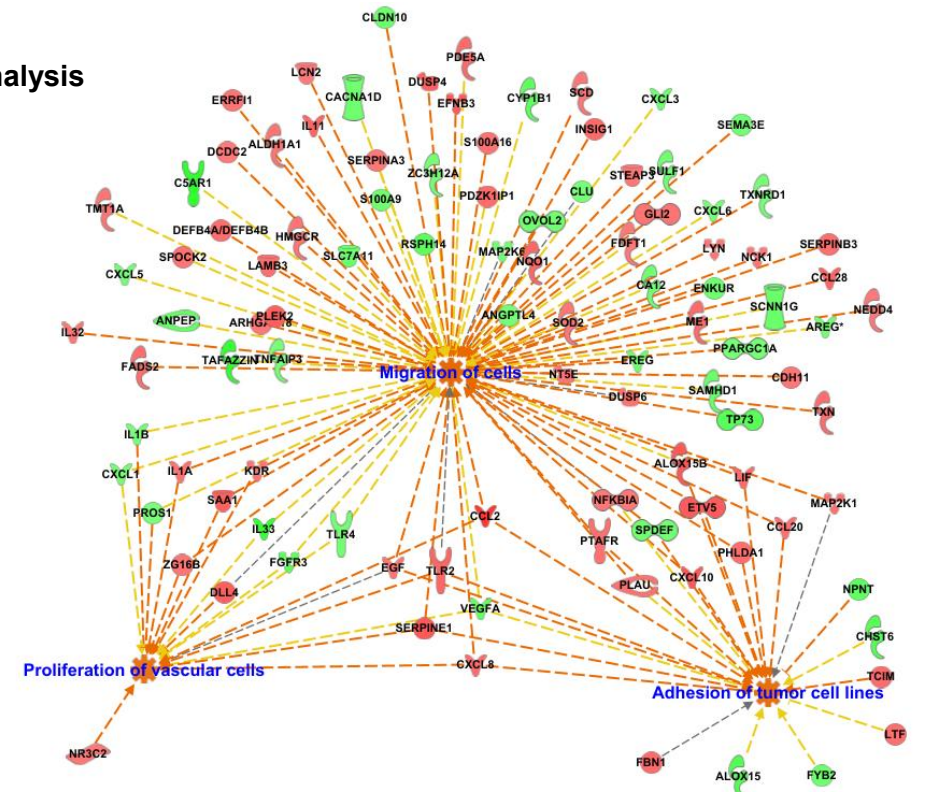
(a) Hierarchical clustering



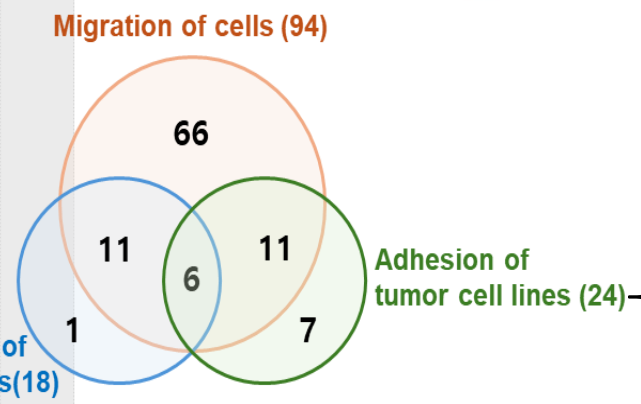
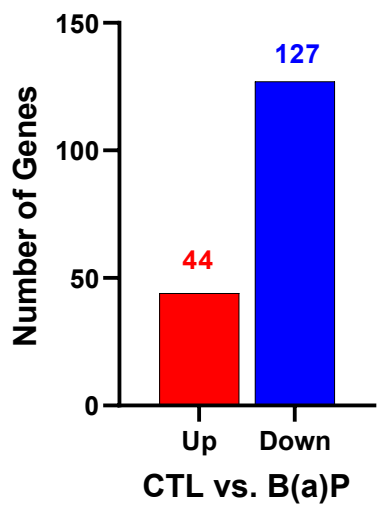
(b) Histogram of GO analysis



(c) IPA analysis



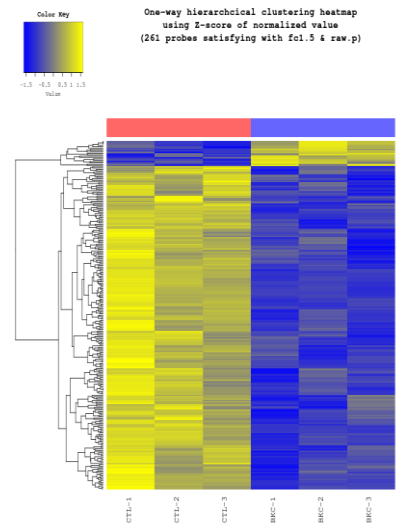
DiffExp Gene Statistics



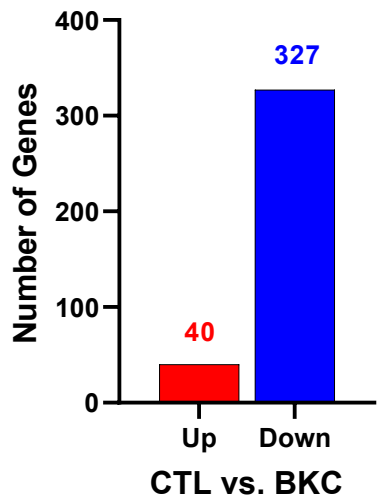
- Respiratory diseases**
- ✓ Lung cancer : 63
 - ✓ Inflammation of respiratory system component : 31
 - ✓ Damage of lung : 21
 - ✓ Acute respiratory disorder : 20

