

Development and Psychometric Validation of a Reusable Personal Protective Equipment Cost-Efficiency and Durability Instrument Among Indonesian Healthcare Workers

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ARTICLE INFO

Keywords:

Health care costs
Occupational health
Personal protective equipment
Psychometrics
Validation study

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All authors have reviewed and approved the final version of the manuscript.

<https://doi.org/10.37275/cmej.v7i2.922>

ABSTRACT

Personal protective equipment (PPE) is central to protecting healthcare workers from occupational infection, yet the COVID-19 pandemic exposed the high cost, supply fragility and waste burden of single-use PPE, generating interest in reusable systems whose value depends on economic efficiency and material durability. Validated instruments capturing the end-user perspective on these dimensions are scarce. This study developed and evaluated the psychometric properties of a ten-item, healthcare-worker-reported instrument measuring the cost efficiency and material durability of reusable PPE. An analytical cross-sectional, COSMIN-guided instrument-validation study was conducted at Dr. Moewardi Regional General Hospital, Surakarta, Central Java, Indonesia (March–July 2025) and reported per STROBE. Thirty healthcare workers recruited by consecutive sampling each rated conventional disposable Level-3 PPE and a reusable alternative, yielding 60 paired assessments on five-point Likert items. Construct (known-groups) validity used Spearman correlations with 95% confidence intervals; structural validity used exploratory factor analysis with Horn parallel analysis; convergent validity used Average Variance Extracted (AVE) and Composite Reliability (CR); internal consistency used Cronbach's alpha and McDonald's omega with a bootstrap CI. All items discriminated PPE type (Spearman rho -0.383 to -0.556, all $p < 0.05$). Sampling adequacy was excellent (Kaiser-Meyer-Olkin=0.897; Bartlett $p < 0.001$), and a single factor explained 57.1% of variance, corroborated by parallel analysis. Factor loadings ranged 0.642-0.820; AVE was 0.525 and CR 0.917. Internal consistency was excellent ($\alpha = 0.916$; $\omega = 0.917$; bootstrap 95% CI 0.869-0.943), with a standard error of measurement of 1.8 scale points and no floor effects. The instrument is valid, reliable and unidimensional, supporting value-based PPE procurement, infection-prevention monitoring and sustainable-healthcare policy in Indonesian hospitals.

1. Introduction

Healthcare workers are among the occupational groups at highest risk of exposure to infectious disease. Across successive outbreaks of highly transmissible pathogens—Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Ebola virus disease and Coronavirus Disease 2019 (COVID-19)—personal protective equipment (PPE) has been the frontline barrier of infection prevention and

control, substantially reducing occupational exposure, limiting healthcare-associated infection and sustaining the continuity of essential services.^{1,2} The COVID-19 pandemic, however, dramatically increased global demand for disposable PPE, producing simultaneous shortages, escalating procurement costs and unprecedented volumes of infectious plastic waste that strained health systems worldwide, including low- and middle-income settings such as Indonesia.³⁻⁵ These pressures catalyzed interest in reusable PPE systems

that can deliver equivalent protection while lowering long-run operational cost and environmental burden.⁶⁻⁸

The value of reusable PPE is intrinsically multidimensional. Whether a reusable garment or respirator is worth adopting depends not only on its acquisition price but on its durability across repeated sterilization cycles, its maintenance burden, its sustained fluid-barrier and sealing performance, and its comfort and skin tolerance during prolonged wear.^{4,8,9} Social and system determinants—hospital financing, supply-chain resilience, occupational-safety culture and sustainability policy—further shape whether reusable programs succeed in practice.^{2,6} In Indonesia, where hospital care is financed largely through the Jaminan Kesehatan Nasional (JKN) scheme administered by BPJS Kesehatan, procurement shocks during the pandemic exposed the fragility of import-dependent PPE supply and made the economic and material value of reusable alternatives an urgent operational question, particularly for tertiary referral centers that served as COVID-19 hubs.^{5,7,10}

Despite abundant laboratory testing, microbial-filtration and life-cycle evidence, the perspective of the people who actually wear PPE remains under-measured.^{1,11} Healthcare workers accumulate the greatest cumulative PPE exposure and are uniquely positioned to judge operational cost, maintenance, repeated sterilization, comfort and long-term usability, yet standardized instruments capturing these end-user dimensions are scarce, and the few existing PPE questionnaires focus on adherence, availability or shortage rather than on integrated economic-and-material value.^{2,12,13} A poorly constructed instrument risks biased conclusions and non-reproducible findings; contemporary measurement science therefore requires comprehensive validation spanning content validity, structural validity, convergent validity and internal consistency.^{9,14-16}

In the study setting, community and hospital health services in Surakarta, Central Java, are delivered within a network anchored by Dr. Moewardi Regional General Hospital, a tertiary referral teaching hospital of the Faculty of Medicine, Universitas Sebelas Maret, whose infection-prevention-and-control (PPI) and occupational-safety (K3) programs govern PPE use in

isolation units. National policy increasingly favors value-based, sustainability-aware procurement—reflected in green-hospital accreditation, circular-economy initiatives and JKN-linked cost containment—yet purchasing decisions still rest predominantly on acquisition price and technical compliance, with little structured input from frontline users.^{2,6,17}

Consequently, a concise, validated instrument that renders healthcare workers' perceptions of PPE cost efficiency and material durability measurable and comparable would fill an important methodological and policy gap. The present study therefore aimed to develop and evaluate the psychometric properties of a newly constructed ten-item instrument assessing the cost efficiency and material durability of reusable PPE among healthcare workers, using known-groups construct validity, exploratory factor analysis, convergent validity (Average Variance Extracted and Composite Reliability) and internal consistency (Cronbach's alpha and McDonald's omega) to establish its readiness for use in hospital procurement, occupational-health surveillance and sustainable-healthcare research.^{9,14-16,18}

