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Research Article

Determination of Sterilization Quality Priorities Based on Analytical Hierarchy Process in High Temperature Sterilizers

Mochammad Nurudin[1]*, Muhamad Haddin[2]

[1] Universitas Islam Sultan Agung, Semarang, Indonesia, E-mail: oedin.rsdm@gmail.com
[2] Universitas Islam Sultan Agung, Semarang, Indonesia, E-mail: haddin@unissula.ac.id
*Corresponding Author: Mochammad Nurudin

Abstract: The issue of high-temperature sterilizer quality in the central sterile supply department is an important matter. This is due to the quality of sterilization, which affects the number of surgical instruments and items that become damaged and dull when sterilized. The impact is an increase in high-temperature sterilizer malfunctions. The solution is how to ensure the quality of high-temperature sterilizers. This study discusses the determination of sterilization priorities for high-temperature sterilizers with the aim of providing recommendations for usage priorities. The model is determined as a sterilizer test with inputs: temperature, time, and type, with the output in the form of a sterilizer ranking priority. Specified parameters: sterilizer specifications, temperature, sterilizer volume, and sterilization time. The research stages begin with testing conducted on 4 (four) high-temperature sterilizer units, namely Odelga ISO 9001, Tuttnauer Stera 120, MMM selection Lokal, and TRIDENT MEDICAL EA-632. The Analytical Hierarchy Process method is used to determine sterilization quality priorities in high-temperature sterilizers. The research results show that the Analytical Hierarchy Process can be used to determine sterilization quality priorities. This is evidenced by the best recommendation results from the four high-temperature sterilizer brands, which are: first place MMM selection Lokal, second ODELGA ISO 9001, third TRIDENT MEDICAL, and fourth Tuttnauer Stera 120. Three high-temperature sterilizers of the brands (Odelga, Tuttnauer, MMM) have a temperature accuracy within a tolerance of ±2°C, while TRIDENT MEDICAL shows a deviation of +4.1°C. The results indicate that accurate temperature and time, selection of the appropriate type of high-temperature sterilizer, and AHP-based evaluation are effective in determining the priority scale of high-temperature sterilizers to ensure patient safety in hospitals.

Keywords: AHP; High-Temperature Sterilizer; Priority Determination; Sterilization; Quality.

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1. Introduction

High-temperature sterilizers are one of the vital healthcare service support equipment, because the accuracy and quality of sterilization of items being sterilized must be carefully considered to ensure the level of sterility. In every laboratory, clinic, and hospital facility, the sterilization of medical equipment is very vital and carries a high risk of being a place for the spread of infection due to the high population of microorganisms. These microorganisms can live and develop in hospital environments such as floors, water, air, hospital furniture, non-medical equipment, and even on food and medical equipment [1]. Sterilization methods are used to remove or kill all forms of disease-causing microbes such as bacterial spores without significantly affecting the physical and chemical properties of medical devices [2]. The government supports sterilization efforts on medical equipment by issuing the Ministry of Health Decree of the Republic of Indonesia No. 1204/Menkes/SK/X/2004, which generally contains guidelines related to hospital environmental health [3]. According to this regulation, it is stipulated that the microbial count must not exceed the permissible contamination threshold value, which is 0 CFU/ml [4]. The problem of high-temperature sterilizers in the central sterile supply department is about the quality of sterilization. The quality factors of sterilization are caused by temperature, time, and the type of sterilizer, which impact the number of surgical instruments and items being sterilized, causing them to become damaged and dull [5]. The impact of high-temperature sterilizer damage causes instruments to become damaged and affects hospital services. The solution is how to ensure the quality of high-temperature sterilizers. The initial step to ensure sterilization quality is testing using a calibrator device.