➤ SAEC ALI 세포모델에서 **BKC** 노출에 의한 호흡기질환 관련 바이오마커 탐색

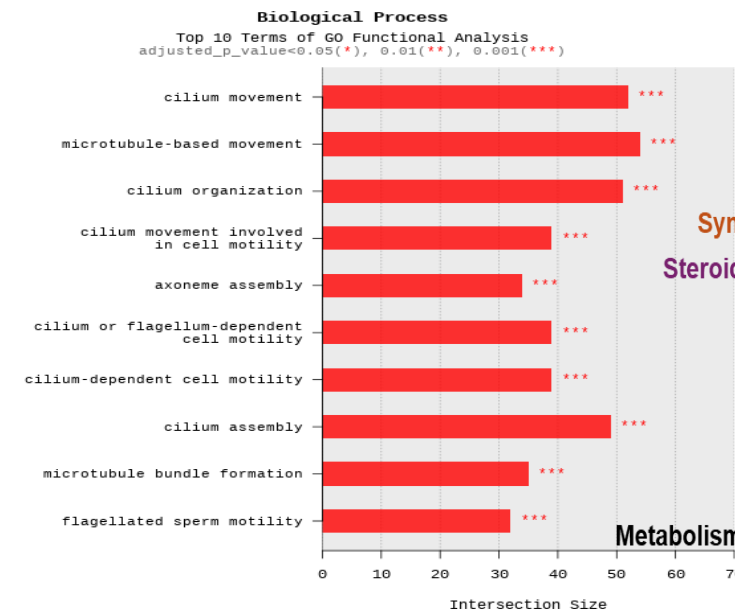
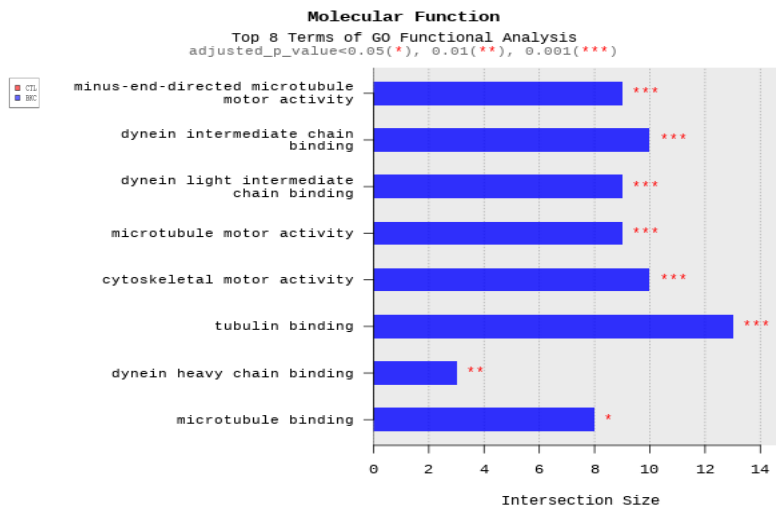
(a) Hierarchical clustering



