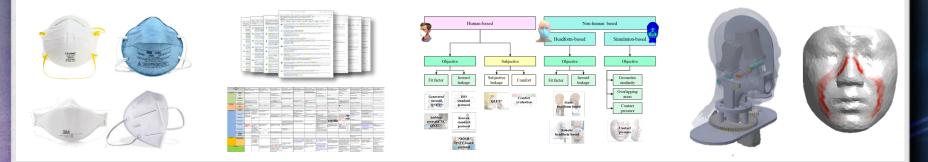




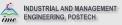
# Fit Evaluation Methods for Filtering Facepiece Respirators

안면부 여과식 마스크의 밀착도 평가 방법 분석



최신아<sup>1</sup>, 이아람<sup>2</sup>, 김희은<sup>2</sup>, 전은진<sup>1</sup>, 유희천<sup>1</sup>





Ergonomic Design

<sup>1</sup> 포항공과대학교 산업경영공학과 <sup>2</sup>경북대학교 의류학과/장수생활과학연구소

This work was funded by a grant from Ministry of Food and Drug Safety.

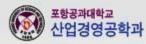
Global Contributor to Eco-Techno-Humanopia

# Contents

- Introduction
- Method of Literature Review
- Results
  - Human-Based Fit Evaluation
  - Non-Human Based Fit Evaluation
  - Comparison of Fit Evaluation Methods

Ergonomic Design Technology Lab

Discussion



# Background

- An effective fit evaluation method for filtering facepiece respirator (FFR) is important to provide proper protection for the wearer from harmful agents in various situations.
- Various fit evaluation methods have been developed for the design and certification stages of FFRs



FFRs

Fit evaluation on FFRs





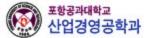


# **Motivation of the Study**

#### A new fit evaluation method with more adaptability and effectiveness is needed

- ✓ Widely used human-based fit evaluation methods are limited in terms of ethics, efficiency, and effectiveness.
- ✓ Non-human based fit evaluation methods are still under development and struggling with verification issues.
- $\rightarrow$  A comprehensive understanding of fit evaluation methods for FFRs are need



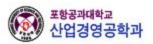


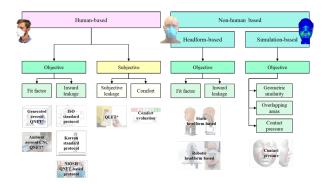


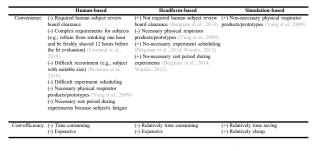
**Objective of the Study** 

# Identify features and research directions for fit evaluation methods of FFRs by literature review

- 1. A comprehensive literature review on fit evaluation methods for FFRs
  - Human-based fit evaluation
  - Non-human based fit evaluation
- 2. Identification of research directions by comparative analysis
  - Positive and negative features
  - Further research directions







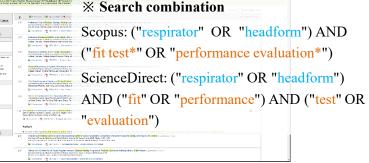


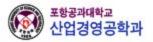
# Literature Review: Search Method

- □ Source: Scopus & ScienceDirect database
- Search criteria: keyword, title, abstract
- □ Keywords:
  - ✓ Evaluation target: respirator, headform
  - ✓ Evaluation measure: fit, design, performance, evaluation/testing



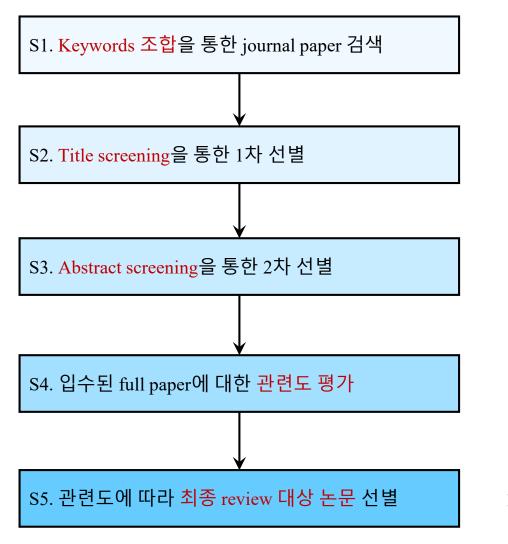
# Search result example







#### **Literature Review: Procedure**



Example: ("respirator" OR "headform") AND ("fit test\*" OR "performance evaluation\*")

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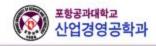
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Classification of high, moderate, and low relevance

115 건

98 건

Additional paper in reference Final review papers with high and moderate relevance



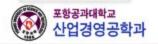


#### **Results: Paper List (Example)**

No.	Author(s)	Year	Title	Category	Relevancy
1	Rengasamy et al.	2014	Total Inward Leakage Measurement of Particulates for N95 Filtering Facepiece Respirators—A Comparison Study	TIL/IL	Н
2	Han et al.	2005	Evaluation of Particulate Filtering Respirators Using Inward Leakage (IL) or Total Inward Leakage (TIL) Testing—Korean Experience	TIL/IL	Н
3	Amy et al.	2020	Quantitative Method for Comparative Assessment of Particle Removal Efficiency of Fabric Masks as Alternatives to Standard Surgical Masks for PPE	Theory	Н
4	Huh et al.	2018	Fit Characteristics of N95 Filtering Facepiece Respirators and the Accuracy of the User Seal Check among Koreans	Theory	Н
5	McKay et al.	2018	Respirator Fit Test Methods – Are Faster Protocols Equivalent to OSHA?	Theory	Н
6	Lam et al.	2016	Evaluation of the user seal check on gross leakage detection of 3 different designs of N95 filtering facepiece respirators	Theory	Н
7	Landsittel et al	2014	Determining Sample Size and a Passing Criterion for Respirator Fit-Test Panels	Theory	Н
8	Lam et al.	2011	Sensitivity and specificity of the user-seal-check in determining the fit of N95 respirators	Theory	Н
9	Zhuang et al.	2008	Correlation Between Respirator Fit and Respirator Fit Test Panel Cells by Respirator Size	Theory	Н
10	Han and Choi	2003	Facial Dimensions and Predictors of Fit for Half-Mask Respirators in Koreans	Theory	Н
11	Sun et al.	2019	Real-time performance of filtering facepiece respirators at the workplace	SWPF	Н
12	Sietsema and Brosseau	2018	Are quantitative fit factors predictive of respirator fit during simulated healthcare activities	SWPF	Н
13	Zhuang et al.	2015	Respirator Performance against Nanoparticles under Simulated Workplace Activities	SWPF	Н
14	Kim et al.	2015	Assessing Real-time Performances of N95 Respirators for Health Care Workers by Simulated Workplace Protection Factors	SWPF	Н
15	Hauge et al.	2012	Real-Time Fit of a Respirator during Simulated Health Care Tasks	SWPF	Н
16	Regli et al.	2021	The role of fit testing N95/FFP2/FFP3 masks: a narrative review	QNFT	Н
17	Crinshpun et al.	2021	Evaluation of AccuFIT 9000: A Novel Apparatus for Quantitative Fit Testing of Particulate Respirators	QNFT	н
18	Fakherpour et al	2021	Quantitative fit testing of filtering face-piece respirators during the COVID-19 pandemic reveals anthropometric deficits in most respirators available in Iran	QNFT	Н

