The Philippine Journal of Orthopaedics

ORIGINAL ARTICLE

Aegis Mark II Study on Powered Air Purifying Innovation Respirator Efficiency Comparison: ASPIRE Study*

Hansel Gould B. Cocjin, MD, Jair Kimri P. Jingco, MD, Pierre Napoleon P. Niere, MD

Department of Orthopaedics and Traumatology, Corazon Locsin Montelibano Memorial Regional Hospital, Bacolod City, Negros Occidental, Philippines

ABSTRACT

Introduction. COVID-19, a respiratory droplet-transmitted disease, has claimed approximately 7 million lives worldwide, partly due to a shortage of Personal Protective Equipment (PPEs) needed for prompt patient care. This study was done to assess if the locally developed Aegis Mark II Powered Air Purifying Respirator (PAPR) can fill this need in terms of usability and filtration efficacy.

Methodology. The battery life was recorded in a controlled environment by running the PAPR continuously on low and high settings. To test usability, participants were allocated to three groups (commercial PAPR, Aegis Mark II, and Aegis Mark I), then participated in a clinical simulation while wearing the PAPR, and answered a questionnaire regarding their satisfaction with the PAPR. Filtration efficacies of the commercial PAPR and Aegis Mark II were compared in a controlled environment (acrylic box) by measuring the number of aerosolized NaCl particles inside the PAPR compared to outside the PAPR.

Results. The Aegis Mark II PAPR's 20,000mAh rechargeable Lithium battery pack lasted for a mean of 11 h and 34 min (SD 16 min), and 8 h and 34 min (SD 38 min), for low and high flow blower settings, respectively. The mean charging time was 2 h and 20 min (SD 19 min) using a Fast Cellphone Charger (2.4 Amps). Participants reported higher satisfaction with the Aegis Mark II compared to the commercial PAPR in terms of factors affecting residency and education use and communication effort (n = 30, overall mean = 7.86 ±1.81) (Table 1), comfort (n = 8.52, overall mean = 8.52 ±1.63), and PAPR care (n = 30, overall mean = 7.76 ±1.75). The mean particle counts inside the hood of the Aegis Mark II PAPR and Commercial PAPR showed that PM2.5 (5.7 and 6.2), and PM10 (6.2 and 6.6) values were within acceptable Ambient Air Quality Standards.

Conclusion. The locally developed Aegis Mark II PAPR displayed a high degree of protection comparable with commercial PAPRs. Its battery life was adequate. It was highly conducive to training and clinical work while being comfortable to use and maintain. It can provide a high degree of protection and alleviate the logistical strain during pandemics and public health emergencies.

Keywords. Aegis Mark II PAPR, filtration efficacy, user comfort and acceptance

INTRODUCTION

The COVID-19 pandemic has caused approximately 7 million reported deaths worldwide.[1] The virus is transmitted through respiratory droplets between people in proximity indoors, placing healthcare workers at risk for infection.[2,3] Personal protective equipment (PPE) were some of the most important means to protect healthcare workers. This massive demand led to a shortage of PPEs.[4,5]

Respiratory protection programs worldwide have increasingly used reusable devices. These devices include loose-fitting powered air-purifying respirators (PAPRs) and elastomeric half mask respirators. Loose-fitting PAPRs are well-accepted and more comfortable but may influence communication and mobility. They provide a high degree of protection when measured in a simulated workplace.[6]

ISSN 0118-3362 (Print)
eISSN 2012-3264 (Online)
Printed in the Philippines.

Received: September 4, 2023.
Accepted: October 10, 2023.
Published Online: November 15, 2023.
https://doi.org/10.69472/poai.2023.03

Corresponding author: Hansel Gould B. Cocjin, MD
Department of Orthopaedics and Traumatology
Corazon Locsin Montelibano Memorial Regional Hospital,
Lacson St., Bacolod City, Negros Occidental 6100, Philippines
E-mail: hanselgouldcocjin@gmail.com

**This study was performed at the Corazon Locsin Montelibano Memorial Regional Hospital (CLMMRH), in cooperation with the Department of Science and Technology and the Western Visayas Health Research and Development Consortium.*

It is important to understand how PAPR use affects employees' physical, psychological, psychomotor, cognitive, and visual abilities. PAPRs enhance compliance and reduce heart, lung, and heat stress by delivering ambient air into the user's breathing zone as opposed to non-powered respirators that require active air intake through a resistive filter.[7] Loose-fitting facepieces do not require fit testing, and improve communication.[8]

Protection factors indicate how safe a device is. Of these, the Assigned Protection Factor (APF) is the expected value when the respirator is used in the prescribed situation by a respiratory protection program. The Program Protection Factor (PPF) is the actual measurement in the workplace or in work simulations. The value of the protection factor for each commercially available filter or device is provided by the manufacturer.[9-13]

A PAPR is a PPE in which a battery-powered blower passes positive air flow through a filter to a hood. The filters are often P100 and high-efficiency particulate air (HEPA) filters, with efficiencies of more than 99%, and are considered more protective than N95 respirators. These PPEs are used when working closely with COVID-19 patients, especially during high risk aerosol-generating procedures.[14-17] While there are several studies determining the efficiency and comfort of N95 respirators, studies on PAPR's are few.