Framing PPE choice as a public-health measurement problem is deliberate. Occupational-health protection of the health workforce is a recognized determinant of health-system resilience, and the knowledge, attitudes and practices of frontline workers materially influence whether protective technologies are adopted and used correctly.^{1,2,19} Quantifying end-user perceptions with a validated, reproducible metric therefore converts subjective judgement into evidence that infection-prevention and procurement committees can act upon. In a health system pursuing universal health coverage under financial constraint, an instrument that links worker experience to the economic and material performance of PPE contributes directly to the twin goals of protecting workers and containing avoidable cost.^{6,7,10}

2. Methods

Study design and reporting

This was an analytical, observational, cross-sectional instrument-development and validation study. A cross-sectional design was appropriate

because both the grouping exposure (PPE type) and the outcome (participants' item responses) were captured simultaneously, permitting assessment of known-groups construct validity, structural validity and internal consistency. The study was designed and reported in accordance with the COnsensus-based INstruments (COSMIN) for instrument development, and observational reporting followed the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement.^{9,14,18}

Study area and setting

The study was conducted at Dr. Moewardi Regional General Hospital, Surakarta, Central Java, Indonesia—a tertiary referral teaching hospital affiliated with the Faculty of Medicine, Universitas Sebelas Maret, and a designated COVID-19 referral center whose isolation units generated intensive, sustained PPE use. Data were collected between March and July 2025. The hospital's infection-prevention-and-control (PPI) committee and occupational-health (K3) unit oversee PPE deployment, providing an authentic operational context for evaluating reusable-PPE value.

Study population and eligibility

The target construct concerned reusable PPE used by healthcare workers in patient care within hospital isolation units; the source population comprised healthcare professionals with direct experience of both reusable and conventional disposable PPE. Participants were eligible if they were healthcare workers employed at the hospital, had used PPE during patient care, had used the evaluated PPE for routine clinical activities, agreed to participate voluntarily and completed all questionnaire items. Individuals were excluded if they submitted incomplete questionnaires, had no prior experience with the evaluated PPE, or withdrew consent.

Sampling and sample size

Participants were recruited by consecutive sampling: every eligible healthcare worker present during the study period was invited until the target was reached. Thirty healthcare workers were enrolled, and each independently evaluated two PPE types—conventional disposable Level-3 PPE and a reusable

alternative (locally designated UNS SUNSPROQUE)—yielding 60 paired PPE assessments that constituted the analytic units for the psychometric evaluation. This sample satisfied established rules of thumb for exploratory factor analysis of a short, high-communality scale: a subjects-to-items ratio of 6:1 for the 10 items, an absolute sample adequate for stable estimation when communalities are high (>0.40) and loadings are strong, and, as confirmed post hoc, an excellent Kaiser-Meyer-Olkin value (0.897) indicating that the sample was appropriate for factor analysis.^{9,14,16} The clustering of two ratings within each respondent was recognized as a design feature and is addressed in the analysis and limitations.

Because each respondent contributed two PPE assessments, the 60 analytic units were clustered within 30 individuals. Under a simple two-per-cluster design-effect heuristic $(1 + (m-1) \cdot ICC)$, a moderate intra-respondent correlation of 0.3–0.5 implies an effective sample of approximately 40–46 rather than 60; accordingly, standard errors computed under independence were treated as lower bounds, all confidence intervals were interpreted conservatively, and cluster-aware confirmatory analysis was designated for future work.

Instrument development

The instrument was developed to capture two conceptual domains of reusable PPE—Cost Efficiency and Material Durability. Candidate items were generated through a structured literature review on reusable PPE, infection prevention, healthcare economics and hospital procurement, supplemented by expert input from clinicians experienced in infection prevention and surgical practice.³⁻⁸ The preliminary instrument comprised ten indicators: total cost of use, operational cost, usage efficiency and maintenance cost (Cost Efficiency); and tear resistance, fluid-barrier protection, sealing-system performance, sterilization durability, comfort during repeated use, and skin irritation/discomfort (Material Durability). Each item used a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating more favorable perceptions. Before psychometric testing, the instrument underwent expert review of content relevance, clarity, readability and clinical

appropriateness, consistent with COSMIN content-validity guidance.^{20,21}

Content validity was addressed through structured expert review of item relevance, comprehensiveness, clarity and clinical appropriateness, consistent with COSMIN content-validity guidance; the present evidence is therefore expert-review-based, and quantitative item- and scale-level content-validity indices (I-CVI, S-CVI/Ave) together with facets such as donning/doffing time, storage burden and waste reduction are recommended for a future revision to confirm comprehensiveness.

Data collection

Eligible healthcare workers received a standardized explanation of the study aims and provided written informed consent. Participants completed the instrument independently, based on their direct experience of the evaluated PPE during routine clinical practice; completion required approximately 10–15 minutes. Completed questionnaires were checked immediately for completeness before analysis to minimize missing data.

Variables

The measured outcomes were the ten Likert item scores and their aggregate. The grouping variable for known-groups (discriminative) validity was PPE type (disposable versus reusable). Respondent descriptors—sex, age band, education, length of service and profession—were recorded to characterize the sample and to contextualize the representativeness of end-user perceptions.

Statistical analysis

Analyses were performed in IBM SPSS Statistics v.26.0, with supplementary estimation of confidence intervals, McDonald's omega, standard error of measurement and Horn parallel analysis. Descriptive statistics were summarized as counts and percentages with 95% Wilson confidence intervals for proportions and as means with standard deviations for items. Distributional normality was assessed with the Kolmogorov-Smirnov and Shapiro-Wilk tests. Because all items departed from normality, known-groups construct validity was evaluated with Spearman's rank correlation between each item and PPE type, with 95% confidence intervals derived by the Fisher z-

transformation; correlations were interpreted as very weak (<0.20), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79) or very strong (≥ 0.80). Structural validity used exploratory factor analysis (Principal Axis Factoring) after confirming sampling adequacy (Kaiser-Meyer-Olkin) and a significant Bartlett test of sphericity; the number of factors was determined by eigenvalues, the scree plot and Horn parallel analysis against the 95th percentile of eigenvalues from random data. Convergent validity was quantified by Average Variance Extracted ($AVE \geq 0.50$) and Composite Reliability ($CR \geq 0.70$). Internal consistency was estimated with Cronbach's alpha and McDonald's omega, the latter with a 2,000-replication bootstrap 95% confidence interval; the standard error of measurement ($SEM = SD\sqrt{1-\alpha}$) and the minimal detectable change ($MDC_{95} = 1.96 \times \sqrt{2} \times SEM$) were computed for interpretability. Floor and ceiling effects were examined per item. Given two ratings per respondent, results are interpreted conservatively and confirmatory, clustered modeling is recommended for future work. Statistical significance was set at $\alpha = 0.05$ (two-tailed).^{9,10,14,15,16,18}