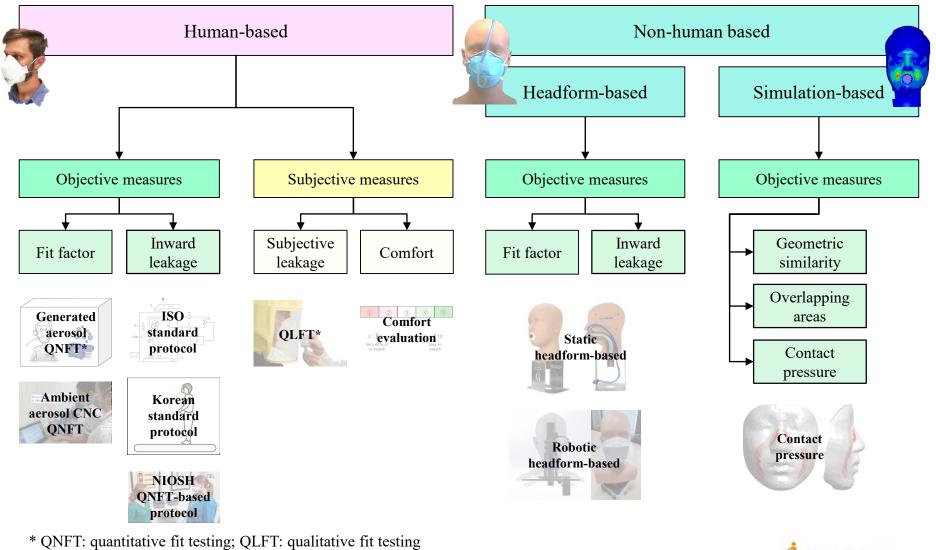
# **Results: Analysis Table**

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		Experiment Analysis Kar														
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Auth Tertzabiectr	uer (year) Title Manhas	Coffeyatal.) Comperirons Filtoning-Fac	(2012) af Five Methads f sepie ce Respirat	or Fit-Tertine N95	Bergman et al. (2012) Impact of Multiple Conrecutive Dannings on Filtering Facepiece Respirator Fit	Brazzowat al. (2010) Fit Tarting Respirators for Public Health Medical Emergencies	Ciattiot al. (2012) Effectivenez af Respiratar Markz fa Healtheare Warkerz, in France 30 (first tort); 20 (second tort)	Orinzhpun at al. (2021) Evaluation of Account 9000: A Nevel Apparatur for Quantitative PitTertin of Particulate Respirators	Fakherpaur et al. (2021) Quantitative Fit Tarting af Filtering Face-piece Respiratur: During the OVUD-14 Pandemic Reveals <u>Anthreasametric Deficits in Mart</u> 22	Foreland et al. (2018) Do Variour Respirator Models Fit the Workers in the Horwegian Smelting Industry? 192	Hauge et al. (2012) Real-Time Fit of a Reepirator during Simulated Health Care Tarkz	Sistroma and Brazzo au (2018) Arc Rouantitative Fit Factarz Prodictive of Respirator Fit During Simulated Healthcare Activities In	Karupp ar any and Obechaurki (2021 Comparizon of Fit for Soalod and Louro - Fitting Surgical Marke and N9 Filtering Focopie co Respirators 20	Laurence et al. (2006) Comportan of Performance of Thre- Different Types of Respiratory Protection Devices     22	Manganyi et al. (2017) e. Quantitative Respirator Fit, Face Sixer, and Determinants of Fit in South Africa Diagnostic Laboratory Respirator 542	
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	Tert exercises	OSHA fit- pratacal	tarting instr (2) a (3)zi exer	uction I hock worszoal ix-denning,zix <u>size SWPF</u> 77 armal breathing,	fittart	marke.	Virual absorvation Testing forted 10 minuter by			Decide mark test order (constantly changed)     Explain how to don the current reminator correctly     reven as remined for marking.	Ptroatment (IV), and us und care [WO])	Initial 2.5 min fit factor (FF1): Five 30 year exe. (normal broathing, hear head year and down, talkir	ured adherive medical tape tare cur- the new derian Check worszeal Perform faur exercises (bending	<ul> <li>pratical that pravider fit factors the are highly correlated with amo aruse of actual expansion during simulated health care.</li> </ul>	e Fallaued (OSHA, 1910),	_
	Time Duration Repetition		mavi	oop broathing, (3) inghoadzido tu Ionoraizo		Each exercise lasted approximately	rorpiratar mark			deep broathing, turning the headride tazide, maving the head up and dawn		The second secon	r alling, moving headride tazide, and maving head up and dawn) far each			
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Analysis	Objective measure Analyzis methnd		wine mean qean devi-	ulate the Sth ontile SWPF value I the quametric n (GM) and the netricatanderd atian (GSD) equired valuer for		evorall fit factor far 7 oxercize (excluding the grimace) (excluding the grimace) (excluding the grimace) (excluding the second	Evaluation critoria:FF≥ 100 Comparizion among the different types of marks (P < 0.05): chi- zyaves tot	All statistical parameters, including the tot searchivity, predictive value of a pars, test predictive, predictive value of a fail, and Kappartetistics, met modetary, advised, and f	The hormanic mean of each exercise fit facture was used to calculate the "averall fit facture" by the PartoDount 9 corpirator fit tarter. The overall fit facture was compared the misimum required FF for FFFc (F -100).	the averall FF data were found to be	data abtained immediately before and after each experimentalizerine, user then applied tartined ardize results from the tun instruments.	Final FF and SWPF wore abtained by calculating the geametric harmonic mean of the five averagine FF and the three activity SWPFs, respectively. Similarly, averall FF and averagin WPF ware calculated ar geametric harmonic mean of FF land FF2, ar SWPF3, SWPF3, SW	The several life factor for the exercise mondate by OSHA reader d's calculate during the harmonic mean of individual exercise fit factors calculate during the harmonic mean of individual exercise fit factors calculate during the factor of the theory of the factors of the factors that the factors of the factors of the theory of the factors of the factors of the theory of the factors of the factors of the theory of the factors of the factors of the factors of the theory of the factors of the factors of the factors of the theory of the factors of the factors of the factors of the theory of the factors of the factors of the factors of the factors of the theory of the factors o	or The generative mean (GM) and the 5th percentile values of the SWPF7 uses computed by cotogory of corpicatory protoction, wins the rise over all SWPF values. Hermonic mean	A participant parred the fi text if the overall fit octor of theri exercises user-100 ANOVA, Kruckel-Wallir, Students t texts and Wilcomm rank-sum texts Chirquese onlyzin	
Kay	findingr		4010	rmining a paperly	The datazuggert that 5 consecutive dennings can be performed before FF consistently drop below 100.	user lagant all y dirtributed; thur, "Far 80% of fit tests; the researcher noted ages at the surprises during me at more extension; must frequently at the annex afterting. "Gaps at the chinaser and cammady abserved during the head we and dams exercise.	The Ret-fail and duckkill respirator marks som tabe better adapted to healthere settings then hard shall respirator marks.	Accur IT 9000 ir capable of identifyin minadequate fit of the tested respirature with assessitivity 0.95 and specificity of 0.97, which meats the AMSI requirement of 20.95.	Cupyrhaps >> vertical flat-fald respirators	hert der crited by Ingrearmal * The rappingtum model user the ztranspace product and the overall fit facture, * The other predictors (supposed, and comfort zone) did not improve the fi of the model.	Azimulated uarkplace protection	FF was highly correlated with the averall SWPF (r. 0.30) Each exercise FF was highly carrelated with the averall SWPF Narmal locathing, head up and dawn, and talking ware mark predictive af averall SWPF.	Among the exercises, talking held a growter offset an reducing averall fi facture for these all developments then for the 1955 FFR These ald energical mark, when annowed with the 1955 FFR, offset all better research all be established by and	t Denni 3000 - 7 June - ander - ander - ander - ander Quametric mean (GH) SWPF valuer	Multiple Ingirtic regression analysis Abaued that face length in mm (add ratis [OR] - 1.04, 95% confidence interval [OI] - 1.00-1.09), nor al root breadth in mm (OR - 1.16, 95% OI - 1.06 - 1.20), and regression and OI - 0.56, 45% OI regression and the other states of the other states of the other states of the other states of the other states of the other states of the other states of the other states of the other states of the other states o	-