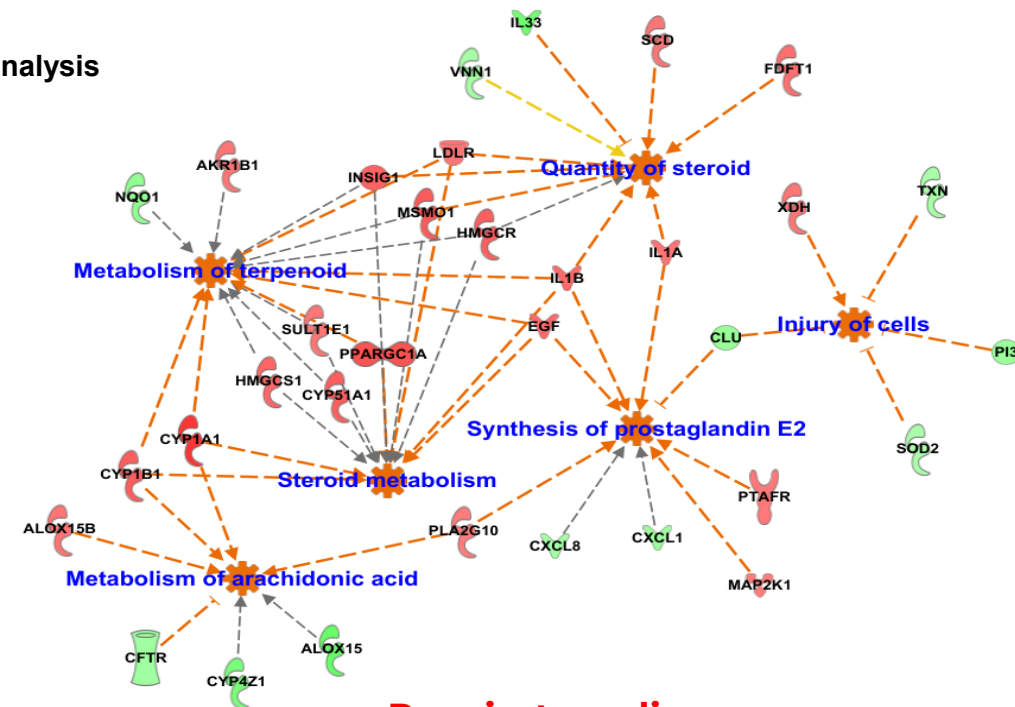
DiffExp Gene Statistics



(b) Histogram of GO analysis

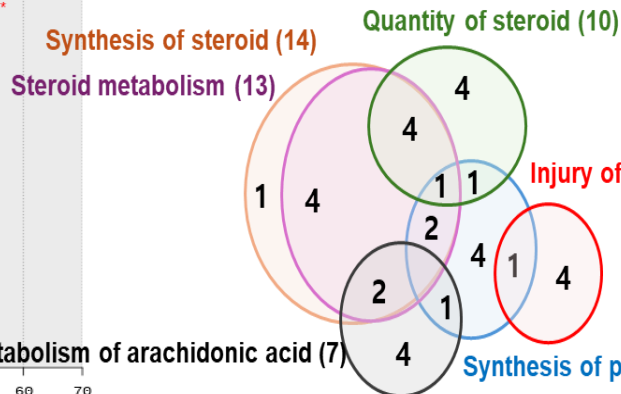


(c) IPA analysis



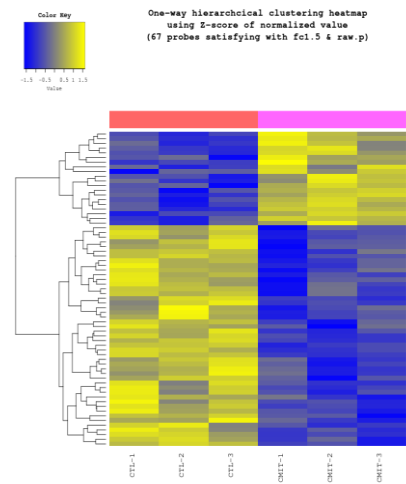
Respiratory diseases

- ✓ Lung cancer : 22
- ✓ Inflammation of respiratory system component : 17
- ✓ Inflammation of lung : 15
- ✓ Damage of lung : 12
- ✓ Lung injury : 11
- ✓ Acute lung injury : 9