Some previous studies on sterilization have been conducted, including: the effectiveness of glutaraldehyde for sterilization [6], the effectiveness of high-temperature sterilizers in terms of sterilization quality [7], and the simulation study of a high-temperature sterilizer based on Atmega2560 [8]. To meet sterilization services in the central sterile supply department, proper sterilization processing is necessary as one effort to prevent infections caused by non-sterile medical equipment, thus it is necessary to determine sterilization priorities based on the Analytical Hierarchy Process for high-temperature sterilizers. This research focuses on the prioritization of sterilization quality in high-temperature sterilizers. The Analytical Hierarchy Process method is used to determine sterilization priorities. This decision determination aims to select the most effective brand and type of high-temperature sterilizer from the four brands studied. The object of the research chosen is high-temperature sterilizers in the central sterile supply department at Dr. Moewardi General Hospital.

2. Literature Review

Previous research discussing high-temperature sterilizers has been conducted, including: Performance qualification of Industrial Steam Sterilizer (High-temperature sterilizer) [9]. This study consists of two steps, namely the first step is to ensure that the equipment is under control. The second step relates to the output. Heat penetration studies are conducted with pre-determined worst-case load items. The study is mapped with external temperature sensors to map the thermal effects on load items during sterilization [10]. Biological indicators are also used to challenge the efficiency against microorganisms.

High-Temperature Sterilizer Modification Based on Atmega328 [11]. This study shows that testing on this device will be compared with a temperature measuring tool, namely a thermometer, timer measurements compared with a stopwatch, and sterilization tests conducted using high-temperature sterilizer tape. The temperature measurement obtained a correction value of 0.5, then in the timer measurement of 900 seconds a correction value of 3.3 was obtained, while for the sterilization test, the effective sterilization time was obtained at 15 to 20 minutes [12]. Measurements and sterilization tests can be concluded that the measurements have correction values that are not far off, and this high-temperature sterilizer modification device can carry out the sterilization process effectively within 15 minutes [13].

Industrial steam sterilizer performance qualification [14]. Periodic requalification is required to test the pre-established time/temperature relationship throughout the equipment's life cycle. Periodic qualification is divided into two parts. The first part is physical verification and critical operational control checks. The second part is performance evaluation. The first step is to ensure the equipment is in a controlled state [15]. The second step relates to output. Heat penetration studies are conducted with pre-determined worst-case load items. The study is mapped with external temperature sensors to map the thermal effects on the load items during sterilization. Biological indicators are also used to test the efficiency of the microbial challenge. Based on previous studies that showed that high-temperature sterilizers have a high proportion of steam sterilization failures, research focusing on the effectiveness of high-temperature sterilization is reviewed from the perspective of sterilization quality.

However, there is still a shortcoming in that there has been no research on determining sterilization quality priorities. This study focuses on determining the priorities of high-temperature sterilization quality in terms of temperature, sterilization time, and type of high-temperature sterilizer. The Analytical Hierarchy Process method is used to determine sterilization quality in sterilizers. The research object is determined at RSUD Dr. Moewardi, Surakarta, Indonesia.

3. Research Method

A high-temperature sterilizer is essentially a tool used to sterilize or perform sterilization on various types of objects, especially those categorized as medical instruments, using high-pressure steam. High-temperature sterilizers provide an effective sterilization process in killing various types of microorganisms, including bacteria, viruses, and even spores [16]. There are several types of high-pressure steam sterilization: Gravity Displacement high-temperature sterilizers, High-Speed Prevacuum Sterilizers, and Steam Flush-Pressure Pulsing.

Sterilization

Sterilization effort is a process of completely destroying or killing microorganisms, including spores, in an object. Vegetative cells of bacteria and fungi can be killed at a temperature of 60°C within 5–10 minutes [17]. However, spores can be killed at temperatures above 80°C, and bacterial spores are only killed at temperatures above 110°C for 10 minutes [18].

Sterilization can be differentiated into three methods: physical sterilization, chemical sterilization, and mechanical sterilization [19]. Sterilization can be carried out using high-temperature techniques, low-temperature techniques, and others. Various factors affecting the effectiveness of sterilization are as follows [20]: the type and number of microorganisms, sterilization time, temperature and pressure, and the type of material being sterilized.