#### **Literature Review Results: Summary**



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👯 산업경영공학과

Ergonomic Design Technology Lab

#### Human-Based Fit Evaluation: General Requirements (1/2)

#### □ 평가인원

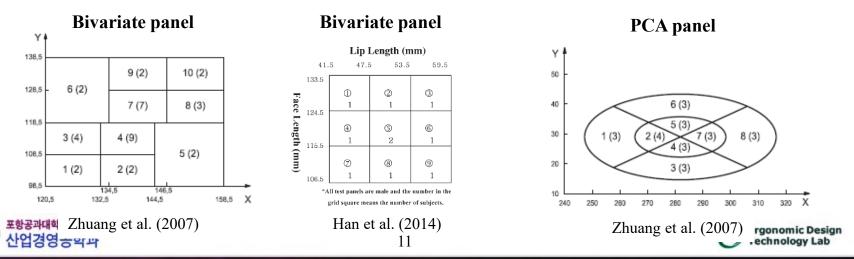
- ✓ 8명 ~ 1,271명 (median: 30)
- ✓ 최소 인원: 10명(식약처), 최소 15명(ISO, NIOSH)

#### 🗖 모집 조건

- ✓ 얼굴 치수
  - ▶ NIOSH bivariate panel: 얼굴 길이(face length), 얼굴 너비(face width)

(note) 기타 bivariate panel: 얼굴 길이(face length), 입 너비(lip width)

▶ NIOSH PCA panel: 10개 얼굴 치수

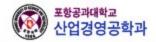


#### □ 모집 조건

- ✓ 건강상태: 심혈관계 질환, 고혈압, 천식, 폐렴, 호흡기 질환이 없는 사람(ISO 16975-3)
- ✓ 얼굴 특징: 얼굴에 흉터가 없어야 함(ISO 16975-3)
- ✓ 성별: 남:여 비율 1:1 (Brosseau et al., 2010)
- ✔ 연령:성인(18~65세)

#### □ 실험 참여 요구 사항

- ✓ 누설이 발생하지 않는 얼굴 상태 제공(ISO 16975-3, 수염이 있는 남성의 경우 면도 필요)
- ✔ 흡연자의 경우 평가 전 30분 금연 후 진행
- ✓ 평가 대상 호흡기의 올바른 착용과 사용 방법 숙지





# **Human-Based Fit Evaluation: Subjective Methods**

### □ 밀착감 평가

 ✓ QLFT(qualitative fit testing): 에어로졸 노출에 따른 주관적 평가로 운동 상황에서의 호흡 평가 (OSHA; NIOSH)

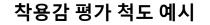
#### □ 착용감 평가

- ✓ 착용감 평가 척도: 1~5점 (1-매우 불편; 5-매우 편안) (Foreland et al., 2018)
- ✔ 통기성 및 착용감 평가 척도: 시각적 평가 척도0~10점

(0-호흡이 어려움, 10-호흡이 쉬움; 0-착용감 매우 불편, 10- 착용감 매우 편안)

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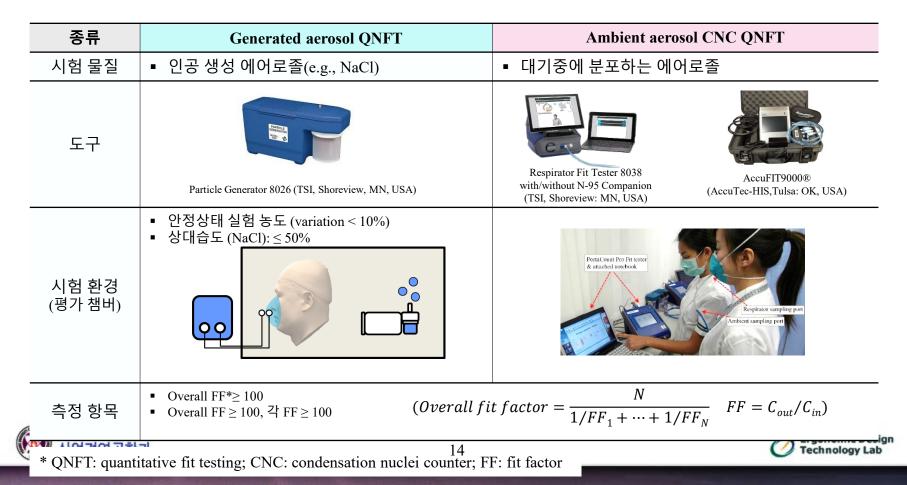




Human-Based Fit Evaluation: Objective Method – Fit Factor (1/2)