The CDC has allowed respirator manufacturers to produce equivalent new classes of PAPR to protect the front lines as soon as possible.[18] Innovation has driven the use of 3D printed materials and arthroplasty helmets repurposed as PPEs.[19] The ultra-portable low-cost improvised powered air-purifying respirator, novel reusable respirators, Bubble-PAPR, and Novel 3D printable powered air purifying respirator were encouraged.[20-23]

The Aegis Mark II PAPR is an improvement from the Aegis Mark I prototype. The current study assessed the Aegis Mark II PAPR's battery power, user acceptance, user comfort, and filtration efficacy.

METHODOLOGY

This laboratory controlled non-interventional study was conducted at the Corazon Locsin Montelibano Memorial Regional Hospital, a Tertiary Hospital, in Lacson St., Bacolod City, Negros Occidental, Philippines, in cooperation with the Department of Science and Technology Region VI and the Western Visayas Health Research and Development Consortium. Ethics approval was granted by the Western Visayas Research and Development Consortium Research Ethics Committee.

The following parameters were tested: battery life in a controlled environment at high and low blower power settings; mechanical and material construct of hood, blower unit, strength of hose and coupling, non-collapsibility, ability of the hose to resist kinking, and detachable coupling (CFR_42 CFR Part 84);[24] filtration efficacy using NaCl particulate (CVB-APR-STP-0081-508);[25] and users' acceptance, communication and comfort (CVB-APR-STP-0089-508).[26]

Participants were surgery and anesthesia residents, scrub nurses, and nurse assists who signed the informed consent, and were completely vaccinated. The study excluded those who are non-surgical/cutting and non-anesthesia residents, and ward nurses, and those who refused consent. Participants with pulmonary disease, cardiac disease, uncontrolled hypertension, claustrophobia, and facial abnormalities that prevent good fit were excluded. The study allowed participants to opt out. Participants who experienced mechanical failures were also excluded. Participants were randomly allocated to one of three groups: commercial PAPR (COLEMATE PAPR CM-200), Aegis Mark I, and Aegis Mark II.

Clinical simulation was performed inside a surgical theater with participants wearing their assigned PAPR for at least three hours. They simulated their respective job roles during a regular operation, including but not limited to transferring the patient, operating surgical equipment, postoperative care, etc.

Participants then answered a questionnaire which measured the study variables (clinical performance, communication, comfort and PAPR care) on a 10-point Likert scale (1-2 not satisfied, 3-4 slightly satisfied, 5-6 neutral, 7-8 very satisfied, and 9-10 extremely satisfied). The parameters included were factors affecting (Appendix 1):

- residency training and education (visual field, fogging, inside lighting/less shadowing, and noise)
- clinical performance (movement restrictions, weight distribution, and ambulation)
- communication effort (voice modulation and less muffling of voice)
- comfort (ease of donning, ease of doffing, ease of operation, and ease of monitoring)
- PAPR care (ease of storage, handling, size, durability of material during cleaning, material disassembly, time required to disinfect, time required for drying)

The Aegis Mark II's filtration efficacy was compared against the commercial PAPR's in a controlled environment. An adult size mannequin wearing the PAPR was placed in an acrylic box where a 0.9 NaCl solution was aerosolized (using a nebulizer) into airborne NaCl particles. Two particle counters (Temtop M2000C Air Quality Monitor for PM2.5 PM10 Particles) (one inside the PAPR hood, the other outside the PAPR hood but inside the acrylic box) measured the number of aerosol particles. The following set-ups were tested:

A: (Aegis Mark II) Nebulizer Off/PAPR Off
B: (Commercial PAPR) Nebulizer Off/PAPR Off
C: (Aegis Mark II) Nebulizer On/PAPR Off
D: (Commercial PAPR) Nebulizer On/PAPR Off
E: (Aegis Mark II) Nebulizer On/PAPR On
F: (Commercial PAPR) Nebulizer On/PAPR On

Efficacy was measured by dividing the number of particles inside the PAPR by those outside the PAPR. The differences between these setups were then analyzed.

Aegis Mark II PAPR System

The Aegis Mark II has two main parts: the blower/power unit and the hood assembly with tubing (Figures 1-3). This system can deliver 245 liters of filtered air per minute, well above the 115-170 lpm basic requirement. The centrifugal fan is housed in an airtight container with intake and output manifolds. The two intake manifolds hold the two filters. The filters are in-line bacterial/viral breathing circuit filters used in anesthesia and ventilator machines. These filters were chosen due to the following reasons: these are already certified for medical use with an APF of 25 (as stated by the manufacturer); these can be easily and safely replaced because the filter membranes are enclosed in a plastic that prevent direct contact; and these are supplied by the hospital. The output manifold connects with the hood's tubing. The fan is supplied by a 20,000 mAh lithium-ion battery. The blower unit, battery, and charger are housed in an integrated pack with a total weight of 1.8 kg. The hood assembly is constructed from a double layer of waterproof nylon fabric. The tubing is a corrugated 40 mm plastic tube, with a maximum length of 1100 mm and a diameter of 40 mm.

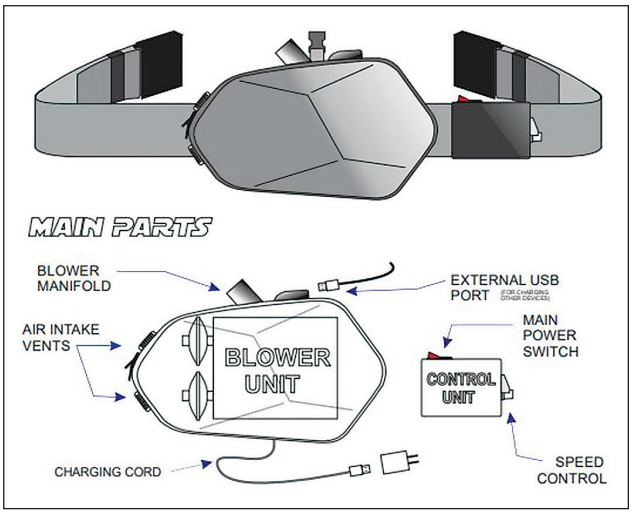

Figure 1. Blower unit.