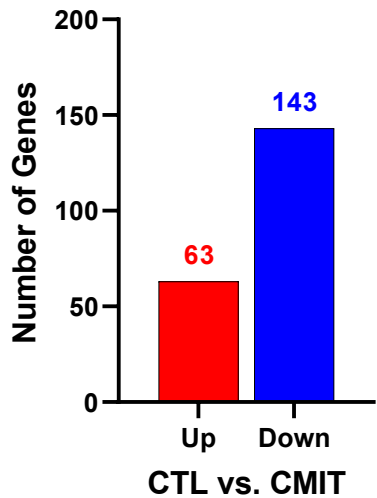


➤ SAEC ALI 세포모델에서 **CMIT/MIT** 노출에 의한 호흡기질환 관련 바이오마커 탐색

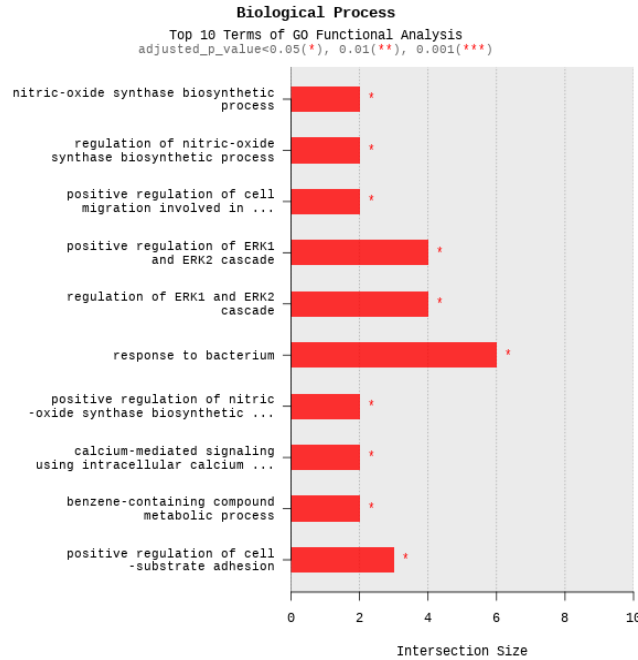
(a) Hierarchical clustering



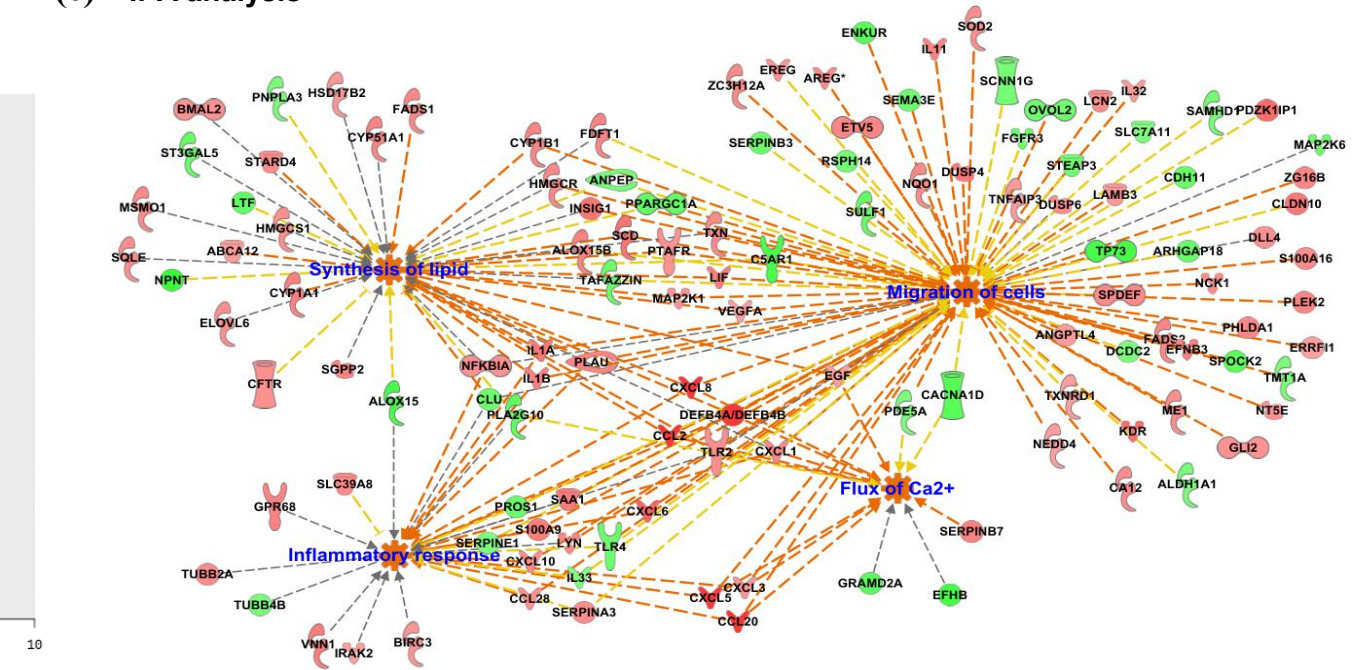
DiffExp Gene Statistics



(b) Histogram of GO analysis



(c) IPA analysis

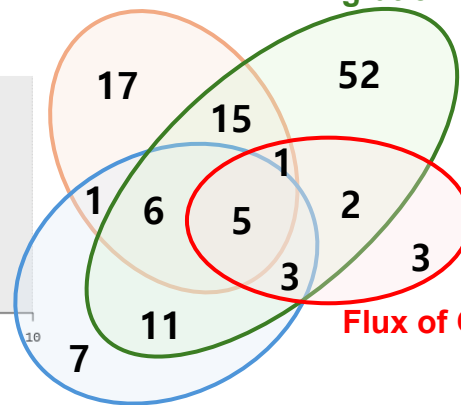


Synthesis of lipid (45)

Migration of cells (10)

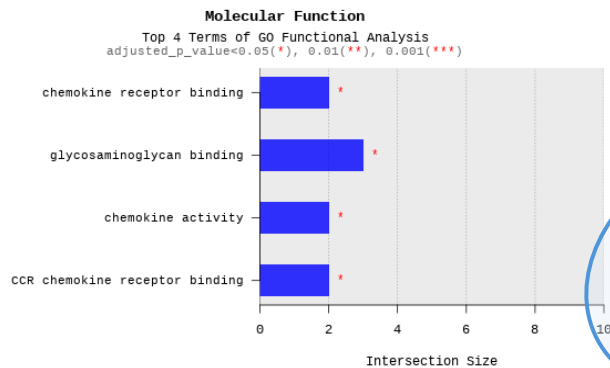
Inflammatory response (33)

Flux of Ca²⁺ (14)