Research Model

The objective is to obtain measurement results for each parameter by conducting tests using a data logger to produce actual temperature and time compared to the temperature and time settings on the high-temperature sterilizer. The research model is designed as a high-temperature sterilizer test with inputs of temperature, time, and type of high-temperature sterilizer to produce several priorities for the use of high-temperature sterilizers. The research model is shown in Figure 1.

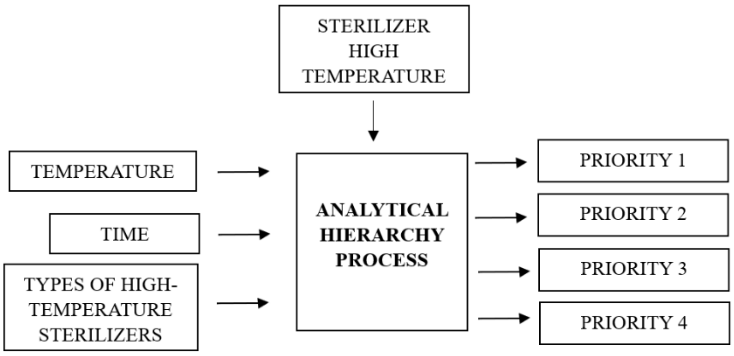

Figure 1. Research Model.

The method used in this study is a quantitative method with testing or calibration of high-temperature sterilizers and bacterial testing with parameters: temperature, type of sterilizer, and processing time using the Analytical Hierarchy Process (AHP) with several alternatives to obtain sterilization quality priorities with rankings: very good, good, moderate, and poor. Furthermore, the measurement results and analysis of the research results are compared with high-temperature sterilizer calibration standards to determine whether the condition is fit for use and safe to use or unfit for use. The research data is shown in Table 1.

Table 1. Data of High-Temperature Sterilizer Brands**.**

No	Brand/Type	Setting temperature (ºC)
1	Odelga ISO 9001	127
2	Tuttnauer Stera 120	134
3	MMM selection Lokal	134
4	TRIDENT MEDICAL EA-632	142

The independent variable in this study is: (1) The optimal sterilization temperature and time affect the sterilization quality in a high-temperature sterilizer. (2) The type and volume of high-temperature sterilizers affect the quality of sterilization. The dependent variable in this study is the optimum result of the best conditions of the high-temperature Sterilizer.

1. Average (Mean)
   Average calculation (mean).
   $$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$
2. Standard deviation
   Calculating the standard deviation.
   $$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{x})^2} \quad (2)$$
3. Standard of uncertainty/repeatability
   Calculating uncertainty.
   $$u_a = \frac{\sigma}{\sqrt{n}} \quad (3)$$
4. Uncertainty of the standard instrument (ub1)
   Uncertainty of the standard tool (Ustd) in measuring instruments.
   $$\mathrm{U}_{b1} = \frac{Ustd}{k} \quad (4)$$

5. Uncertainty of Readability Ability UUT (U_{b2})
   Calculating reading power UUT.
   $$U_{b2} = \frac{1}{2}\frac{Resolusi}{\sqrt{3}} \tag{5}$$
6. Uncertainty of Calibrator Drift (U_{b3})
   Calculating the uncertainty of calibrator drift.
   $$U_{b3} = \frac{\frac{1}{2}x\ (koreksi\ sertif\ terbaru - koreksi\ sertif sebelum)}{\sqrt{3}} \tag{6}$$
7. Combined Uncertainty (U_c)
   Calculating combined uncertainty.
   $$Uc = \sqrt{(U_{(a)}^2 + (U_{(b1)}^2 + (U_{(b2)}^2 + (U_{(b3)}^2} \tag{7}$$
8. Span Uncertainty.
9. Calculating the span uncertainty.
   $$(\text{Veff}) = \frac{(u.c)^4}{\sum_{i=1}^{N}\frac{(u_i.c_i)^4}{vi}} \tag{8}$$

Analytical Hierarchy Process (AHP)

The hierarchy in the process of determining the priority of sterilization quality in high-temperature sterilizers assisted by the use of the Analytical Hierarchy Process method is shown in Fig. 2.