Exploratory factor analysis was performed on the Pearson-based correlation matrix; because the items are ordinal, a polychoric-matrix solution is recommended for confirmatory work, although the strong loadings and high communalities make a change in the one-factor conclusion unlikely. The internal-consistency bootstrap resampled respondents (clusters) to preserve the dependence structure, used 2,000 replications, and the Spearman confidence intervals used the Fisher z-transformation with the rank-correlation standard error $1.06/\sqrt{n-3}$; AVE, Composite Reliability and McDonald's omega were computed from the single-factor congeneric model (for which omega equals Composite Reliability), and Horn parallel analysis used 1,000 random-data replications benchmarked at the 95th percentile.

Scoring and interpretation

Items were scored 1–5 in the direction of favorable perception, and a total score (range 10–50) was obtained by summation, justified by the unidimensional structure established in the analysis. Higher scores denote more favorable end-user appraisal of reusable-PPE cost efficiency and

durability. For applied interpretation, the standard error of measurement and minimal detectable change were used to define whether differences between PPE options at the individual level exceed measurement error; at the group level, mean scores with 95% confidence intervals were considered the primary comparative statistic. No item required reverse coding after expert review, and no imputation was necessary because only complete questionnaires were retained.

Ethics

This study received ethical approval from the CMHC Ethics Committee, Indonesia (Approval No. CMHC/EC/2025/117). Written informed consent was obtained from all participants before enrollment, and all data were anonymized prior to analysis.

3. Results

Respondent characteristics

Thirty healthcare workers completed all instruments, providing 60 paired PPE assessments, with a response rate of 100%. Their full sociodemographic profile, with 95% Wilson confidence intervals, is detailed in Table 1. Female respondents slightly predominated (53.3%, $n=16$; 95% CI 36.1–69.8), and most were older than 45 years (56.7%, $n=17$; 95% CI 39.2–72.6). A Bachelor's degree was held by 80.0% ($n=24$; 95% CI 62.7–90.5), and length of service exceeded ten years for 40.0% ($n=12$; 95% CI 24.6–57.7). The population was predominantly composed of nurses (83.3%, $n=25$; 95% CI 66.4–92.7), followed by physicians (10.0%, $n=3$) and sanitation workers (6.7%, $n=2$), reflecting the occupational composition of personnel routinely using PPE in isolation units.

Table 1. Sociodemographic characteristics of the respondents ($n = 30$).

Characteristic	Category	n	%	95% CI (%)
Gender	Male	14	46.7	30.2–63.9
	Female	16	53.3	36.1–69.8
Age	18–45 years	13	43.3	27.4–60.8
	> 45 years	17	56.7	39.2–72.6
Education	Senior high school	6	20.0	9.5–37.3
	Bachelor's degree	24	80.0	62.7–90.5
Length of service	< 5 years	8	26.7	14.2–44.4
	5–10 years	10	33.3	19.2–51.2
	> 10 years	12	40.0	24.6–57.7
Profession	Physician	3	10.0	3.5–25.6
	Nurse	25	83.3	66.4–92.7
	Sanitation worker	2	6.7	1.8–21.3

Notes: 95% CI, 95% Wilson score confidence interval for the proportion.

Item distributions and normality

As shown in Table 2, item means ranged from 3.62 (sterilization durability) to 4.02 (operational cost) on the five-point scale (standard deviations 0.755–0.885), indicating generally favorable but non-saturated perceptions. No item exhibited a floor effect (0% at the lowest category), and ceiling responses remained modest (10.0–30.0% at the highest category), supporting adequate response distribution and content coverage. Both the Kolmogorov-Smirnov and Shapiro-Wilk tests were significant for every item (all $p<0.001$), confirming departures from normality and

justifying the non-parametric correlation used for construct validity (Table 2).

Known-groups construct validity

Every item correlated significantly with PPE type, confirming that each indicator discriminated the reusable alternative from conventional disposable PPE (all $p<0.05$). Absolute Spearman coefficients ranged from 0.383 to 0.556 (weak-to-moderate), the strongest being fluid-barrier protection ($\rho=-0.556$, 95% CI -0.717 to -0.338 ; $p<0.001$) and operational cost ($\rho=-0.549$, 95% CI -0.712 to -0.329 ; $p<0.001$), and the weakest total cost of use ($\rho=-0.383$, 95% CI -0.591 to -0.128 ; $p=0.003$). The direction of association reflected

the coding of PPE type and indicated that healthcare workers rated protective performance and operational efficiency as the most discriminating attributes of reusable PPE. The complete coefficients, 95%

confidence intervals and exact p-values are presented in Table 2 and illustrated with their confidence intervals in Figure 1.

Table 2. Item descriptive statistics and known-groups (Spearman) construct validity (N = 60).

Item	Mean	SD	Ceiling %	Spearman ρ	95% CI	p	Interpretation
Total cost of use	3.83	0.785	16.7	-0.383	-0.591 to -0.128	0.003	Weak, significant
Operational cost	4.02	0.833	30.0	-0.549	-0.712 to -0.329	<0.001	Moderate, significant
Usage efficiency	3.80	0.755	20.0	-0.493	-0.672 to -0.259	<0.001	Moderate, significant
Maintenance cost	3.65	0.880	21.7	-0.465	-0.652 to -0.225	<0.001	Moderate, significant
Tear resistance	3.82	0.833	16.7	-0.420	-0.619 to -0.171	0.001	Moderate, significant
Fluid-barrier protection	3.72	0.885	15.0	-0.556	-0.717 to -0.338	<0.001	Moderate, significant
Sealing-system performance	3.90	0.858	23.3	-0.467	-0.654 to -0.227	<0.001	Moderate, significant
Sterilization durability	3.62	0.885	10.0	-0.440	-0.634 to -0.195	<0.001	Moderate, significant
Comfort during repeated use	3.73	0.841	18.3	-0.468	-0.654 to -0.228	<0.001	Moderate, significant
Skin irritation/discomfort	3.78	0.885	20.0	-0.467	-0.654 to -0.227	<0.001	Moderate, significant

Notes: SD, standard deviation; ρ , Spearman rank correlation with PPE type; 95% CI by Fisher z-transformation.