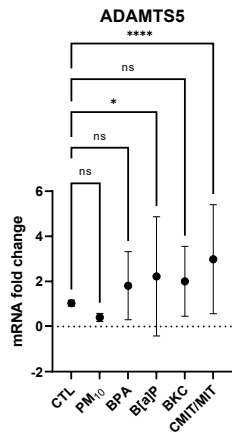
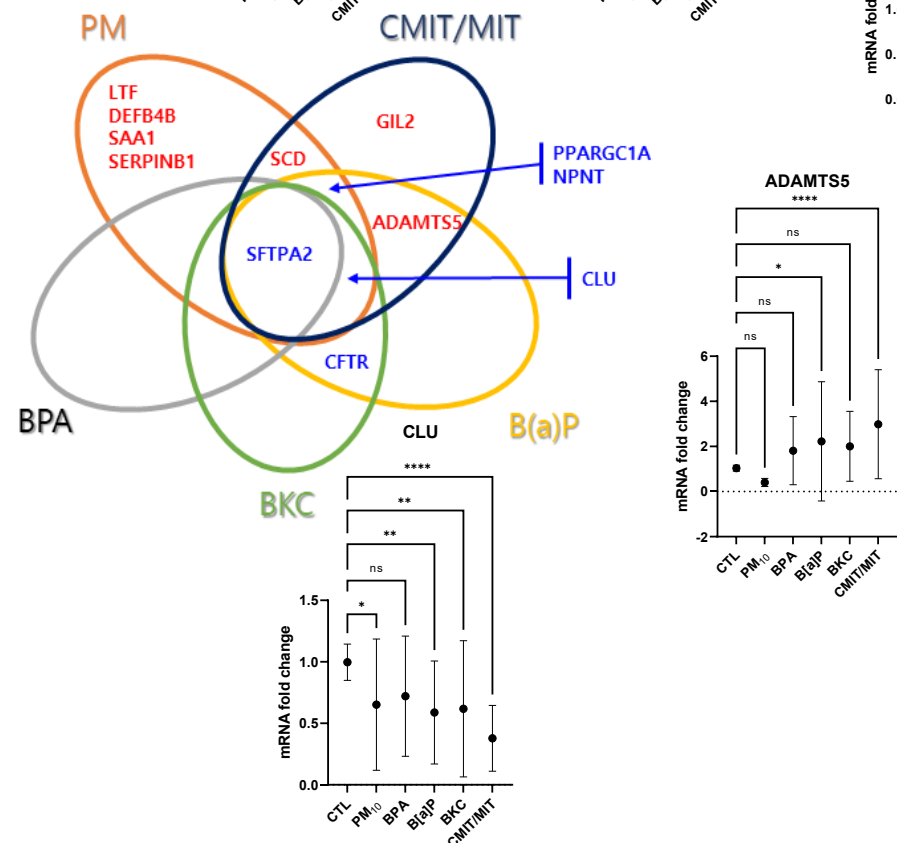
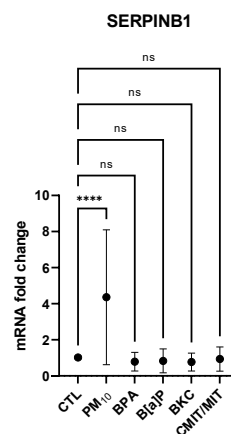
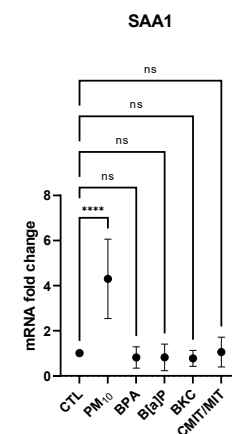
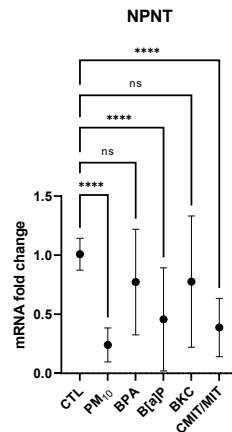
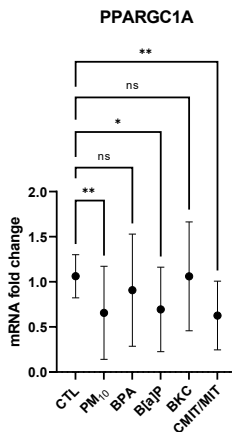
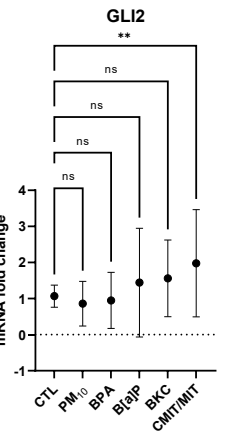
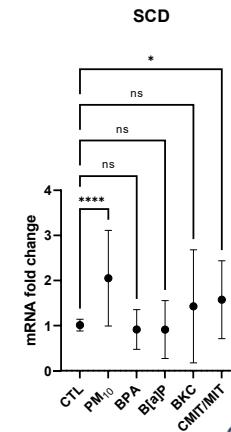
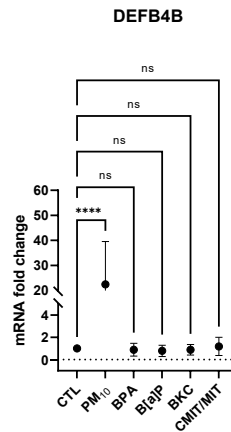
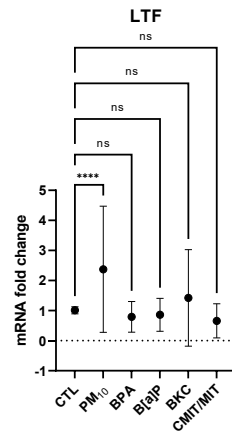


Respiratory diseases

- ✓ Lung cancer : 71
- ✓ Inflammation of respiratory system component : 42
- ✓ Inflammation of lung : 27
- ✓ Acute lung injury : 23