Statistical analysis was done using Microsoft Excel and SPSS (v.26, IBM). Descriptive statistics (mean and standard deviation) were used to summarize battery power supply, filtration efficacy, and participant questionnaire answers. Kruskall-Wallis H-test was used to determine if there were significant differences in the responses among those who tested the Commercial PAPR, Aegis Mark I, and Aegis Mark II. Furthermore, Mann-Whitney U-Test was used to determine which two groups showed significant differences. Welch's One-way Analysis of Variance was used for comparing filtration efficacy for Aegis Mark II and the commercial type since the homogeneity of variances requirement for the F-test using One-way ANOVA was violated (Levene's tests for all dependent variables returned $p<0.05$). Consequently, the Games-Howell Post Hoc test was used to identify significant differences among the set-ups for each dependent variable.

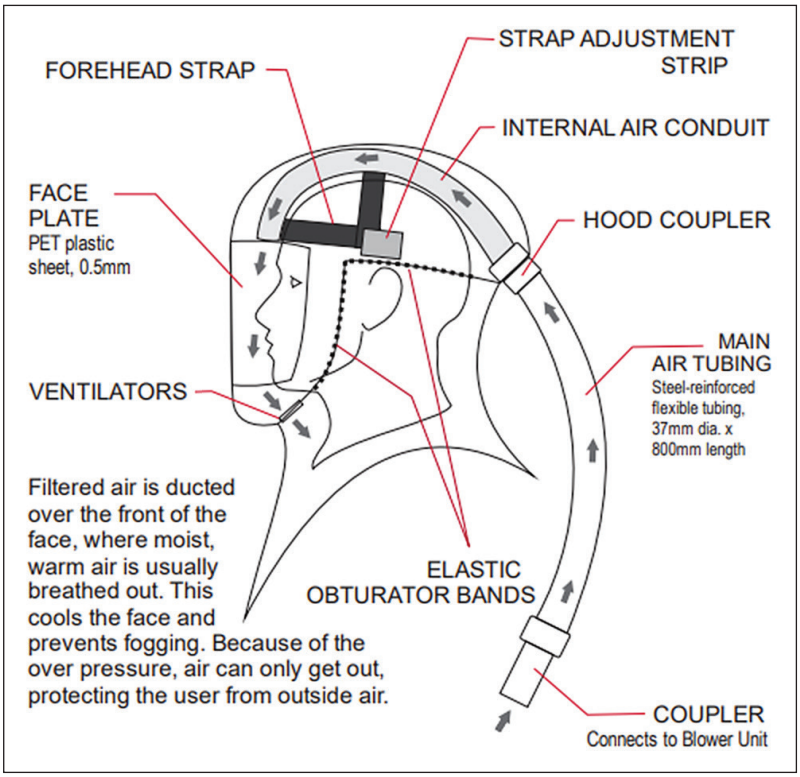

Figure 2. Surgical hood. Direction of airflow shown by the arrows.

Figure 3. Hood and blower unit when worn.

RESULTS

The Aegis Mark II PAPR rechargeable lithium battery pack required a mean total charging time of 2 h and 20 min (SD 19 min), while the mean service time was 11 h and 34 min (SD 16 min), and 8 h and 34 min (SD 38 min), in low and high flow blower setting, respectively.

Its materials and construction were durable; the hoses and coupling were non-collapsible, non-kinking, and detachable. A total of 50 participants were recruited. Ten participants were allocated to the commercial PAPR and Aegis Mark I groups, while 30 participants were allocated to the Aegis Mark II group. No participant experienced mechanical failure.

Most of the participants were very satisfied with the Aegis Mark II on factors affecting residency and education use and communication effort (n = 30, overall mean = 7.86 ± 1.81) (Table 1), comfort (n = 8.52, overall mean = 8.52 ± 1.63), and PAPR care (n = 30, overall mean = 7.76 ± 1.75) (Table 2). These all differed significantly from satisfaction with the commercial PAPR (Table 3).

The Aegis Mark II PAPR and commercial PAPR both showed significant decreases in the particle counts on PM2.5 and PM10 particle size counts when compared with environmental baseline data where the nebulizer is off (Setup E vs A, and Setup F vs B, respectively). Both PAPRs also show significant differences when compared with setups when the nebulizer is on (Setup E vs C, and Setup F vs D, respectively). The mean particle counts inside the user's breathing zone of both PAPRs (Setup E and F) showed that PM2.5 (5.7 and 6.2), and PM10 (6.2 and 6.6) values were within acceptable Ambient Air Quality Standards (Tables 4 and 5).