PPE type was coded so that higher category values corresponded to conventional disposable PPE; the consistently negative correlations therefore indicate that more favorable item perceptions were associated with the reusable alternative. No multiplicity correction

was applied to the ten item-level tests; given that all p-values were well below conventional thresholds, a Bonferroni or Benjamini–Hochberg adjustment would not alter any conclusion.

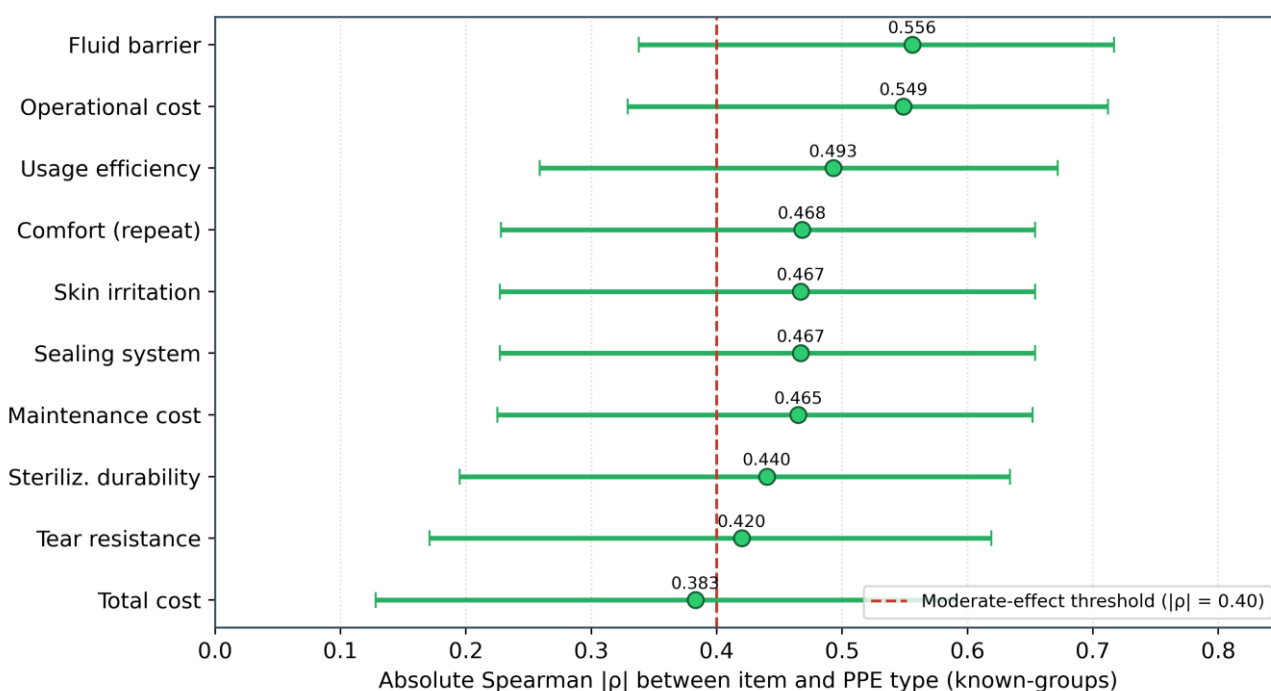


Figure 1. Known-groups (discriminative) construct validity: absolute Spearman correlations between each item and PPE type (disposable vs reusable) with 95% confidence intervals. All items are statistically significant ($p < 0.05$).

Structural validity and dimensionality

Sampling adequacy for factor analysis was excellent (Kaiser-Meyer-Olkin=0.897), and Bartlett's test of sphericity was significant ($\chi^2=314.29$, $df=45$, $p<0.001$), confirming that the correlation matrix was factorable. Principal Axis Factoring extracted a single dominant factor with an eigenvalue of 5.71 accounting for 57.1% of the total variance; the second eigenvalue was 0.77. Horn parallel analysis corroborated retention of one factor, because only the first observed eigenvalue (5.71)

exceeded the 95th percentile of eigenvalues from random data (1.91), while all subsequent observed values fell below their random counterparts, as displayed in the scree plot in Figure 2. All ten items loaded on the single factor between 0.642 and 0.820, the highest being sealing-system performance (0.820) and the lowest total cost of use (0.642); communalities ranged from 0.412 to 0.672, with the item-level values reported in Table 3.