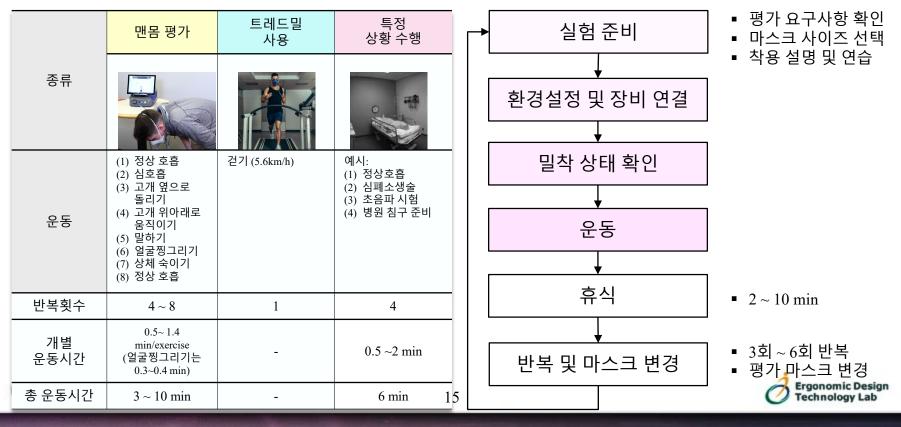
□ 호흡기 내부 및 외부의 에어로졸 농도를 측정을 통한 정량적 적합성 평가

- ✓ 에어로졸 생성을 통한 QNFT : 테스트 챔버에서 생성된 에어로졸 사용
- ✓ 대기중에어로졸을 활용한 CNC QNFT: 테스트 주변에어로졸을 사용



Human-Based Fit Evaluation: Objective Method – Fit Factor (2/2)

- □ <mark>평가 절차:</mark> 실험 준비, 환경설정 및 장비 연결, 마스크 밀착 상태 확인, 운동, 휴식의 절차로 진행
- □ 총 소요시간: 35분 (Sietsema and Brosseau, 2016)



밀착도 평가 사용 도구 및 동작 내용

Human-Based Fit Evaluation: Objective Method – Inward Leakage (1/3)

# 호흡기 내부와 외부의 에어로졸 입자 농도 차이와 들숨과 날숨의 총 소요 시간을 이용하여 누설율 평가

종류	ISO 표준기반	한국 표준 기반	NIOSH FF testing 기반
에어로졸	• NaCl	<ul> <li>NaCl</li> </ul>	<ul> <li>NaCl</li> </ul>
시험환경	• Test chamber 3 4 5 7 10 7 10 1 1 1 1 1 1 1 1	Test chamber	Test room/chamber
측정항목	<ul> <li>호흡 기구 내부/외부 농도 (C<sub>2</sub>/C<sub>1</sub>)</li> <li>건조공기유량 (D)</li> <li>호흡 기구 계면의 샘플 유량 (S)</li> </ul>	<ul> <li>호흡 기구 내부/외부 농도 (C<sub>2</sub>/C<sub>1</sub>)</li> <li>들숨/날숨의 총 지속시간(T<sub>in</sub>/T<sub>ex</sub>)</li> </ul>	■ 호흡 기구 내부/외부 농도 (C <sub>2</sub> /C <sub>1</sub> )
	$TIL(\%) = 1.6. \left[\frac{C_2}{C_1}\right] \times \left[\frac{S+D}{S}\right] \times 100$	$TIL(\%) = \frac{C_2}{C_1} \times \frac{T_{in} + Tex}{T_{in}} \times 100$	$TIL = \frac{100\%}{FF} = \frac{C_2}{C_1}$
운동종류	• 트레드밀 시험 (5.5 km/h)	▪ 트레드밀 시험 (6 km/h)	<ul> <li>도구사용하지 않는 시험</li> </ul>

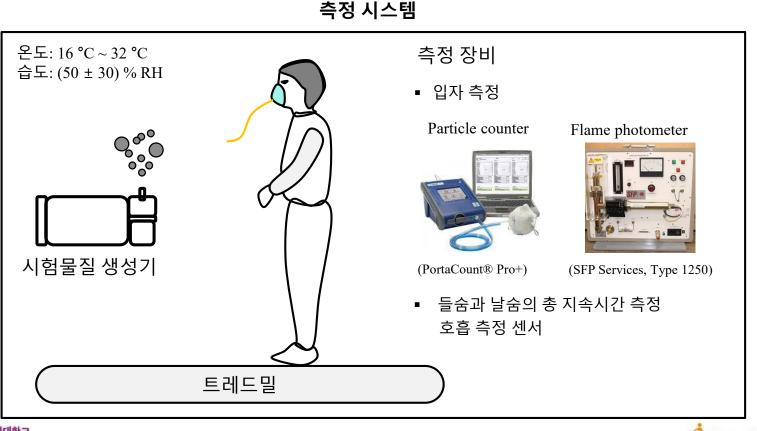
(ISO 16900-1 2019, KR MFDS 2019, NIOSH)

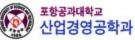
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Human-Based Fit Evaluation: Objective Method – Inward Leakage (2/3)

□ 측정 장비: 시험물질, 시험물질 생성기, 평가 챔버, 실험 장비 및 측정 시스템
 □ 측정 환경: 온도(16°C ~ 32°C), 습도(50±30% RH), 공기 청정도, 주변 환경 조정

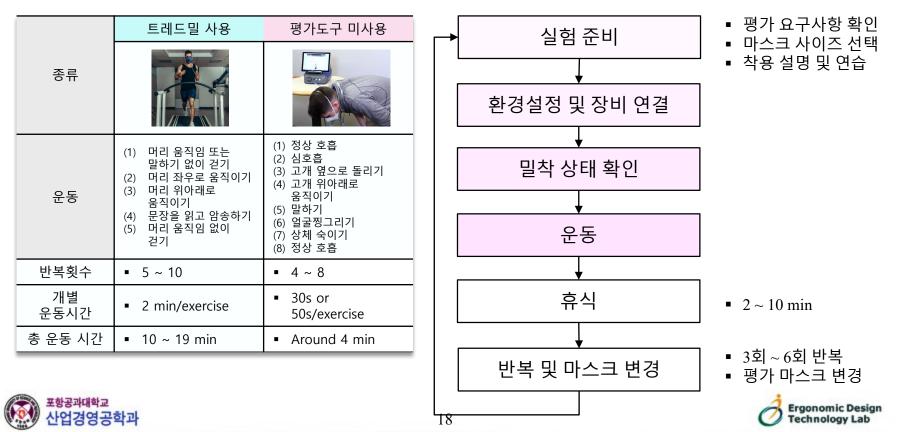




Human-Based Fit Evaluation: Objective Method – Inward Leakage (3/3)