Table 1. Residency Training and Education, Clinical Performance and Communication

	Mean (±Std. Dev.)		
	Commercial (n = 10)	**Aegis Mark I (n = 30)**	**Aegis Mark II (n = 10)**
Residency training and education use (visual field)	7.10 (±1.29)	8.23 (±1.87)	8.80 (±0.92)
Residency training and education use (fogging)	6.40 (±1.35)	7.40 (±2.6)	9.10 (±0.57)
Residency training and education use (inside lighting / less shadow)	6.80 (±1.23)	8.40 (±1.35)	8.90 (±0.74)
Residency training and education use (PAPR noise reduction)	7.00 (±1.33)	7.13 (±1.96)	8.80 (±0.92)
Clinical performance (movement restrictions)	6.50 (±1.35)	8.40 (±1.65)	9.10 (±0.57)
Clinical performance (weight distribution)	6.10 (±2.02)	8.30 (±1.64)	8.90 (±0.74)
Clinical performance (ambulation)	6.40 (±1.78)	8.57 (±1.41)	9.20 (±0.63)
Communication effort (voice modulation)	6.80 (±1.23)	7.13 (±1.72)	9.30 (±0.67)
Communication effort (less muffling of voice)	6.80 (±1.14)	7.17 (±1.70)	8.70 (±1.16)
Overall Mean (±Std. Dev)	6.66 (±1.41)	7.86 (±1.81)	8.98 (±0.78)

Table 2. Comfort and Aegis II PAPR Care

	Mean (±Std. Dev.)		
	Commercial (n = 10)	**Aegis Mark I (n = 30)**	**Aegis Mark II (n = 10)**
Comfort			
Ease of donning	5.80 (±0.92)	8.57 (±1.63)	9.30 (±0.67)
Ease of doffing	5.80 (±0.92)	8.63 (±1.45)	9.40 (±0.52)
Ease of operation	6.60 (±1.17)	9.07 (±1.11)	9.50 (±0.53)
Ease of monitoring	6.80 (±1.03)	8.47 (±1.74)	9.20 (±0.79)
Ease of storage	6.90 (±1.20)	7.87 (±1.96)	9.20 (±0.42)
Overall Mean (±Std. Dev)	6.45 (±1.12)	8.52 (±1.63)	9.27 (±0.59)
Aegis II PAPR Care			
PAPR handling	6.80 (±1.23)	8.17 (±1.68)	9.00 (±0.82)
PAPR size/dimensions	6.70 (±1.16)	7.10 (±1.83)	8.60 (±1.43)
Ease of cleaning (durability of material)	7.10 (±1.45)	7.97 (±1.47)	9.2 (±0.63)
Ease of cleaning (material breakdown)	7.10 (±1.45)	7.90 (±1.81)	9.20 (±0.63)
Ease of disinfection (time required to disinfect)	7.40 (±1.51)	7.70 (±1.80)	9.30 (±0.48)
Ease of disinfection (time required for drying)	7.40 (±1.51)	7.70 (±1.80)	9.30 (±0.48)
Overall Mean (±Std. Dev)	7.08 (±1.36)	7.76 (±1.75)	9.10 (±0.82)

DISCUSSION

The National Institute for Occupational Safety and Health (NIOSH) suggested that the battery must operate for a minimum period of four hours. The airflow level or battery status generally should be checked prior to use, after four hours, and every two hours thereafter. The battery performance depends on the battery capacity, air-purifying components used, and the environment.[27] The average battery life of Aegis Mark II is 11 h and 34 min, (SD 16 min), and 8 h and 34 min, (SD 38 min) in low and high blower settings, respectively. providing an adequate use-time with approximately 2 h and 20 min charging time. The user can also monitor battery levels using the indicators, and extend use by connecting the charger continuously.

The study instructed the use of N95 mask inside the hood to maintain the user's protection during donning and doffing. Using an N95 mask concurrently with a loose-fitting PAPR has multiplicative protection.[28] The Program Protection Factor (PPF) provided by a loose-fitting PAPR exceeds its original Assigned Protection Factor (APF) of 25,[29] and provides 150%

Table 3. Results of the tests for significant differences in the responses to the questionnaire

	Multiple comparison			Commercial vs Aegis Mark I		Aegis Mark I vs Aegis Mark II		Commercial vs Aegis Mark II	
	Kruskal-Wallis H	df	Asymp. Sig.	Mann-Whitney U	Asymp. Sig. (2-tailed)	Mann-Whitney U	Asymp. Sig. (2-tailed)	Mann-Whitney U	Asymp. Sig. (2-tailed)
Residency Training and Education, Clinical Performance and Communication									
Residency training and education use (visual field)	8.119	2	0.017*	74.000	0.015*	131.000	0.537	15.000	0.006*
Residency training and education use (fogging)	14.432	2	0.001*	89.000	0.053	67.500	0.008*	1.000	0.000*
Residency training and education use (inside lighting/ less shadow)	12.664	2	0.002*	55.500	0.003*	120.000	0.331	7.000	0.001*
Residency training and education use (PAPR noise reduction)	8.016	2	0.018*	145.000	0.874	74.000	0.016*	12.000	0.003*
Clinical performance (movement restrictions)	13.728	2	0.001*	55.000	0.002*	124.500	0.409	1.000	0.000*
Clinical performance (weight distribution)	12.464	2	0.002*	54.500	0.002	126.500	0.448	7.000	0.001*
Clinical performance (ambulation)	16.316	2	0.000*	43.500	0.001**	113.500	0.235	1.500	0.000*
Communication effort (voice modulation)	15.708	2	0.000*	130.000	0.524	40.000	0.000*	2.000	0.000*
Communication effort (less muffling of voice)	9.162	2	0.010*	131.000	0.545	70.500	0.011*	10.500	0.002*
Comfort									
Ease of donning	18.742	2	0.000*	30.000	0.000*	122.500	0.367	0.000	0.000*
Ease of doffing	21.440	2	0.000*	24.500	0.000*	106.000	0.136	0.000	0.000*
Ease of operation	20.831	2	0.000	22.000	0.000*	125.000	0.399	0.000	0.000*
Ease of monitoring	12.796	2	0.002*	59.000	0.004*	123.000	0.379	3.000	0.000*
Aegis II PAPR Care									
Ease of storage	9.601	2	0.008*	97.000	0.092	97.000	0.089	4.000	0.000*
PAPR handling	10.557	2	0.005*	72.500	0.013*	109.500	0.193	8.000	0.001*
PAPR size/dimensions	7.833	2	0.020*	129.000	0.503	77.500	0.021*	13.500	0.004*
Ease of cleaning (durability of material)	10.823	2	0.004*	101.500	0.123	74.000	0.015*	9.000	0.001*
Ease of cleaning (material breakdown)	9.278	2	0.010*	105.000	0.152	84.000	0.035*	9.000	0.001*
Ease of disinfection (time required to disinfect)	10.299	2	0.006*	128.000	0.482	65.500	0.006*	10.500	0.001*
Ease of disinfection (time required for drying)	10.299	2	0.006*	128.000	0.482	65.500	0.006*	10.500	0.001*