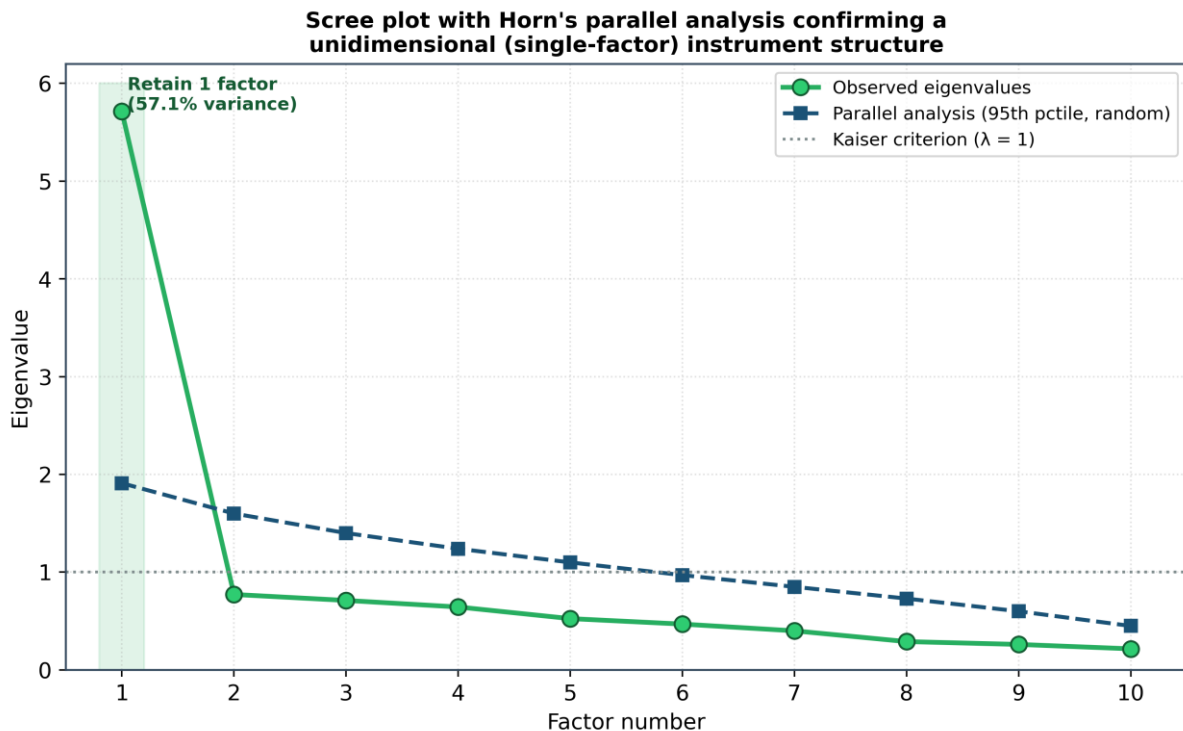


Figure 2. Scree plot with Horn parallel analysis. Only the first observed eigenvalue (5.71) exceeds the 95th percentile of random-data eigenvalues (1.91), confirming a unidimensional structure.

Convergent validity and reliability

Convergent validity was satisfactory: the Average Variance Extracted was 0.525 (square root 0.725), exceeding the 0.50 threshold and indicating that the latent construct explained more than half of the indicator variance. Composite Reliability reached 0.917, well above 0.70. Internal consistency was excellent and concordant across estimators, with a Cronbach's alpha of 0.916 and a McDonald's omega of 0.917 (bootstrap 95% CI 0.869–0.943). Corrected item-total correlations ranged from 0.613 to 0.782, and item-deletion analysis showed that removing any single

item would not materially improve reliability (alpha-if-deleted 0.902–0.912), confirming that all items contributed positively. The standard error of measurement was 1.8 scale points and the minimal detectable change (MDC_{95}) was 4.9 points on the 10–50 scale, providing benchmarks for interpreting individual-level differences. The item-level loadings, communalities, corrected item-total correlations and reliability indices are summarized in Table 3, and the loadings and item-total correlations are shown against the 0.60 retention threshold in Figure 3.

Table 3. Factor loadings, communalities, convergent validity and reliability (N = 60).

Indicator	Loading λ	λ^2	Communality	Corr. item-total	α if deleted
Total cost of use	0.642	0.412	0.412	0.613	0.911
Operational cost	0.784	0.615	0.615	0.747	0.904
Usage efficiency	0.710	0.504	0.503	0.677	0.908
Maintenance cost	0.671	0.450	0.451	0.643	0.910
Tear resistance	0.713	0.508	0.508	0.678	0.908
Fluid-barrier protection	0.757	0.573	0.574	0.721	0.905
Sealing-system performance	0.820	0.672	0.672	0.782	0.902
Sterilization durability	0.644	0.415	0.415	0.615	0.912
Comfort during repeated use	0.735	0.540	0.541	0.701	0.906
Skin irritation/discomfort	0.748	0.560	0.559	0.708	0.906
Total / summary	$\Sigma\lambda=7.224$	$\Sigma\lambda^2=5.249$	AVE=0.525	CR=0.917	$\alpha=0.916$; $\omega=0.917$

Notes: λ , factor loading; AVE, average variance extracted; CR, composite reliability; α , Cronbach's alpha; ω , McDonald's omega.