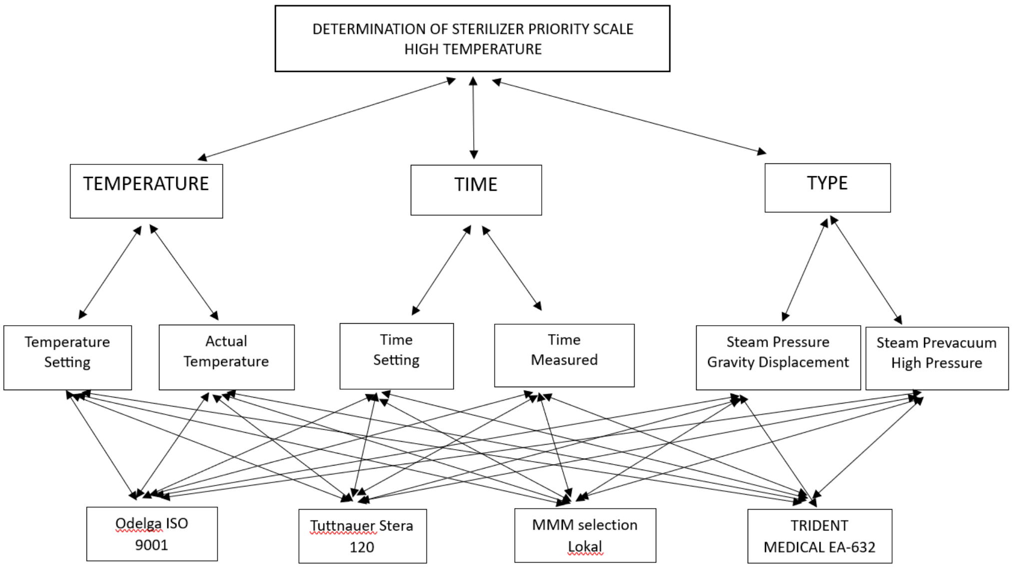

Figure 2. AHP hierarchy as the research architecture.

Figure 2 is the architecture for determining sterilization quality priorities in high-temperature sterilizers of several brands available at Dr. Moewardi General Hospital with input of temperature, time, and type. The temperature has two influences: between the set temperature and the actual temperature, the time includes the set time and the measured time which can help determine priorities, and it is assisted by the type of sterilizer as input which is processed by AHP to obtain priorities 1 to 4 in high-temperature sterilizers studied in the research.

Research Steps.

The initial stage of the research is to determine the background and objectives of the study. The second stage is to determine the parameters or variations of the variables to be tested. The next stage is to conduct testing with various variable parameters to find out the optimal conditions that can be achieved by the high-temperature sterilizer to be safe for use. The research flow diagram is explained in Fig. 3.