* Difference is significant at $\alpha = 0.05$

more protection than just an N95 mask (APF of 10).[18] This study found that the filtration efficacy of the Aegis Mark II PAPR was comparable with the commercial PAPR, thanks to its two certified anesthesia machine breathing circuit filters with 99.99% filtration efficacy (APF of 25)[2,6,9] The mean particle counts inside the hood or the user's breathing zone between PAPRs were within acceptable Ambient Air Quality Standards. Both groups showed a significant decrease of particle counts once the PAPR was turned on. In the NIOSH standards, the filtration efficiency of the device is measured by challenging the device with sodium chloride particles having a diameter in the most penetrating particle size range for the filter media made between filters supplied by different manufacturers.[30-33] However, in the absence of any other recommendations, it may be considered appropriate to use a breathing system filter that has a filtration efficiency of at least 95% when challenged with sodium chloride particles in the most penetrating particle size range to prevent the air-borne transmission of microbes.[34-36]

Users of the Aegis Mark II were on average very satisfied with the PAPR's performance in factors affecting user training, user clinical performance, user communication, user comfort, and PAPR care variables, compared to the commercial PAPR. Since design features can affect utilization and acceptance, clinical simulation is a better measure of APF. In addition,

Table 4. PM2.5 Particle Count Assessment on the different testing set-up: differences in particles counts between two set-ups at a time

Set-up 1	Set-up 2					
	A	B	C	D	E	F
A	---	5.2667*	-22.2667*	-15.2000*	7.6000*	7.1000*
B	-5.2667*	---	-27.5333*	-20.4667*	2.3333*	1.8333
C	22.2667*	27.5333*	---	7.0667	29.8667*	29.3667*
D	15.2000*	20.4667*	-7.0667	---	22.8000*	22.3000*
E	-7.6000*	-2.3333*	-29.8667*	-22.8000*	---	-0.5000
F	-7.1000*	-1.8333	-29.3667*	-22.3000*	0.5000	---

Notes:
1) Filtration Efficacy Setup:
   A: (Aegis Mark II) Nebulizer Off/PAPR Off
   B: (Commercial PAPR) Nebulizer Off/PAPR Off
   C: (Aegis Mark II) Nebulizer On/PAPR Off
   D: (Commercial PAPR) Nebulizer On/PAPR Off
   E: (Aegis Mark II) Nebulizer On/PAPR On
   F: (Commercial PAPR) Nebulizer On/PAPR On
2) Each entry represents the difference in particle counts between Set-up 1 and Set-up 2; e.g., the difference in particle counts between A ((Aegis Mark II) Nebulizer Off/PAPR Off) and B ((Commercial PAPR) Nebulizer Off/PAPR Off), that is, A – B = 5.2667
3) Asterisk (*) means that the difference is significant at $\alpha = 0.05$
4) The comparison of the PM2.5 particle counts on the different filtration efficacy set-up showed that there is a significant decrease of the particle counts in the groups C – E (29.8667*) and groups D – F (22.3000*).

Table 5. PM10 Particle Count Assessment on the different testing set-up: differences in particles counts between two set-ups at a time

Set-up 1	Set-up 2					
	A	B	C	D	E	F
A	---	8.1333*	-35.7667*	-24.9333*	12.6667*	12.7333*
B	-8.1333*	---	-43.9000*	-33.0667*	4.5333	4.6000*
C	35.7667*	43.9000*	---	10.8333	48.4333*	48.5000*
D	24.9333*	33.0667*	-10.8333	---	37.6000*	37.6667*
E	-12.6667*	-4.5333	-48.4333*	-37.6000*	---	0.0667
F	-12.7333*	-4.6000*	-48.5000*	-37.6667*	-0.0667	---

Notes:
1) Filtration Efficacy Set-up:
   A: (Aegis Mark II) Nebulizer Off/PAPR Off
   B: (Commercial PAPR) Nebulizer Off/PAPR Off
   C: (Aegis Mark II) Nebulizer On/PAPR Off
   D: (Commercial PAPR) Nebulizer On/PAPR Off
   E: (Aegis Mark II) Nebulizer On/PAPR On
   F: (Commercial PAPR) Nebulizer On/PAPR On
2) Each entry represents the difference in particle counts between Set-up 1 and Set-up 2; e.g., the difference in particle counts between A ((Aegis Mark II) Nebulizer Off/PAPR Off) and B ((Commercial PAPR) Nebulizer Off/PAPR Off), that is, A – B = 8.1333
3) Asterisk (*) means that the difference is significant at $\alpha = 0.05$
4) The comparison of the particle counts on the PM10 different filtration efficacy set-up showed that there is a significant decrease of the particle counts in the groups C – E, (48.4333*) and groups D – F, (37.6667*).