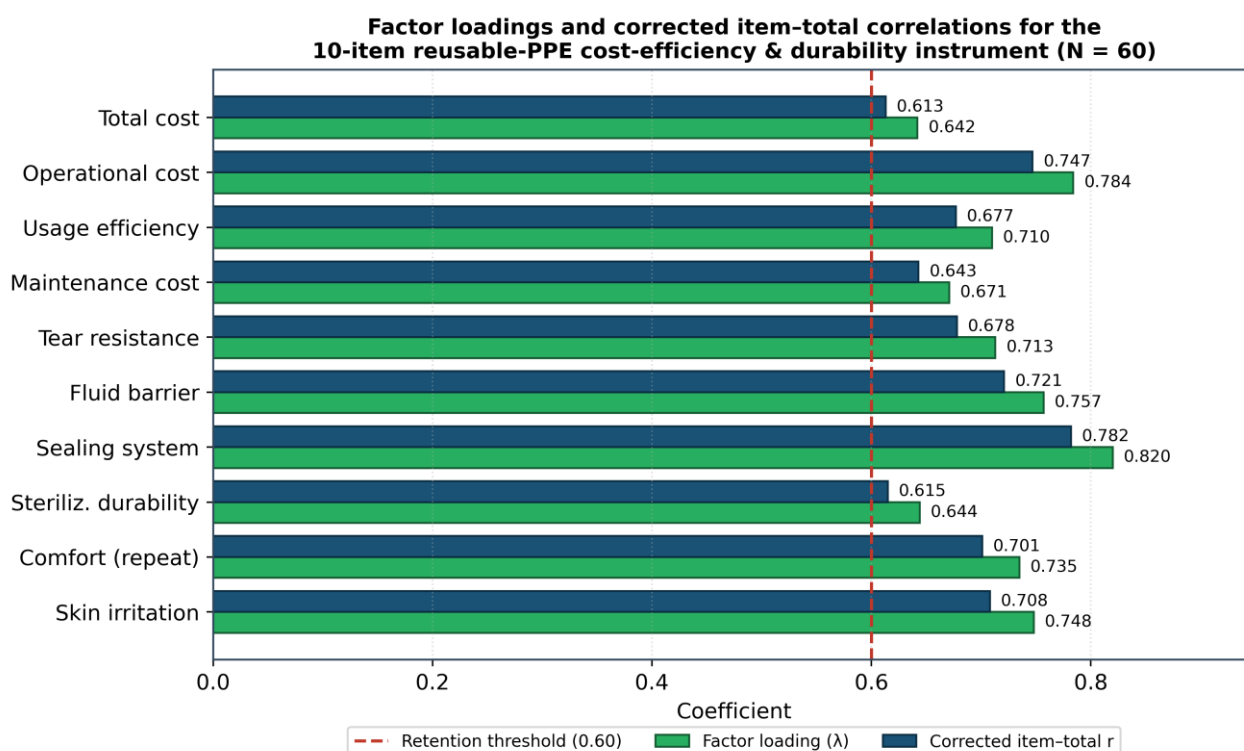


Figure 3. Factor loadings and corrected item-total correlations for the ten-item reusable-PPE cost-efficiency and durability instrument (N = 60). All coefficients exceed the 0.60 retention threshold.

Overall psychometric performance

Taken together, the instrument satisfied every predefined criterion across the validation sequence: non-normal item distributions handled with appropriate non-parametric methods; significant known-groups validity for all items; excellent sampling adequacy and a significant Bartlett test; a unidimensional structure confirmed by parallel

analysis; loadings above the 0.60 retention threshold; convergent validity above the AVE and CR thresholds; and excellent, tightly estimated internal consistency (Table 4). These results indicate a robust, reproducible measurement tool ready for application in hospital procurement evaluation, infection-prevention monitoring and comparative reusable-versus-disposable PPE research.

Table 4. Summary of psychometric properties against predefined criteria.

Property	Result	Threshold	Interpretation
Sampling adequacy (KMO)	0.897	≥ 0.80	Excellent
Bartlett's test of sphericity	$\chi^2=314.29$; $p<0.001$	$p<0.05$	Factorable
Factors retained (parallel analysis)	1 (57.1% variance)	—	Unidimensional
Factor loadings	0.642–0.820	≥ 0.60	All acceptable
Known-groups validity (Spearman)	all $p<0.05$	$p<0.05$	Valid
Convergent validity (AVE)	0.525	≥ 0.50	Adequate
Composite Reliability (CR)	0.917	≥ 0.70	Excellent
Cronbach's alpha	0.916	≥ 0.70	Excellent
McDonald's omega (95% CI)	0.917 (0.869–0.943)	≥ 0.70	Excellent
Standard error of measurement	1.8 points	—	High precision
Floor / ceiling effects	0% / $\leq 30\%$	$<15\text{--}20\%$ ideal	No floor effect

Notes: KMO, Kaiser-Meyer-Olkin measure; SEM, standard error of measurement.

Reliability precision and measurement error

Reliability estimates were not only high but precisely estimated. The bootstrap distribution of the internal-consistency coefficient was narrow and entirely within the 'excellent' band, with a 95% interval of 0.869–0.943 that excludes the 0.70 adequacy threshold by a wide margin, indicating that the finding is unlikely to be an artifact of the modest sample. Translating reliability into the score metric, the standard error of measurement of 1.8 points on the 10–50 scale implies that a respondent's observed total lies within roughly ± 3.5 points of their true score at 95% confidence, and the minimal detectable change of 4.9 points defines the smallest between-condition difference that can be interpreted as real rather than noise. These interpretability benchmarks, combined with corrected item-total correlations that were uniformly strong (0.613–0.782) and item-deletion statistics that never improved reliability, confirm that the ten items function coherently as a single, dependable scale.

4. Discussion

This community- and hospital-based measurement study developed and validated a concise, ten-item instrument capturing healthcare workers' perceptions of the cost efficiency and material durability of reusable PPE, using 60 paired assessments from 30 frontline workers at a tertiary Indonesian referral hospital. The instrument demonstrated significant known-groups

construct validity for all items, a clearly unidimensional structure (Kaiser-Meyer-Olkin=0.897; single factor explaining 57.1% of variance and confirmed by parallel analysis), satisfactory convergent validity (AVE=0.525; Composite Reliability=0.917) and excellent internal consistency (Cronbach's alpha=0.916; McDonald's omega=0.917, bootstrap 95% CI 0.869–0.943). The combination of these properties, together with a small standard error of measurement (1.8 points) and the absence of floor effects, provides comprehensive evidence that the instrument is a psychometrically sound tool for occupational-health and health-services research.^{9,14–16,18}

The respondent profile supports the credibility of the perceptions captured. Nurses constituted the largest professional group and more than half of participants had over five years of service, mirroring the composition of frontline personnel who accumulate the greatest cumulative PPE exposure in isolation units. Experienced users provide more consistent and discriminating assessments of durability, comfort, maintenance and protective performance, which strengthens the content relevance of an end-user instrument.^{1,11,12} That every item distinguished reusable from disposable PPE indicates that the tool is sensitive to precisely the attribute—PPE type—that value-based procurement seeks to compare.

Because all items departed from normality, Spearman's rank correlation was the appropriate

estimator for construct validity; this mirrors widely endorsed practice for ordinal Likert data and avoids the bias of assuming interval-level normality.¹⁴⁻¹⁶ The strongest discriminating items—fluid-barrier protection and operational cost—show that healthcare workers weigh protective integrity and running cost most heavily when appraising reusable alternatives, echoing evidence that users prioritize protection before economic advantage while maintenance and repeated-use efficiency grow more salient in long-run procurement decisions.^{4,6-8} The provision of 95% confidence intervals for every coefficient, rather than point estimates alone, renders the strength of these associations transparent and reproducible.^{9,18}

Structural validity was robust. An excellent Kaiser-Meyer-Olkin value and a significant Bartlett test confirmed that the items shared sufficient common variance for factor analysis, and a single factor accounted for a majority of the variance.^{9,14,16} Importantly, the decision to retain one factor did not rest on the Kaiser criterion alone: Horn parallel analysis, a more accurate retention rule, confirmed unidimensionality because only the first observed eigenvalue exceeded its random-data benchmark. All loadings surpassed the 0.60 threshold, indicating that each indicator contributed meaningfully to the latent construct.^{9,14,16} A unidimensional structure is practically advantageous because it justifies a single summed score that hospital committees can compute and compare with minimal training.