#### □ 누설율 평가 절차는 밀착도 평가 절차와 동일

□ 총 소요시간: 40분 (Zhang et al., 2016)



누설율 평가 사용 도구 및 동작 내용

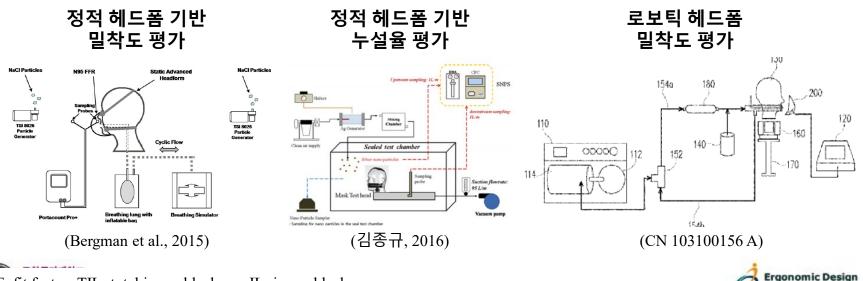
**Headform-Based Fit Evaluation: Headform Type** 

#### □ 정적 로보틱 헤드폼 기반 평가

✓ 호흡 속도, 호흡 빈도의 설정에 따라 맞음새 요인(FF), 누설율(TIL), 내부 누출(IL)
 측면에서 적합성 평가

#### □ 로보틱 헤드폼 기반 평가

- ✓ 인간대상 평가 시 수행되는 동작 구현
- ✓ 개발 및 평가 방법은 개발 완료되었으나 평가 결과는 발표되지 않았음



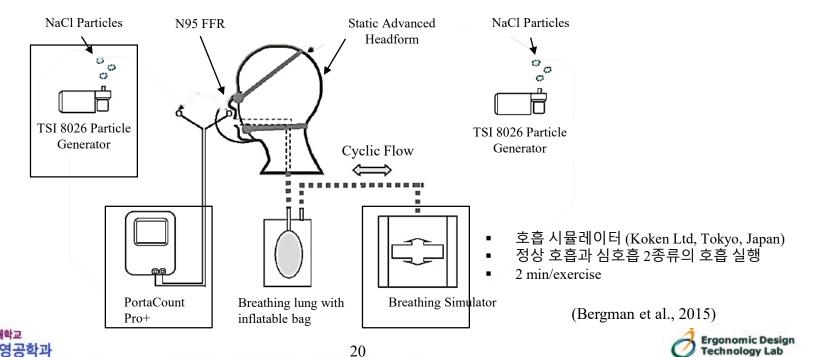
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\* FF: fit factor; TIL: total inward leakage; IL: inward leakage

# **Static Headform-Based Fit Evaluation: Fit Factor**

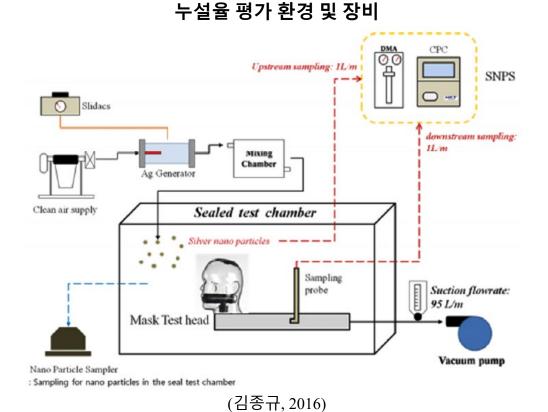
- 에어로졸 생성 방법 이용하여 2가지 호흡(정상 호흡, 심호흡)시의 전체 밀착도 평가
- 환경 및 장비: NaCl 에어로졸 생성기(Model 8026, TSI Inc., Shoreview: MN, USA)
   밀착도 측정(TSI PortaCount Pro+ Model 8038, TSI Inc., Shoreview: MN, USA)

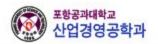


실험 환경 및 장비

**Static Headform-Based Fit Evaluation: Inward Leakage** 

 정적 헤드폼과 인공폐를 이용하여 평균 50 L/min 유량을 흡입한 조건에서 챔버내의 공기를 흡입하여 마스크를 통과하였을때 은나노 입자수의 농도를 측정하여 평가







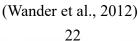
# **Robotic Headform-Based Fit Evaluation** (1/2)

- □ 로보틱 헤드폼(NIOSH medium size)의 외피에 인체 피부 두께 (19~22세 백인 남성)
   적용하여 제작(Wander et al., 2012).
- □ 목 관절 구조를 파악하여 얼굴을 움직이는 **3개 동작 구동**이 가능하도록 제작
  - ✓ 구동 동작: 좌/우로 돌리기, 위/아래로 움직이기, 말하기
- □ **인간의 머리와 로보틱 헤드폼**의 **기능적 측면**의 유사성을 검증할 수 있는 연구 및 검증은 현재 진행중



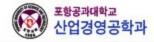








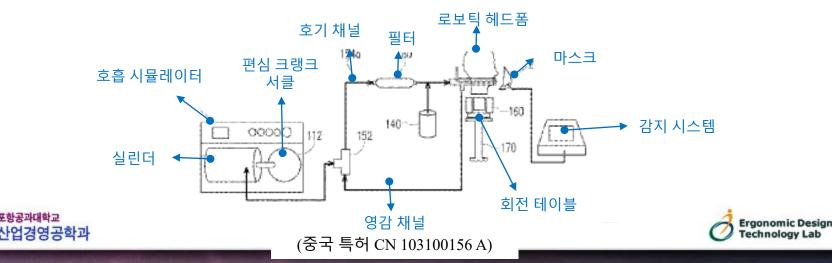




#### **Robotic Headform-Based Fit Evaluation** (2/2)

#### □ **로보틱 헤드폼, 호흡 시뮬레이터, 감지 시스템** 이용하여 마스크의 **밀착도 평가**

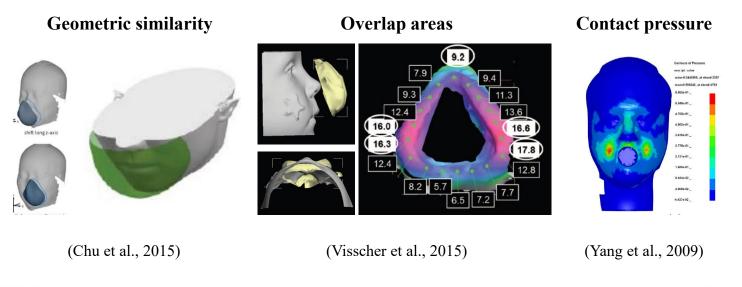
- □ 로보틱 헤드폼 **5가지 동작**을 수행하여 평가
  - ✔ 머리 정지
  - ✔ 좌/우로 돌리기
  - ✔ 위/아래로 기울이기
  - ✔ 앞/뒤로 기울이기
  - ✔ 좌/우로 기울이기

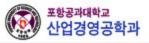


로봇틱 헤드폼 기반 평가 환경 및 장비

### **Simulation-Based Fit Evaluation**

Evaluate fit of FFRs in the simulated virtual environment by investigating measures such as geometric similarity, overlapping areas, and contact pressure between digital face models and respirators.