users are diverse and have differing respiratory demands.[8] The Aegis Mark II's filters, durability, and long battery life offered reliability and inspired confidence among the users. The visual field, clinical performance, communication, and comfort were on par with the published literature.[28,37,38] In contrast, N95 respirators resist air intake and retain heat and moisture, causing heat stress; these factors can reduce focus on the critical tasks. The adequate and cooling air flow rate, wide visual field, and clear communication helps the user perform clinical duties.[39-44] PAPRs have become indispensable during infectious disease outbreaks.[40,45-48]

CONCLUSION

The locally developed Aegis Mark II PAPR displayed a high degree of protection comparable with commercial PAPRs by using 99.99% filtration efficacy bacterial and viral filters. It is highly conducive to training and clinical work while being comfortable to use and maintain. Materials are more durable and can withstand repeated use and disinfection procedures. The high level of user satisfaction and acceptance can lead to a higher user's compliance. The Aegis Mark II may prevent the spread of infection to healthcare workers, reduce physiologic stress, and reduce the healthcare sector's financial burden.

STATEMENT OF AUTHORSHIP

All authors certified fulfillment of ICMJE authorship criteria.

AUTHORS DISCLOSURE

The authors declared no conflict of interest.

FUNDING SOURCE

This study was funded through a research grant by the Department of Science and Technology (DOST VI) in cooperation with the Western Visayas Health Research and Development Consortium (WVHRDC).

REFERENCES

1. Christie A, Henley SJ, Mattocks L, et al. Decreases in COVID-19 cases, emergency department visits, hospital admissions, and deaths among older adults following the introduction of COVID-19 vaccine - United States, September 6, 2020-May 1, 2021. Morb Mortal Wkly Rep. 2021;70(23):858–64. PMID: 34111059 PMCID: PMC8191865 DOI: 10.15585/mmwr.mm7023e2
2. World Health Organization. Rational use of personal protective equipment for coronavirus disease (COVID–19) and consideration during severe shortages. 2020. Accessed Oct. 15, 2023. https://www.who.int/publications/i/item/rational-use-of-personal-protective-equipment-for-coronavirus-disease-(covid-19)-and-considerations-during-severe-shortages
3. Yao W, Wang T, Jiang B, et al. Emergency tracheal intubation in 202 patients with COVID-19 in Wuhan, China: lessons learnt and international expert recommendations. Br J Anaesth. 2020; 125(1):e28–37. PMID: 32312571 PMCID: PMC7151238 DOI: 10.1016/j.bja.2020.03.026
4. Ranney ML, Griffeth V, Jha AK. Critical supply shortages - the need for ventilators and personal protective equipment during the Covid-19 pandemic. N Engl J Med. 2020;382(18):e41. PMID: 32212516 DOI: 10.1056/NEJMp2006141
5. McMahon DE, Peters GA, Ivers LC, Freeman EE. Global resource shortages during COVID-19: bad news for low-income countries. PLoS Negl Trop Dis 2020;14(7):e0008412. PMID: 32628664 PMCID: PMC7337278 DOI: 10.1371/journal.pntd.0008412
6. Cohen HJ, Hecker LH, Mattheis DK, Johnson JS, Biermann AH, Foote KL. Simulated workplace protection factor study of powered air-purifying and supplied air respirators. AIHAJ. 2010;62(5):595–604. PMID: 11669385 DOI: 10.1080/15298660108984658
7. Khoo KL, Leng PH, Ibrahim IB, Lim TK. The changing face of healthcare worker perceptions on powered air-purifying respirators during the SARS outbreak. Respirology. 2005;10(1):107–110. PMID: 15691247 PMCID: PMC7169158 DOI: 10.1111/j.1440-1843.2005.00634.x