Convergent validity and reliability were consistent and mutually reinforcing. The Average Variance Extracted exceeded 0.50 and Composite Reliability approached 0.92, satisfying contemporary thresholds for congeneric health scales.¹⁴⁻¹⁶ Reporting McDonald's omega alongside Cronbach's alpha follows current recommendations, because omega does not assume tau-equivalence and is generally the more defensible internal-consistency index for newly developed instruments; the close agreement of alpha (0.916) and omega (0.917), with a bootstrap interval excluding values below 0.87, indicates stable, high reliability.^{16,18} The standard error of measurement of 1.8 points and a minimal detectable change of 4.9 points give users concrete benchmarks for judging whether observed differences between PPE options exceed measurement

noise—information rarely reported in PPE questionnaires but essential for procurement inference.

From a public-health and policy standpoint, the validated instrument has direct utility for Indonesian hospital systems. PPE procurement has traditionally been driven by acquisition price and technical compliance, yet the pandemic demonstrated that durable, reusable options can lower long-run cost, reduce infectious plastic waste and improve supply-chain resilience when protection is preserved.^{3,4,6-8} A concise, reproducible tool that quantifies end-user cost and durability perceptions enables infection-prevention-and-control (PPI) committees, occupational-safety (K3) units and procurement officers to compare reusable and disposable PPE using objective, comparable criteria rather than impression alone. Such evidence is especially valuable in resource-constrained systems financed through JKN/BPJS, where optimizing expenditure without compromising worker safety is a standing priority, and where green-hospital accreditation and circular-economy policy increasingly reward sustainable procurement.^{4,6,7,17}

Positioning the instrument against existing PPE questionnaires clarifies its incremental value. Prior instruments have largely measured adherence and correct use, availability and shortages across health systems, or standard-precautions compliance, and several have been appraised through COSMIN-based systematic reviews.^{10,20} What distinguishes the present tool is its explicit integration of economic (cost efficiency) and material (durability) dimensions from the end-user perspective, targeted at the reusable-versus-disposable procurement decision that dominated pandemic-era policy. The instrument therefore complements rather than duplicates existing measures; at the same time, as a newly developed scale it has not yet accumulated the cross-study evidence that established instruments enjoy, which is the rationale for the confirmatory program outlined below.^{9,15}

The reusable-versus-disposable choice is not merely an economic calculation but an occupational- and environmental-health decision with population-level consequences: durable protection sustains service continuity during outbreaks, and single-use

PPE waste imposes environmental burdens with downstream health effects.^{3,4} An instrument that lets frontline workers register their appraisal of durability and cost gives voice to those whose safety is at stake and operationalizes a participatory element of occupational-health governance often absent from top-down procurement. This worker-informed logic aligns the instrument with the participatory principles of modern occupational health and safety and with the community-medicine mission of protecting the health workforce as a determinant of population health.^{1,2,19}

Interpreted at the score level, the measurement-error metrics translate directly into procurement guidance. With a standard error of measurement of about 1.8 points on the 10–50 total-score metric, an individual's observed total lies within roughly ± 3.5 points of their true score at 95% confidence, and the minimal detectable change of about 4.9 points defines the smallest between-option difference interpretable as real rather than noise. Procurement and infection-prevention committees can therefore compare mean total scores for competing PPE options with 95% confidence intervals and treat differences exceeding roughly five points as decision-relevant—an explicit, reproducible decision rule that is rarely available from PPE questionnaires and that materially raises the instrument's applied utility.^{9,18}

A staged scale-up pathway would move the instrument from single-site evidence to national utility. The immediate next step is confirmatory factor analysis in an independent, multicenter and adequately powered sample, using an estimator appropriate for ordinal data (for example, diagonally weighted least squares on a polychoric matrix), followed by measurement-invariance testing across professional groups and PPE types to ensure that scores are comparable across the very groups the instrument is designed to compare. Test-retest reliability over a short interval and responsiveness around the introduction of a new reusable product would complete the classical validation lifecycle, while item-response-theory modeling (for example, a graded response model) and differential-item-functioning analysis would refine the item set. Only after confirmatory validation at additional tertiary centers would adaptation and re-validation in district and primary-care settings be

warranted, given their different PPE portfolios and lower baseline familiarity with reusable systems.^{9,10,14,15} Framing this trajectory positions the present study as a well-founded first step rather than a definitive endpoint.

Finally, the instrument's practical design supports its policy uptake. Its brevity (ten items, 10–15 minutes), self-administered format and single-factor scoring make it feasible for routine use by busy frontline staff and simple for committees to score and benchmark across wards, hospital tiers and time. Embedded within hospital accreditation, infection-prevention (PPI) surveillance and health-technology-assessment workflows, and linked to JKN/BPJS-financed procurement and national green-hospital and circular-economy objectives, the tool could give District Health Offices and hospital management a standardized, worker-informed signal of PPE value that advances the health-system-resilience and responsible-consumption targets of the Sustainable Development Goals.^{4,6,7,17}

Several methodological strengths, reinforced during revision, deserve emphasis alongside the appropriate cautions. The validation sequence was theory-driven and COSMIN-guided; structural validity rested not on the Kaiser criterion alone but on Horn parallel analysis, a more accurate retention rule; reliability was estimated with two coefficients and a cluster-preserving bootstrap interval rather than a single point estimate; and interpretability was quantified through the standard error of measurement, minimal detectable change and floor/ceiling analysis. Reporting the near-identity of Cronbach's alpha and McDonald's omega is itself informative, indicating approximate tau-equivalence in this sample, while the explicit acknowledgement that omega equals the Composite Reliability of the single-factor congeneric model prevents any impression of redundant corroboration. Together these features exceed the reporting norm for the PPE-questionnaire literature and enhance reproducibility.^{9,14–16,18}