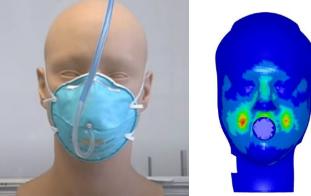
# **Comparison of Fit Evaluation Methods**

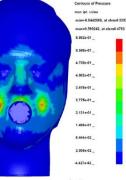
The positive and negative features of the human-based and non-human-based fit evaluation methods were compared in terms of convenience, cost-effectiveness, representativeness, and applications.

#### Human-based fit evaluation



#### Non-human based fit evaluation





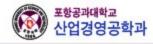


# **Comparison of Fit Evaluation Methods**

#### □ Convenience: non-human based (simulation > headform) > human-based

□ Cost-efficiency: non-human based (simulation > headform) > human-based

	Human-based	Headform-based	Simulation-based
Convenience	(-) Required human subject review	(+) Not required human subject review	(+) Non-necessary physical respirator
	board clearance	board clearance (Bergman et al., 2014)	products/prototypes (Yang et al., 2009)
	(-) Complex requirements for subjects	(-) Necessary physical respirator	
	(e.g., refrain from smoking one hour	products/prototypes (Yang et al., 2009)	
	and be freshly shaved 12 hours before	(+) No-necessary experiment	
	the fit evaluation) (Foreland et al.,	scheduling (Bergman et al., 2014;	
	2018)	Wander, 2012)	
	(-) Difficult recruitment (e.g., subject	(+) No-necessary rest period during	
	with suitable size) (Brosseau et al.,	experiments (Bergman et al., 2014;	
	2010)	Wander, 2012)	
	(-) Difficult experiment scheduling		
	(-) Necessary physical respirator		
	products/prototypes (Yang et al., 2009)		
	(-) Necessary rest period during		
	experiments because subject's fatigue		
Cost-efficiency	(-) Time consuming	(-) Relatively time consuming	(+) Relatively time saving
	(-) Expensive	(-) Expensive	(+) Relatively cheap





# **Comparison of Fit Evaluation Methods**

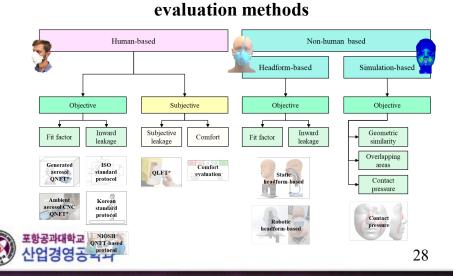
# □ **Representativeness: non-human based** (simulation $\approx$ headform) $\approx$ human-based

□ Application: non-human based (simulation > headform) > human-based

	Human-based	Headform-based	Simulation-based
Representa-	(+) Experiment with realistic human	(+) Can use headform that represent	(+) Can use head model that represent
tiveness	facial features (Bergman et a., 2015;	facial diversities of the target population	facial diversities of the target population
	Bergman et al., 2014; Richardson et al.,	(+) Can preliminarily simulate some of	(+) Can preliminarily simulate human
	2007)	human facial texture and head/facial	facial texture and head/facial dynamic
	(+) Use realistic human movement in	dynamic movements (Bergman et al.,	movements (Lei et al., 2014)
	experimental environment to represent	2014; Richardson et al., 2007)	(-) Need to verify actual physical (real-
	real world activities or experiment with	(-) Need to verify human facial texture	world) properties
	practical activities in workplace/real	and head/facial dynamic movement	
	world conditions	properties	
	(-) Can only use non-hazardous aerosols	s (+) Enable experiment with more	
	(Bergman et al., 2015)	accurately representative aerosols such	
		as hazardous (e.g., silver nano-particles,	
		pathogenic microorganisms and	
		industrial aerosols) and higher challenge	e
		concentrations (Seo et al., 2020;	
		Bergman et al., 2015; Bergman et al.,	
		2014; He et al., 2014)	
Application	(-) Only evaluate the overall fit (Yang e	t (-) Only evaluate the overall fit (Yang et	t (+) Provide feedback of the location of
	al., 2009)	al., 2009)	unfit (Yang et al., 2009)
산업경영공	<u>-</u> 공학과	27	C Ergonomic Design Technology Lab

# **Discussion** (1/2)

- A comprehensive knowledge of human-based and non-human based fit evaluation methods were organized in terms of subject, apparatus, environment, requirement, protocol and analysis.
- The positive and negative features of the human-based and non-human-based fit evaluation methods were compared in terms of convenience, cost-effectiveness, representativeness, and applications.



Summary of fit

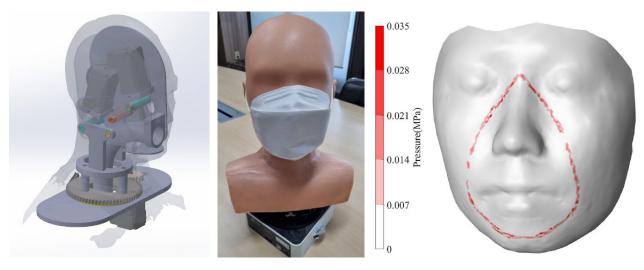
# Positive and negative features of fit evaluation methods

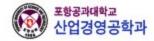
	Human-based	Headform-based	Simulation-based
Convenience	(e.g., refrain from smoking one hour and be freshly shaved 12 hours before the fit evaluation) (Foreland et al., 2018)	(+) Not required human subject review board dentime (Brigmann et al., 2014) (+) Necessary physical respirator products prototypes (Ving et al., 2009) (+) No-accessary experiment scheduling (Bergmann et al., 2014; Winder, 2012) (-) No-accessary rest preiod during experiments (Bergmann et al., 2014; Wander, 2012)	(*) Non-necessary physical respirator products products products products (Yang et al., 2009)
st-efficiency	(-) Time consuming	(-) Relatively time consuming (-) Expensive	(+) Relatively time saving (+) Relatively cheap
Representa- tiveness	ficial features (Bergmm et a., 2015; Bergman et al., 2014; Relativitos et al., 2007) (e) Use realistic human movement in experimental environment lo represent panetical activities in workplacetical workd conditions (Bergman et al., 2015)	(+) Can preliminarity simulate some of human fiscal texture and head/fiscal dynamic movements (Bergman et al., 2007) (-) Need to verify human fiscal texture and head/fiscal dynamic novement // (-) Enable experiment with more accurately representative aerosols such as humarkout (e.g., whore mano-pathetic balandrase), a solver mano-pathetic industrial neovoly and higher challenge concentrations (See et al., 2020; Bergman et al., 2014). Bergman et al., 2014; He et al., 2014)	facial texture and head/facial dynamic movements (Le da da, 2014) (-) Need to verify actual physical (real- world) properties
Application	(-) Only evaluate the overall fit (Yang et al., 2009)	<ul> <li>i (-) Only evaluate the overall fit (Yang e al., 2009)</li> </ul>	t (+) Provide feedback of the location of unfit (Yang et al., 2009)

# **Discussion** (2/2)

Non-human based fit evaluation methods trends to be developed and apply in practice instead of human-based methods, but the effectiveness of non-human-based methods need to be further verified.