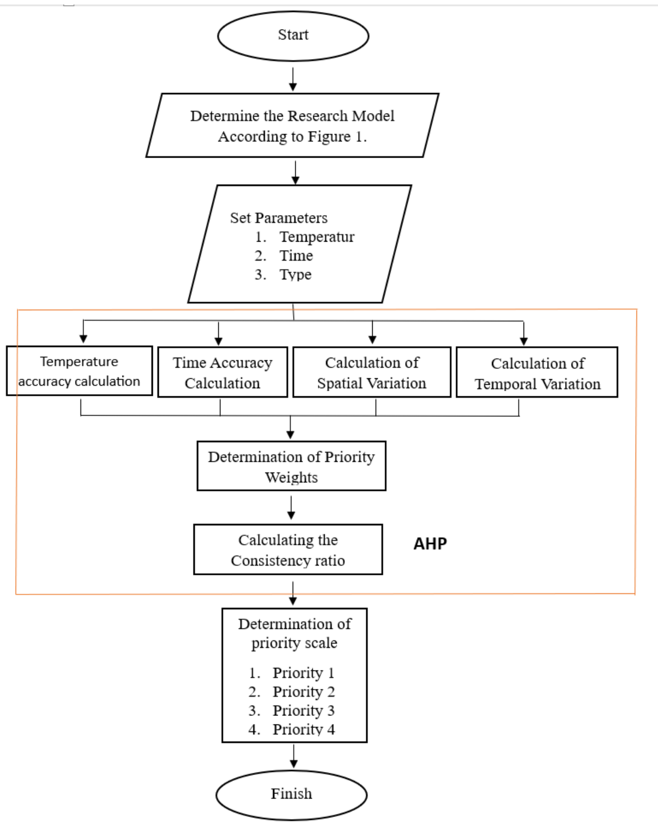

Figure 3. Research Flow Diagram.

Figure 3 is a research flow diagram with problem determination and parameter determination for testing to produce temperature accuracy calculations, time accuracy calculations, spatial variation calculations, and temporal variation calculations, then weighting determination can be carried out to calculate the ratio and determine the priority scale.

4. Results and Discussion

Data processing is carried out by identifying training data and testing data with reference to the research model shown in Figures 1 and 2 and Table 1. This research data uses parameters of temperature, time, and type of sterilizer machine, so calculations can be made for the temperature accuracy score, time accuracy criteria score, spatial variation accuracy criteria score, and temporal variation accuracy to determine priority weights and to calculate the consistency ratio to obtain results with four alternatives. This test data is used for prediction and assessment in determining the priority scale of sterilization quality in high-temperature sterilizers.

The Effect of Sterilization Temperature

The sterilization process using a high-temperature Sterilizer is influenced by four main factors: temperature, pressure, time, and steam quality. High temperatures are required to kill microorganisms within the range of 121–134°C. The CDC sets the standard temperature at 121°C (250°F) or 132–135°C (270–275°F), with the minimum duration adjusted based on the type of sterilizer. The CDC recommends a duration of 30 minutes at 121°C for gravity-type high-temperature Sterilizers, while for pre-vacuum high-temperature Sterilizers, the duration is 3–4 minutes at 132–135°C. If the temperature or duration is below the specified standard, the likelihood of microorganisms (including spore forms) surviving increases significantly. On the other hand, increasing the temperature to 134°C can shorten the sterilization time to only 3–4 minutes under vacuum conditions.

Based on the research results, the temperature variations of the four types of high-temperature Sterilizers studied in this research are presented in Table 2.

Table 2. Temperature Variations of Various Types of High-Temperature Sterilizers.

No	Sterilizer Brand	Setting temperature (ºC)	Actual Temperature (ºC)	Temperature Variation (ºC)		
				Spasial	Temporal	Total
1	Odelga ISO 9001	127	128,4	0.2	0.4	0.5
2	Tuttnauer Stera 120	134	135	0.2	-0.5	-0.3
3	MMM selection Lokal	134	135,2	0.2	0.1	0.3
4	TRIDENT MEDICAL EA-632	142	146,1	0.2	0.2	0.3

Table 2 shows that for 4 (four) high-temperature sterilizer brands, there are different variations in temperature performance. The measured parameters analyzed are the actual device temperature and temperature variations (spatial, temporal, and total).
Based on research results, the temperature variations of the four types of high-temperature sterilizers studied in this research are presented in Table 3.

Table 3. Time Variation of Various Types of High-Temperature Sterilizers.

No	Sterilizer Brand	Setting time (minutes)	Measured time (minutes)
1	Odelga ISO 9001	15	15,3
2	Tuttnauer Stera 120	3	4,1
3	MMM selection Lokal	4	4,15
4	TRIDENT MEDICAL EA-632	15	15,15

Table 3 shows the variation in time for four types of high-temperature sterilizers with differences between the actual measured time and the set time on 4 high-temperature sterilizer units.