➤ In vitro와 in vivo에서 환경유해인자에 의한 호흡기 독성 예측 바이오마커 발굴 **in vitro**



→ 12개의 유전자와 환경유해인자와의 연관성 확인

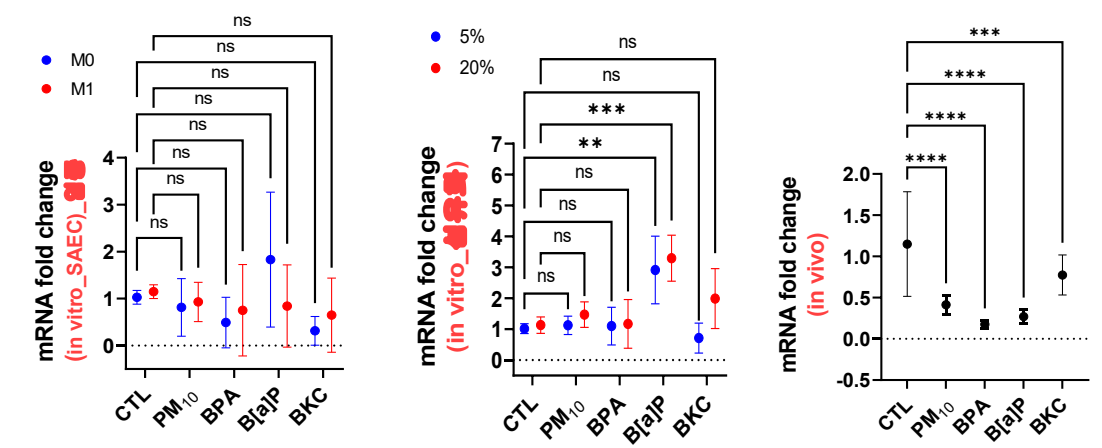
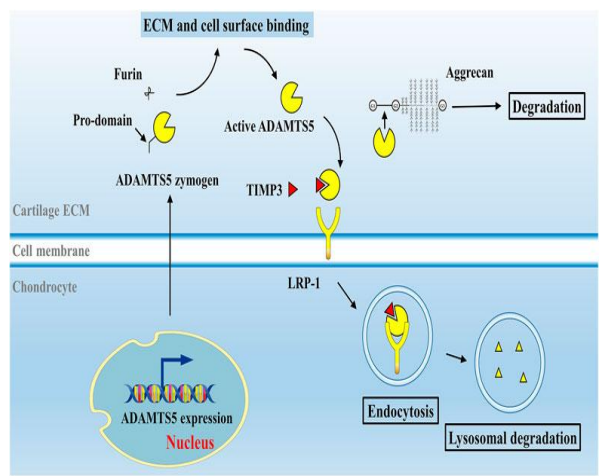
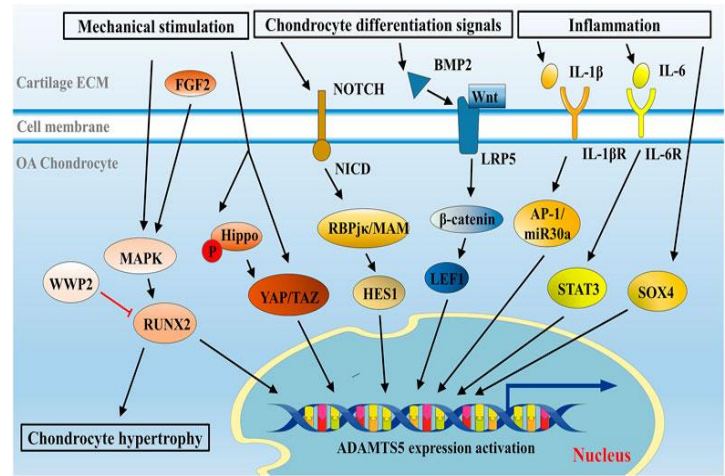
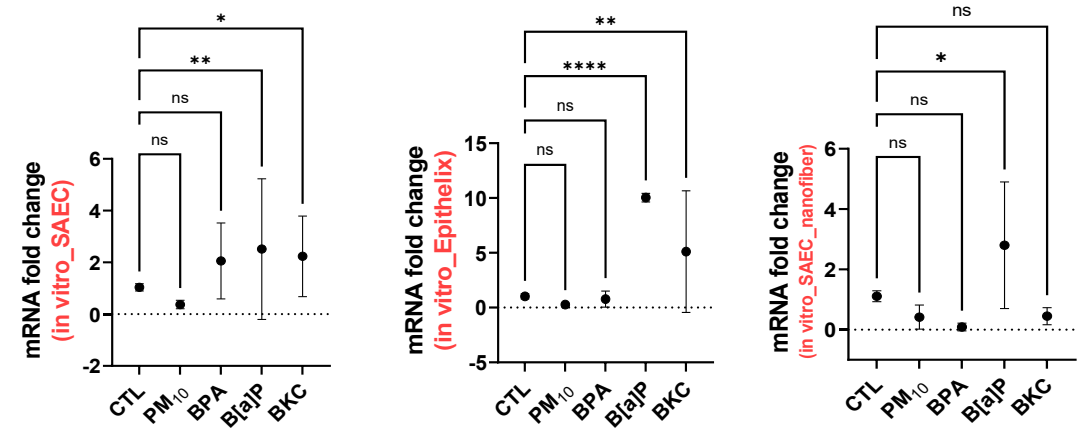
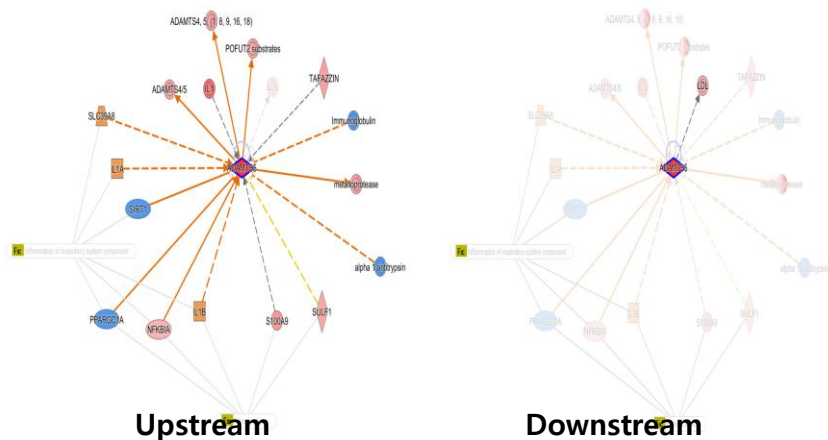
: UP-7개, DOWN-5개