#### Non-human based fit evaluation method development



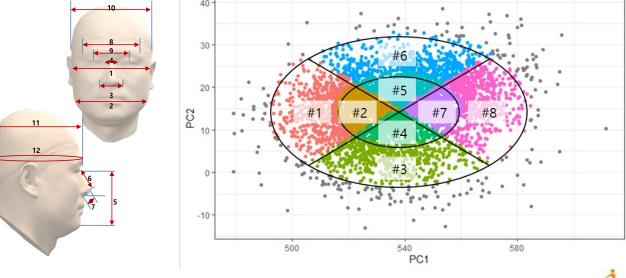




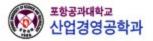
### **Future Work**

# Non-human-based fit methods needs to be improved by providing adequate representativeness and accurate partial feedback of unfit.

- ✓ Represent realistic human using representative headform/3D models
- ✓ Simulate real-world using conditions by applying dynamic movement and toxic environment



#### Korean representative headform development

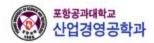




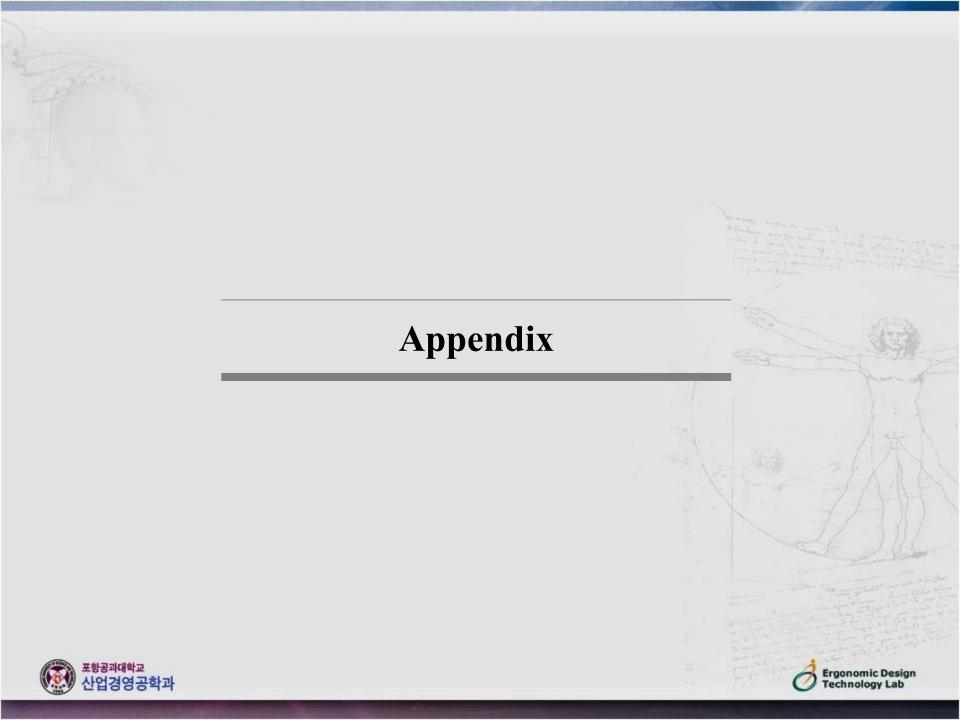
# 경청해 주셔서 감사합니다.



This work was funded by a grant from Ministry of Food and Drug Safety.





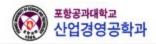


## **Appendix: Paper List (H)**

No.	Author(s)	Year	Title	Category	Relevancy
19	Karuppasamy and Obuchowski	2021	Comparison of Fit for Sealed and Loose-Fitting Surgical Masks and N95 Filtering Facepiece Respirators	QNFT	Н
20	Rollings	2020	FFP3 respirator face fit testing – what is it all about?	QNFT	Н
21	Foreland et al.	2018	Do Various Respirator Models Fit the Workers in the Norwegian Smelting Industry?	QNFT	Н
22	Manganyi et al.	2017	Quantitative Respirator Fit, Face Sizes, and Determinants of Fit in South African Diagnostic Laboratory Respirator Users	QNFT	Н
23	Zhuang et al.	2017	Recommended test methods and pass/fail criteria for a respirator fit capability test of half-mask air-purifying respirators	QNFT	Н
23	Zhuang et al.	2017	Recommended test methods and pass/fail criteria for a respirator fit capability test of half-mask air-purifying respirators	QNFT	Н
24	Or et al.	2016	A novel approach to fit testing the N95 respirator in real time in a clinical setting	QNFT	Н
25	Sietsema and Brosseau	2016	Comparison of Two Quantitative Fit-Test Methods Using N95 Filtering Facepiece Respirators	QNFT	Н
26	Lawrence et al.	2014	Comparison of Performance of Three Different Types of Respiratory Protection Devices	QNFT	Н
27	Yu et al.	2014	Fitting Characteristics of N95 Filtering-Facepiece Respirators Used Widely in China	QNFT	Н
28	Bergman et al.	2012	Impact of multiple consecutive donnings on filtering facepiece respirator fit	QNFT	Н
29	Coffey et al.	2012	Comparison of Five Methods for Fit-Testing N95 Filtering-Facepiece Respirators	QNFT	Н
30	Ciotti et al.	2012	Effectiveness of respirator masks for healthcare workers, in France	QNFT	Н
31	Park et al.	2011	Fit Test for N95 Filtering Facepiece Respirators and KF94 Masks for Healthcare Workers: a Prospective Single-center Simulation Study	QNFT	Н
32	Spies et al.	2011	Respirator fit of a medium mask on a group of South Africans: a cross-sectional study	QNFT	Н
33	Brosseau	2010	Fit Testing Respirators for Public Health Medical Emergencies	QNFT	Н
34	McMahon et al.	2008	Implementing fit testing for N95 filtering facepiece respirators: Practical information from a large cohort of hospital workers	QNFT	Н