The Effect of High-Temperature Sterilizer Types on Sterilization Quality

High-temperature sterilizers are medical devices used to sterilize medical instruments and other materials through exposure to high-pressure saturated steam. The effectiveness of sterilization is greatly influenced by the type of high-temperature sterilizer used, as each type has different working mechanisms, advantages, and limitations. This study identifies two main categories of high-temperature sterilizers used, namely the steam pressure gravity displacement type and the steam pre-vacuum high-pressure type. The four types of high-temperature sterilizers tested are shown in Table 4.

Table 4. Types of high-temperature sterilizers.abel 4.

No	Sterilizer Brand	Types of Sterilizers
1	Odelga ISO 9001	Steam pressure (Gravity Displacement)
2	Tuttnauer Stera 120	Steam prevacuum high pressure
3	MMM selection Lokal	Steam prevacuum High Pressure
4	TRIDENT MEDICAL EA-632	Steam pressure (Gravity Displacement)

Table 4 shows the types of high-temperature sterilizers in the study. Steam Pressure Gravity Displacement, or "pressure-cooker," is the most commonly used type of high-temperature sterilizer. The efficiency of the prevacuum system has a much shorter sterilization duration, namely 3-4 minutes at 134-142°C, compared to gravity which requires 3-15 minutes at 127-134°C. Although the difference in time is not very significant, the prevacuum system still offers advantages in terms of superior temperature stability, which contributes to better consistency and reliability of the sterilization process. A comparison of the two types of high-temperature sterilizers is shown in the graph presented in Fig. 4.

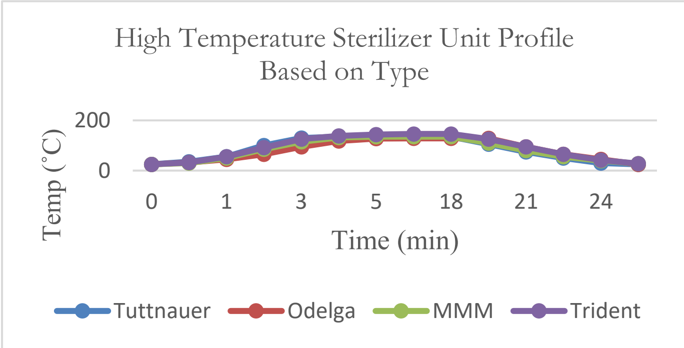

Figure 4. High-temperature Sterilizer Profile Based on Its Type.

Figure 4 shows the profile of high-temperature sterilizer units based on their types. The temperature versus time profile graph illustrates the performance characteristics of the four high-temperature sterilizer units categorized into two types. The gravity displacement type high-temperature sterilizers Odelga and TRIDENT show an operating temperature profile of 128.4-146.1°C with a holding time of 15 (fifteen) minutes to maintain the target temperature. Odelga ISO 9001 demonstrates good performance with an actual temperature of 128.4°C and a temporal variation of 0.4°C. TRIDENT MEDICAL EA-632 experiences a critical overshoot of +4.1°C, which could potentially damage heat-sensitive materials, although temporal stability remains good at 0.2°C. The prevacuum high-pressure type high-temperature sterilizers MMM and Tuttnauer display superior characteristics with an operating temperature of 135-146°C and a heating rate of 50-60°C/min, which is much faster. The local MMM selection showed the best performance with a temperature of 135.2°C, a holding time of only 4 (four) minutes, and very low temporal variation of 0.1°C, resulting in an almost perfectly flat curve. In contrast, the Tuttnauer Stera 120 experienced an undershoot of 1.3°C with the highest temporal variation of 1.8°C, visible from the curve fluctuations, indicating a delayed controller response that could potentially reduce spore effectiveness. The total gravity cycle time reached 25-30 minutes, while the prevacuum cycle was only 15-18 minutes, providing a significant advantage in operational throughput.