8. Institute of Medicine. The Use and effectiveness of Powered Air Purifying Respirators in health care: workshop summary. Washington, DC: The National Academies Press; 2015. DOI: 10.17226/18990
9. OSHA US Department of Labor. Assigned protection factors for the revised respiratory protection standard. OSHA 3352-02; 2009. https://www.osha.gov/sites/default/files/publications/3352-APF-respirators.pdf
10. Janssen LL, Nelson TJ, Cuta KT. Workplace protection factors for an N95 filtering facepiece respirator. J Occup Environ Hyg. 2007;4(7):698–707. PMID: 18464097 DOI: 10.1080/15459620802115930
11. Janssen L, Bidwell J, Cuta K, Nelson T. Workplace performance of a hood-style supplied-air respirator. J Occup Environ Hyg. 2008;5: 438–43.
12. Janssen L, Zhuang Z, Shaffer R. Criteria for the collection of useful respirator performance data in the workplace. J Occup Environ Hyg. 2014;11(4):218–26. PMID: 24579751 PMCID: PMC4739800 DOI: 10.1080/15459624.2013.852282
13. Code of Federal Regulations. Title 29 (6). Respiratory Protection. 2006. Section 1910.134. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134
14. Roberts V. To PAPR or not to PAPR? Can J Respir Ther. 2014;50(3): 87–90. PMID: 26078617 PMCID: PMC4456839
15. Wong J, Goh QY, Tan Z, et al. Preparing for a COVID-19 pandemic: a review of operating room outbreak response measures in a large tertiary hospital in Singapore. Can J Anaesth. 2020;67(6): 732–45. PMID: 32162212 PMCID: PMC7090449 DOI: 10.1007/s12630-020-01620-9
16. Roberge MR, Vojtko MR, Roberge RJ, Vojtko RJ, Landsittel DP. Wearing an N95 respirator concurrently with a powered air-purifying respirator: effect on protection factor. Respir Care. 2008;53(12):1685-90. PMID: 19025703
17. Beckman S, Materna B, Goldmacher S, et al. Evaluation of respiratory protection programs and practices in California hospitals during the 2009-2010 H1N1 influenza pandemic. Am J Infect Control. 2013;41(11):1024–31. PMID: 23932825 PMCID: PMC4615716 DOI: 10.1016/j.ajic.2013.05.006
18. Centers for Disease Control and Prevention, HHS. Approval tests and standards for air-purifying particulate respirators: a rule by the health and human services department on 04/14/2020. Published April 14, 2020. Accessed October 15, 2023. https://www.federalregister.gov/documents/2020/04/14/2020-07804/approval-tests-and-standards-for-air-purifying-particulate-respirators
19. Erickson MM, Richardson ES, Hernandez NM, Bobbert DW, Gall K, Fearis P. Helmet modification to PPE with 3D printing during the COVID-19 pandemic at Duke University Medical Center: a novel technique. J Arthroplasty. 2020;35(7):S23–7. PMID: 32354536 PMCID: PMC7166108 DOI: 10.1016/j.arth.2020.04.035
20. Khoo D, Yen CC, Chow WT, et al. Ultra-portable low-cost improvised powered air-purifying respirator: feasibility study. Br J Anaesth. 2020;125(2):e264–6. PMID: 32446500 PMCID: PMC7203042 DOI: 10.1016/j.bja.2020.04.082
21. Zhuang E, Chen HH, Kolesnik O, Hines SE. Tolerability, user acceptance and preference for a novel reusable respirator among health care workers. Am J Infect Control. 2023;51(7):821–6. PMID: 36122632 DOI: 10.1016/j.ajic.2022.09.006
22. McGrath BA, Shelton CL, Gardner A, et al. Bubble-PAPR: a phase 1 clinical evaluation of the comfort and perception of a prototype powered air-purifying respirator for use by healthcare workers in an acute hospital setting. BMJ Open. 2023;13(5):e066524. PMID: 37156585 PMCID: PMC10174029 DOI: 10.1136/bmjopen-2022-066524
23. Nagel J, Gilbert C, Duchesne J. Novel 3D printable powered air purifying respirator for emergency use during PPE shortage of the COVID-19 pandemic: a study protocol and device safety analysis. BMJ Open. 2021;11(8):e049605. PMID: 34446492 PMCID: PMC8392741 DOI: 10.1136/bmjopen-2021-049605