- ✓ PM : LTF, DEFB4B, SAA1, SERPINB1
- ✓ CMIT/MIT : GIL2
- ✓ PM, CMIT/MIT : SCD
- ✓ B[a]P, CMIT/MIT : ADAMTS5
- ✓ BKC, B[a]P : CFTR
- ✓ 미세먼지, CMIT/MIT, B[a]P : PPARGC1A, NPNT
- ✓ 5종의 유해인자 : SP-A2, CLU

ADAMTS-5 (ADAM Metallopeptidase With Thrombospondin)

: 염증, 조직 재형성, 섬유화와 관련된 병리적 과정에 중요한 역할

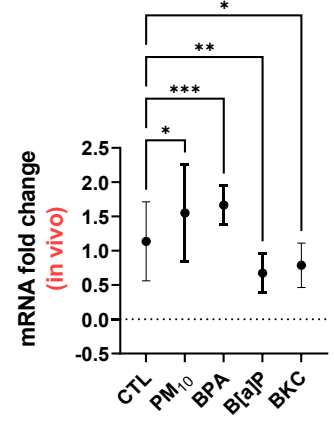
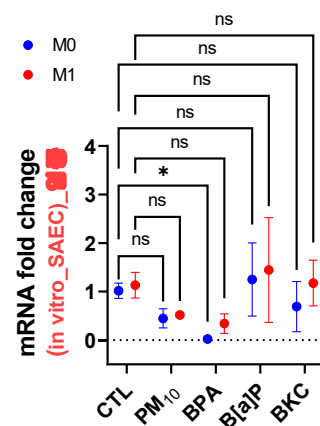
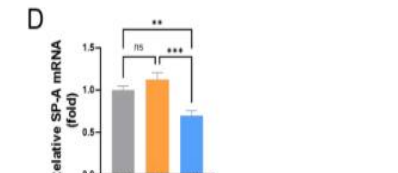
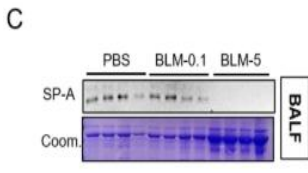
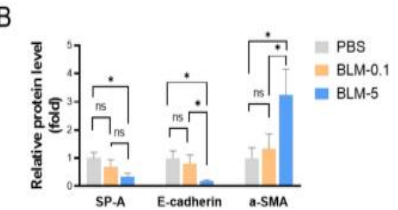
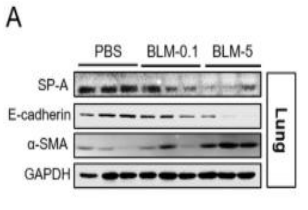
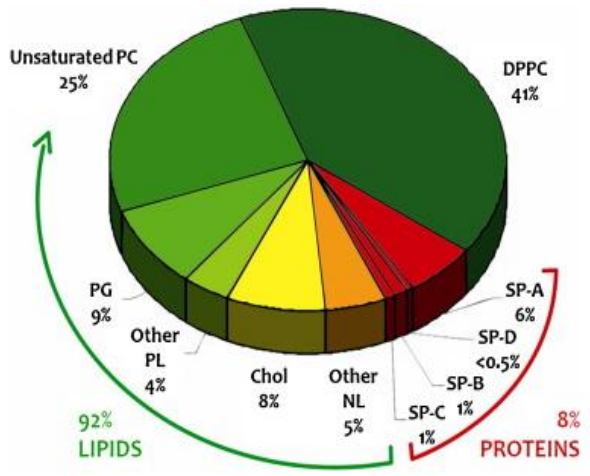
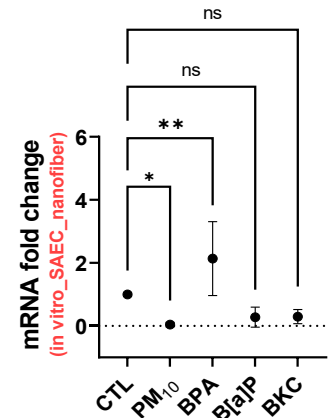
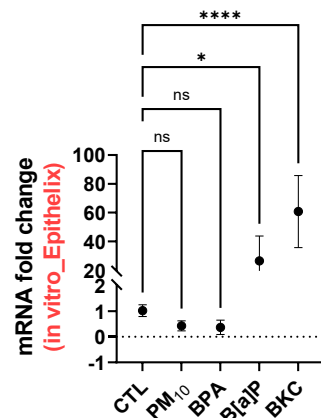
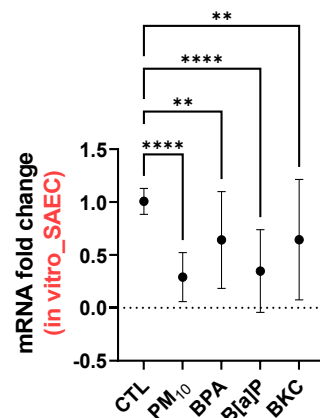
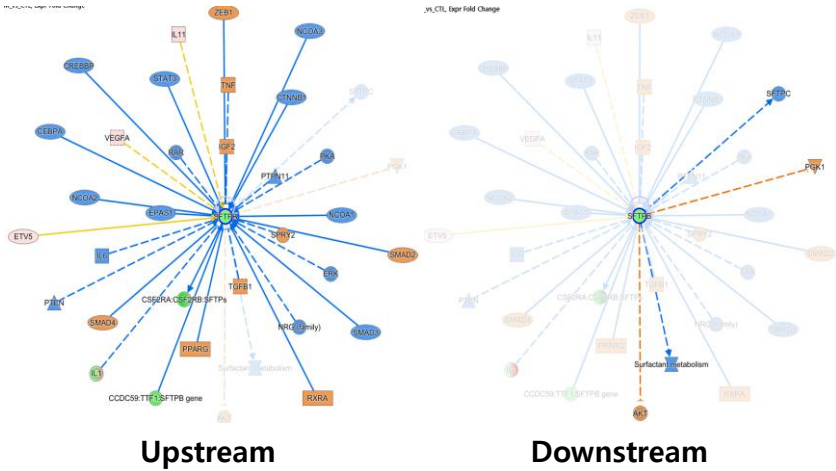
: ECM의 과도한 분해로 인해 폐조직의 구조적 손실 발생하고 분해산물로 염증 반응을 작용하여 질환에서의 진행을 악화