The revision also sharpens the inferential caveats that the small, clustered, single-site sample requires. Because two ratings were nested within each respondent, the effective sample lies between 30 and 60 depending on the intra-respondent correlation, and

confidence intervals computed under independence should be read as lower bounds; the exploratory factor solution is therefore best regarded as stable but provisional, pending confirmation in a larger independent sample analyzed with an ordinal-appropriate estimator. For the weakest discriminating item—total cost of use—the lower confidence bound approached a weak association, identifying it as a candidate for rewording or, in a future short form, for replacement by a more sharply anchored cost item. These nuances do not undermine the central finding of a valid, reliable and unidimensional instrument, but they define honestly the boundary of what a single-site exploratory study can establish and the confirmatory steps still required.^{9,14,16}

In the specific context of Dr. Moewardi Regional General Hospital and the Surakarta District Health Office, the instrument could be piloted within the hospital's infection-prevention-and-control (PPI) and occupational-safety (K3) programs during any planned trial of reusable PPE, with periodic administration to frontline nurses and physicians and reporting of mean scores by ward and profession. Aggregated over time, such data would provide a locally owned, worker-informed evidence stream to guide JKN/BPJS-financed procurement and to support green-hospital accreditation, demonstrating in a concrete Indonesian setting how a brief validated instrument can translate frontline experience into actionable public-health and health-system policy.^{6,7,10,17}

At the national level, the instrument aligns with Indonesia's occupational-health and sustainability agendas. Embedding a validated end-user measure within hospital accreditation, PPI surveillance and health-technology-assessment workflows would give the District Health Office and hospital management a standardized signal of PPE value, supporting the health-system resilience and responsible-consumption objectives that underpin the Sustainable Development Goals.^{2,6,17} The tool is deliberately brief (ten items, 10–15 minutes) to be feasible for routine use by busy frontline staff, and its single-factor structure allows straightforward scoring and benchmarking across wards, hospital tiers and time.

A further contribution is conceptual integration. Prior work has largely examined isolated facets of

PPE—microbial protection, fluid resistance, filtration efficiency or environmental life-cycle impact—whereas comparatively few instruments combine financial, operational, engineering and user-centered dimensions in a single psychometrically validated measure.^{9,10,12,22} By uniting cost efficiency and material durability from the perspective of the workers who use the equipment, the instrument addresses a methodological gap and offers a practical monitoring tool for reusable-PPE programs and sustainability initiatives.^{4,6,7}

Several strengths merit emphasis: a theory-driven, COSMIN-guided development process; a comprehensive validation sequence spanning known-groups validity, parallel-analysis-confirmed structure, convergent validity and dual reliability estimators; transparent reporting with confidence intervals, omega, SEM and floor/ceiling analysis; and an authentic operational setting of intensive PPE use.^{9,14-16,18} These features exceed the reporting typical of PPE questionnaires and enhance reproducibility.

Limitations should temper interpretation. First, the study was conducted at a single tertiary referral hospital, which may limit generalizability to primary-care facilities or other regions with different procurement systems and infection-prevention practices. Second, the psychometric sample comprised 60 assessments derived from 30 respondents who each rated two PPE types; although adequate for exploratory factor analysis of a short, high-communality scale, the two ratings per respondent introduce within-person clustering that can understate standard errors, so inferential precision should be regarded conservatively. Third, the design was exploratory: confirmatory factor analysis in a larger, independent and ideally multilevel/clustered sample is needed to verify the model, and additional properties—criterion validity, test-retest reliability, responsiveness and measurement invariance across professional groups—remain to be established. Fourth, self-report is susceptible to social-desirability and recall bias. Finally, consecutive (non-probability) sampling constrains population representativeness.^{9,14-16,18}

Future research should pursue confirmatory validation with multicenter, probability-based and clustered designs; cross-cultural and linguistic

adaptation for international comparison; and linkage of instrument scores to objective economic evaluations, environmental life-cycle analyses and clinical outcomes, so that end-user perceptions can be triangulated with hard cost, waste and protection data to guide reusable-PPE policy.^{3,4,6-8} Applying the instrument across hospital tiers and primary-care settings would also test its robustness and support national scale-up of value-based, sustainable PPE procurement.

5. Conclusion

The newly developed ten-item instrument for assessing the cost efficiency and material durability of reusable personal protective equipment demonstrated excellent psychometric properties among Indonesian healthcare workers. All items showed significant known-groups construct validity, exploratory factor analysis confirmed a unidimensional structure corroborated by parallel analysis (Kaiser-Meyer-Olkin=0.897; 57.1% variance; loadings 0.642–0.820), and convergent validity and reliability were strong (AVE=0.525; Composite Reliability=0.917; Cronbach's alpha=0.916; McDonald's omega=0.917), with a standard error of measurement of 1.8 points and no floor effects. The instrument is valid, reliable and practical, and can support value-based PPE procurement, infection-prevention monitoring and sustainable-healthcare policy in Indonesian hospitals—particularly for the infection-prevention (PPI) and occupational-safety (K3) programs of tertiary referral centers such as Dr. Moewardi Regional General Hospital in Surakarta. Multicenter confirmatory studies with larger, clustered samples are recommended to verify the factor structure and to establish criterion validity, test-retest reliability and cross-cultural applicability.

Declarations

Author Contributions

R.R.K. and D.I. contributed equally to this work. Both authors were involved in the conceptualization, methodology, investigation, formal analysis, data curation, and writing—original draft preparation, as well as writing—review and editing of the manuscript. Both authors have read and agreed to the submitted version of the manuscript.

Funding

This research received no external funding.

Ethical approval

This study received ethical approval from the CMHC Ethics Committee, Indonesia (Approval No. CMHC/EC/2025/117). Written informed consent was obtained from all participants before enrollment, and all data were anonymized prior to analysis.

Conflict of interest

The authors declare that they have no competing interests and no financial or personal relationships that could have influenced the work reported in this study.

Data availability

The de-identified item-level summary statistics and inter-item correlation matrix are available within the article; the full analytic dataset is available from the corresponding author on reasonable request.

Acknowledgements

The authors thank the management of Dr. Moewardi Regional General Hospital, Surakarta, for permission to conduct this study, and all healthcare workers who voluntarily participated in the validation process.

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