24. Public Health Service, Department of Health and Human Services. 42 CFR 84.142 Air supply source; hand-operated or motor driven air blowers; Type A supplied-air respirators; minimum requirements. Published Apr 9, 2004. Accessed October 15, 2023. https://www.ecfr.gov/current/title-42/chapter-I/subchapter-G/part-84/subpart-J/section-84.142
25. Determination of particulate filter efficiency level against solid particulates for powered air purifying respirators (PAPRs), series PAPR100-N, Standard Testing Procedure (STP). National Institute for Occupational Safety and Health. National Personal Protective Technology Laboratory. Procedure No. CVB-APR-STP-0081. Mar 23, 2020.
26. Determination of Communication Performance Test for Speech Conveyance and Intelligibility of Powered Air-Purifying Respirator (PAPR) Series. PAPR Standard Testing Procedure. National Institute for Occupational Safety and Health. National Personal Protective Technology Laboratory. Procedure No. CVB-APR-STP-0089. Mar 21, 2020. https://www.cdc.gov/niosh/npptl/stps/pdfs/CVB-APR-STP-0089-508.pdf
27. Getting optimal performance from a powered air-purifying respirator (PAPR) depends on the condition of its battery! NIOSH Fact Sheet. DHHS (NIOSH) Publication No. 2013–146. https://www.cdc.gov/niosh/docs/2013-146/pdfs/2013-146.pdf
28. Dalli J, O'Keeffe DA, Khan F, Traynor O, Cahill RA. Powered Air Purifying Respirators (PAPR) for the protection of surgeons during operative tasks: a user perspective assessment. Br J Surg. 2020;107(9):e328–30. PMID: 32671824 PMCID: PMC7405207 DOI: 10.1002/bjs.11782
29. Koivisto AJ, Aromaa M, Koponen IK, et al. Workplace performance of a loose-fitting powered air purifying respirator during nanoparticle synthesis. J Nanopart Res. 2015;17(4):177. DOI:10.1007/s11051-015-2990-9
30. National Institute for Occupational Safety and Health (NIOSH). Respiratory Protective Devices. Code of Federal Regulations, Title 42, Part 84. Morgantown, West Virginia, USA: National Institute for Occupational Safety and Health; 1995.
31. Atkinson MC, Girgis Y, Broome IJ. Extent and practicalities of filter use in anaesthetic breathing circuits and attitudes towards their use: a postal survey of UK hospitals. Anaesthesia 1999;54(1):37–41. PMID: 10209368 DOI: 10.1046/j.1365-2044.1999.00638.x
32. British Standards Institution. Breathing system filters for anaesthetic and respiratory use. Part 1: test method to assess filtration performance. EN 13328-1:2001. Milton Keynes, UK: British Standards Institution; 2001.
33. Stevens J. Testing breathing systems. Anaesthesia 2000;55(10):1027. PMID: 11012505 DOI: 10.1046/j.1365-2044.2000.01727-6.x
34. Wilkes AR, Benbough JE, Speight SE, Harmer M. The bacterial and viral filtration performance of breathing system filters. Anaesthesia 2000;5(5):458–65. PMID: 10792138 DOI: 10.1046/j.1365-2044.2000.01327.x
35. Wilkes AR. Measuring the filtration performance of breathing system filters using sodium chloride particles. Anaesthesia, 2002; 57(2):162–8. PMID: 11871953 DOI: 10.1046/j.1365-2044.2002.02328.x
36. Lenhart SW, Seitz T, Trout D, Bollinger N. Issues affecting respirator selection for workers exposed to infectious aerosols: emphasis on healthcare settings. Appl Biosaf. 2004;9(1):20-36. DOI:10.1177/153567600400900104
37. Licina A, Silvers A. Use of powered air-purifying respirator (PAPR) as part of protective equipment against SARS-CoV-2-a narrative review and critical appraisal of evidence. Am J Infect Control. 2021;49(4):492–9. PMID: 33186678 PMCID: PMC7654369 DOI: 10.1016/j.ajic.2020.11.009
38. Hines SE, Brown C, Oliver M, et al. User acceptance of reusable respirators in health care. Am J Infect Control. 2019;47(6):648–55. PMID: 30638674 PMCID: PMC7115316 DOI: 10.1016/j.ajic.2018.11.021
39. Martyny J, Glazer CS, Newman LS. Respiratory protection. N Engl J Med. 2002;347(11): 824–30. PMID: 12226154 DOI: 10.1056/NEJMra012670
40. Fennelly KP. Personal respiratory protection against Mycobacterium tuberculosis. Clin Chest Med. 1997;18(1):1–17. PMID: 9098607 DOI: 10.1016/s0272-5231(05)70352-x
41. Leidel NA, Mullan RJ. NIOSH-recommended guidelines for personal respiratory protection of workers in healthcare facilities potentially exposed to tuberculosis. US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health: Atlanta, GA; 1992.
42. DiLeo T, Roberge RJ, Kim JH. Effect of wearing an N95 filtering facepiece respirator on superomedial orbital infrared indirect brain temperature measurements. J Clin Monitor Comput. 2017;31: 67–73. PMID: 26759336 PMCID: PMC4942410 DOI: 10.1007/s10877-016-9828-6
43. Johnson AT, Mackey KR, Scott WH, Koh FC, Chiou KY, Phelps SJ. Exercise performance while wearing a tight-fitting powered air purifying respirator with limited flow. J Occup Environ Hyg. 2005;2(7):368–73. PMID: 16020100 DOI: 10.1080/15459620591005044
44. AlGhamri AA, Murray SL, Samaranayake VA. The effects of wearing respirators on human fine motor, visual, and cognitive performance. Ergonomics. 2013;56(5):791–802. PMID: 23514088 DOI: 10.1080/00140139.2013.767383
45. Roberge R, Benson S, Kim JH. Thermal burden of N95 filtering facepiece respirators. Ann Occup Hyg. 2012;56(7):808–14. PMID: 22294505 DOI: 10.1093/annhyg/mes001
46. Coca A, Quinn T, Kim JH, et al Physiological evaluation of personal protective ensembles recommended for use in West Africa. Disaster Med Public Health Prep. 2017;11(5):580–6. PMID: 28303774 PMCID: PMC9901493 DOI: 10.1017/dmp.2017.13
47. Wizner K, Stradtman L, Novak D, Shaffer R. Prevalence of respiratory protective devices in U.S. health care facilities: implications for emergency preparedness. Workplace Health Saf. 2016;64(8):359–68. PMID: 27462029 PMCID: PMC4976391 DOI: 10.1177/2165079916657108. Erratum in: Workplace Health Saf. 2017;65(8):380. DOI: 10.1177/2165079917691526
48. Powell JB, Kim JH, Roberge RJ. Powered air-purifying respirator use in healthcare: Effects on thermal sensations and comfort. J Occup Environ Hyg. 2017;14(12):947–54. PMID: 28763290 PMCID: PMC6198805 DOI: 10.1080/15459624.2017.1358817

APPENDIX

Questionnaire Form

Name of Participant: _____
Date: _____
Study Group: _____

Questionnaire: Likert scale 1-10 (1-2- not satisfied, 3-4 slightly satisfied, 5-6 neutral, 7-8 very satisfied, 9-10 extremely satisfied).
Check box according to your response.

Variables	Responses									
	1	2	3	4	5	6	7	8	9	10
Residency Training and Education										
Visual field										
Fogging										
Inside lighting/less shadow										
PAPR noise reduction										
Clinical Performance										
Movement restrictions										
Weight distribution										
Ambulation										
Communication Effort										
Voice modulation										
Less muffling of voice										
User's Comfort										
Ease of donning										
Ease of doffing										
Ease of operation										
Ease of monitoring										
Aegis II PAPR care										
Ease of storage										
PAPR handling										
PAPR size/dimensions										
Ease of cleaning (durability of material)										
Ease of cleaning (material breakdown)										
Ease of disinfection (time required to disinfect)										
Ease of disinfection (time required for drying)										