Calibration testing is carried out and necessitates the physical and functional inspection of the equipment to be tested/calibrated, which consists of several parameters, with the results of the physical inspection displayed in Table 5. Before data collection for testing on the high-temperature sterilizer, physical and functional tests are conducted as shown in Table 5.

Table 5. Physical Examination and Function of High-Temperature Sterilizer.

No	Parameter	Observation Results	Weight	Conclusion
1	Body and surface	1	10	Good
2	Tool contact box	1		
3	Main Power Cable	1		
4	Buttons, switches, and controls	1		
5	Display and indicators	1		

The results of physical and functional aspects examinations carried out on 4 (four) high-temperature sterilizer units evaluated: Odelga ISO 9001, Tuttnauer Stera 120, MMM selection Local, and TRIDENT MEDICAL EA-632 showed that all units obtained a "good" rating for all observation parameters.

Electrical safety testing is carried out after all four high-temperature Sterilizer units are declared physically and functionally qualified. Electrical safety testing uses an Electrical Safety Analyzer as shown in Table 6.

Table 6. High-temperature Sterilizer Electrical Safety Inspection.

No	Parameter	Standard Measured	Threshold	Result	Weight	Conclusion
1	The protective grounding resistance of the cable can be removed	-	≤ 0,3 Ω	Fulfill	40	Good
2	Direct method equipment leakage current Class I type BF	-	≤ 500 µA	Fulfill		
3	Insulation Resistance	-	>2 MΩ	Fulfill		

The results of the electrical safety inspection conducted on the four high-temperature Sterilizer units showed that all types of high-temperature Sterilizers evaluated received good ratings for all observed parameters.

Performance Measurement of High-Temperature Sterilizer.

The temperature calibration process is carried out to assess the accuracy of the working temperature readings of high-temperature sterilizers against a reference standard. Performance measurements are conducted on all four high-temperature sterilizer units. The evaluation of the calibration results for high-temperature sterilizer temperature measurements is described as follows:

a. Average (Mean)
   The calculation of the average refers to Eq. (1).

$$\bar{x} = \frac{128{,}4 + 128{,}4 + 128{,}7}{3}$$
$$\bar{x} = 128{,}5$$

b. Standard deviation
   The calculation of standard deviation refers to Eq. (2)

$$\sigma\sigma = \sqrt{\frac{(128{,}4 - 128{,}5)^2 + (128{,}4 - 128{,}5)^2 + (128{,}7 - 128{,}5)^2}{3 - 1}}$$
$$\sigma = 0{,}2$$

c. Correction
   Correction = 127 – 128,5 = -1,5

d. Uncertainty standard type A/ repeatibility.
   Calculating uncertainty refers to Eq. (3).

$$u_a = \frac{0{,}2}{\sqrt{3}} = 0{,}0133$$

e. Uncertainty of the standard instrument (ub1).
   The uncertainty of the standard device (Ustd) on the measuring instrument is 0.7. The values of U and the Divisor are obtained from the Uncertainty Budget Table with calculations referring to Eq. (4).

$$\mathrm{U}_{b1} = \frac{0{,}7}{2}$$
$$\mathrm{U}_{b1} = 0{,}35$$

f. Uncertainty of Reading Ability (U_{b2}).
   The calculation of the UUT reading power refers to Eq. (5).
   Temperature calibration using a MadgeTech temperature data logger with a resolution of 0.1°C that has been traceable to the national standard (KAN) so that it is obtainedv:

$$\mathrm{U}_{b2} = \frac{0{,}05}{\sqrt{3}}$$
$$\mathrm{U}_{b2} = 0{,}03$$

g. Uncertainty of Calibrator Drift (U_{b3}).
The calculation of the calibrator drift uncertainty refers to Eq. (6).

$$U_{b3} = \frac{\frac{1}{2} x\ (-1{,}5 - (-1{,}5)}{\sqrt{3}}$$

$$U_{b3} = 0$$

h. Combined Uncertainty (U_c).
The calculation of combined uncertainty refers to Eq. (7).