Biomarker Genes	환경유해인자	SAEC ALI (PET, 0.4uM)	Small ALI (Epithelix)	SAEC ALI (nanofiber)	SAEC 염증 ALI (nanofiber)		MRC-5 섬유화 ALI (nanofiber)		mice
					M0_LPS (-)	M0_LPS (+)	5%	20%	
ADAMTS5	B[a]P	↑	↑	↑	↑	-	↑	↑	↓

SP-A (Surfactant A): 폐포의 표면 장력을 감소시켜 폐포의 안정성을 유지하고, 호흡 유지에 중요한 역할

: cytokine의 분비를 조절하게 되는데 불균형을 초래하여 과도한 염증 반응을 억제시키지 못함으로써 조직 손상을 유발

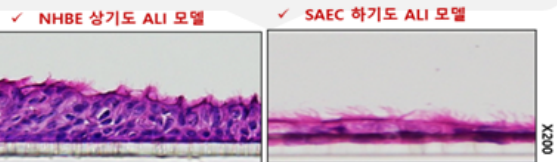


Biomarker Genes	환경유해인자	SAEC ALI (PET, 0.4uM)	Small ALI (Epithelix)	SAEC ALI (nanofiber)	SAEC 염증 ALI (nanofiber)		MRC-5 섬유화 ALI (nanofiber)		mice
					M0_LPS (-)	M0_LPS (+)	5%	20%	
SP-A	미세먼지	↓	-	↓	↓	↓			↑

고도화 및 추진 내용

현재

- ✓ 인체 유래 · 상하기도 세포 보유
- ✓ 기도 상피세포를 이용한 ALI 배양기술 보유

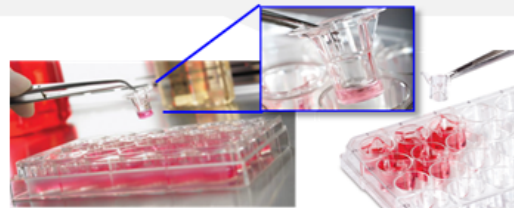


- ✓ ALI 배양에 대한 분화 관련 측정장비 및 분석지표 확인 방법 기술 보유

- ✓ 환자 유래 기도 상피세포 (IPF, COPD, 천식) 확보
- ✓ 각 세포별 ALI 배양 조건 확립

- ✓ ALI 분화 기간 단축 확립 (기존 4주 → 3주)
- ✓ 제작된 ALI 세포모델의 장기간 유지 (기존 4주 → 6-8주까지 기능 유지)
- ✓ 호흡기 장벽 기능 강화 (TEER값 제시)

- ✓ 3D ALI 세포모델 **시제품 제작**
 - 정상 호흡기 모델
 - 질환 특이적 호흡기 모델



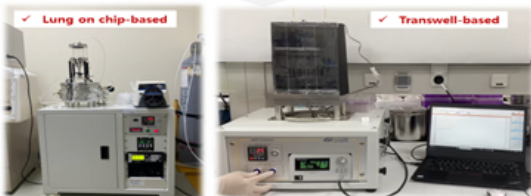
- ✓ 3D ALI 세포모델별 **SOP 작성**
 - 모델별 최적의 배양조건
 - 기능 및 반응성에 대한 프로토콜 확립

목표

고도화 및 추진 내용

현재

- ✓ Transwell 및 lung on chip 기반 에어로졸 자체 제작 장비 보유



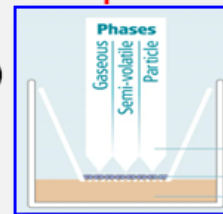
- ✓ 노출량을 정량적으로 제시할 수 있는 QCM 장착되어 있음
- ✓ 에어로졸 흡입 노출만 가능
- ✓ 흡입물질을 수동적으로 주입

- ✓ 가스상 및 미립자 노출 기능 추가
- ✓ 각 성상을 제어할 수 있는 모듈 장착 (반복 노출 → 노출 제어 오차 ±5% 이내)

- ✓ 노출 시스템 정밀 제어 기술 개발 (가스, 미립자, 에어로졸 노출 최적화)
- ✓ 온도, 습도, 유량 제어 기능 추가를 통한 실험 환경 표준화
- ✓ 자동화된 장비 제어 및 데이터 기록 기능 개발

- ✓ 다양한 물질을 노출시킬 수 있는 흡입 노출 **장비 고도화**

- 가스상
- 미립자 (미세먼지)
- 에어로졸 (액상)



- ✓ 흡입 노출 장비 **성능 표준화**
- 자동화 기능을 강화하여 정확도 95% 이상의 노출량 제어
- 실시간 모니터링 및 데이터 기록 확보

목표

**경청해 주셔서
감사합니다.**