## **Appendix: Paper List (H)**

No.	Author(s)	Year	Title	Category	Relevancy
35	Sreenath et al.	2001	A Modified Protocol for Quantitative Fit Testing Using the PortaCount ®	QNFT	Н
36	Fakherpour et al	2019	Feasibility of replacing homemade solutions by commercial products for qualitative fit testing of particulate respirators: a mixed effect logistic regression study	QLFT	Н
37	Seo et al.	2020	Development of Korean Head forms for Respirator Performance Testing	Manikin	Н
38	Pacitto et al.	2019	Effectiveness of commercial face masks to reduce personal PM exposure	Manikin	Н
39	Yao et al.	2019	Impact of structural features on dynamic breathing resistance of healthcare face mask	Manikin	Н
40	Bergman et al.	2017	Development of a Manikin-Based Performance Evaluation Method for Loose-Fitting Powered Air-Purifying Respirators	Manikin	Н
41	Kim	2016	Filtration efficiency and Manikin-based Total Inward Leakage Study of Particle Filtering Mask Challenged with Silver Nanoparticles	Manikin	Н
42	Bergman et al.	2015	Correlation of Respirator Fit Measured on Human Subjects and a Static Advanced Headform	Manikin	Н
43	Bergman et al.	2014	Development of an Advanced Respirator Fit-Test Headform	Manikin	Н
44	He et al.	2014	Effects of Breathing Frequency and Flow Rate on the Total Inward Leakage of an Elastomeric Half-Mask Donned on an Advanced Manikin Headform	Manikin	Н
45	Rengasamy et al.	2014	A Quantitative Assessment of the Total Inward Leakage of NaCl Aerosol Representing Submicron-Size Bioaerosol Through N95 Filtering Facepiece Respirators and Surgical Masks	Manikin	Н
46	Wander et al.	2012	Humanlike Articulate Robotic Headform to Replace Human Volunteers in Respirator Fit Testing	Manikin	Н





# **Appendix: Paper List (M)**

No.	Author(s)	Year	Title	Category	Relevancy
47	Rengasamy et al.	2018	A comparison of total inward leakage measured using sodium chloride (NaCl) and corn oil aerosol methods for air- purifying respirators	TIL/IL	М
48	Zhang et al.	2016	Temporal changes in filtering-facepiece respirator fit		М
49	Zhang et al.	2015	Inward Leakage Variability between Respirator Fit Test Panels – Part I. Deterministic Approach	TIL/IL	М
50	Zhang et al.	2011	Laboratory Study to Assess Causative Factors Affecting Temporal Changes in Filtering Facepiece Respirator Fit: Part I – Pilot Study	TIL/IL	М
51	Kelly et al.	2021	Comparing the fit of N95, KN95, surgical, and cloth face masks and assessing the accuracy of fit checking	Theory	М
52	Stemen et al.	2021	Frame to Improve the Fit of N95 Filtering Face Mask Respirators	Theory	М
53	Trehan et al.	2021	Comparing the quantitative fit-testing results of halfmask respirators with various skin barriers in a crossover study design: a pilot study	Theory	М
54	Singh et al.	2020	Under-mask beard cover (Singh Thattha technique) for donning respirator masks in COVID-19 patient care	Theory	М
55	Sandaradura et al.	2019	A close shave? Performance of P2/N95 respirators in health care workers with facial hair: results of the BEARDS (Adequate Respiratory DefenceS) study	Theory	М
56	Suen et al.	2019	Comparing mask fit and usability of traditional and nanofibre N95 filtering facepiece respirators before and after nursing procedures	Theory	М
57	Viscusi et al.	2019	Evaluation of the Benefit of the User Seal Check on N95 Filtering Facepiece Respirator Fit	Theory	М
58	Vuma et al.	2019	The Effect on Fit of Multiple Consecutive Donning and Doffing of N95 Filtering Facepiece Respirators	Theory	М
59	Rembialkowski et al.	2017	Impact of Time and Assisted Donning on Respirator Fit	Theory	М
60	Roberge et al.	2015	Effect of Pregnancy Upon Facial Anthropometrics and Respirator Fit Testing	Theory	М
61	Niezgoda et al.	2013	Flat Fold and Cup-Shaped N95 Filtering Facepiece Respirator Face Seal Area and Pressure Determinations: A Stereophotogrammetry Study	Theory	М
62	Danyluk et al.	2011	Health Care Workers and Respiratory Protection: Is the User Seal Check a Surrogate for Respirator Fit-Testing?	Theory	М
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# **Appendix: Paper List (M)**

No.	Author(s)	Year	Title	Category	Relevancy
63	Reponen et al.	2011	Effect of Fit Testing on the Protection Offered by N95 Filtering Facepiece Respirators Against Fine Particles in a Laboratory Setting	Theory	М
64	Oestenstad et al.	2007	The Effect of Gender and Respirator Brand on the Association of Respirator Fit with Facial Dimensions	Theory	М
65	Campbell et al.	2005	Reducing Respirator Fit Test Errors: A Multi-Donning Approach	Theory	М
66	Derrick et al.	2005	Predictive value of the user seal check in determining half-face respirator fit	Theory	М
67	Zhang et al.	2000	The Relationship between the Filtering Facepiece Respirator Fit and the Facial Anthropometric Dimensions Among Chinese People	Theory	М
68	Elmashae et al.	2017	Performance of Two Respiratory Protective Devices Used by Home-Attending Health-Care Workers (A Pilot Study)	SWPF	М
69	Robertson and Ramsdale	2021	Audit of qualitative fit testing for FFP3 respirators	QNFT	М
70	Clapp et al.	2020	Evaluation of Cloth Masks and Modified Procedure Masks as Personal Protective Equipment for the Public During the COVID-19 Pandemic	QNFT	М
71	Kim et al.	2016	Physiologic and fit factor profiles of N95 and P100 filtering facepiece respirators for use in hot, humid environments	QNFT	М
72	Colton	2001	Respirator Fit Testing: Choosing the Best Method	QNFT	М
73	Pan et al.	2021	Assessment of Use and Fit of Face Masks Among Individuals in Public During the COVID-19 Pandemic in China	QLFT	М
74	Wardhan et al	2020	Does a Modified Adhesive Respirator Improve the Face Seal for Health Care Workers Who Previously Failed a Fit Test?: A Pilot Study During the Coronavirus Disease 2019 Pandemic	QLFT	М
75	He et al.	2013	Manikin-Based Performance Evaluation of Elastomeric Respirators Against Combustion Particles	Manikin	М
76	Davidson et al.	2013	Performance Evaluation of Selected N95 Respirators and Surgical Masks When Challenged with Aerosolized Endospores and Inert Particles	Manikin	М
77	Balazy et al.	2006	Manikin-Based Performance Evaluation of N95 Filtering-Facepiece Respirators Challenged with Nanoparticles	Manikin	М