$$Uc = \sqrt{0{,}0001 + 0{,}1225 + 0{,}0008 + 0}$$

$$Uc = 0{,}3513$$

i. Span Uncertainty (U).
The value vi refers to the degrees of freedom set at v = 50, and the value c is a coefficient with a value of 1 because all parameters of the mathematical model use the same unit of measurement.
The calculation of the effective degrees of freedom value refers to Eq. (8).
(Veff) = $\frac{0.1234^4}{0{,}0003} = 50.7284$

j. The coverage factor for Veff of 50.7284 and 95% CL is determined to be 2.01, so by using the following formula it is obtained:

U = k.uc
= 2,01 x 0,3513
= 0,71

1. Percentage Value (Correction +U95)

% (C+U95) = $\frac{|-1{,}5+0{,}74|}{127}\ x\ 100\%$ = 1,74% < 2%, so it is declared passed.

The Effectiveness of Sterilization Quality Reviewed from the Analytical Hierarchy Process.

Evaluation of the effectiveness of sterilization quality in 4 (four) high-temperature sterilizer units by integrating multiple criteria with different importance weights. The Analytical Hierarchy Process (AHP) method was chosen as the decision-making framework due to its ability to structure complex problems into measurable and objective decision hierarchies. The AHP hierarchy for sterilization quality assessment is arranged in three levels as shown in Table 7.

Table 7. Hierarchical Structure of Sterilization Quality

Level	Component	Description
Level 0: Objective	Sterilization Quality Effectiveness	Determining the performance of the best high-temperature sterilizer at Dr. Moewardi Regional General Hospital
Level 1: Criteria	Assessment Parameters	C1: Temperature Accuracy C2: Time Accuracy C3: Spatial Variation C4: Temporal Variation C5: Total Variation C6: Uncertainty C7: Physical Examination C8: Electrical Safety
Level 2: Alternative	4 High-temperature Sterilizer Units	1. Odelga ISO 9001 2. Tuttnauer Stera 120 3. MMM Selection Lokal 4. Trident Medical Ea-632

Calculations on other types of high-temperature sterilizers are carried out according to the calculations so that the results are shown in Table 8.

Table 8. Time Accuracy Criteria

High temperature sterilizer	Setting time (minutes)	Elapsed time (minutes)	Δt	|Δt|	Threshold	Score
Odelga ISO 9001	15	15.3	-0.3	0.3	3	90.00
Tuttnauer Stera 120	15	15.1	-0.1	0.1	3	96.67
MMM selection Lokal	4	4.15	-0.15	0.15	3	95.00
TRIDENT MEDICAL EA-632	15	15.15	-0.15	0.15	3	95.00

Tuttnauer Stera 120 achieved the highest score (96.67) while Odelga ISO 9001 obtained the lowest score of 90.

Calculation of Spatial Variation Criteria Score.

Spatial variation measures the homogeneity of vapor distribution in a high-temperature Sterilizer chamber. Scores are calculated based on the range of temperature differences between measurement points with a threshold of 2°C. Calculations on other types of high-temperature Sterilizers are carried out according to the calculation, resulting in the results shown in Table 9.

Table 9. Criteria for Spatial Variation

High temperature sterilizer	Spatial	|Spatial|	Threshold	Score
Odelga ISO 9001	0.2	0.2	2	90
Tuttnauer Stera 120	0.2	0.2	2	90
MMM selection Lokal	0.2	0.2	2	90
TRIDENT MEDICAL EA-632	0.2	0.2	2	90

The results show that all four units have a homogeneous or uniform temperature distribution with a value of 0.2.

Calculation of Temporal Variation Criteria Score.

Temporal variation measures the stability of temperature during the holding time phase. This parameter is to ensure the consistency of thermal energy received by the sterilization load. The threshold is set at ±1°C. Calculations for other types of high-temperature sterilizers are carried out according to calculations so that the results shown in Table 10.

Table 10. Temporal Variation Criteria

High temperature sterilizer	Temporal	|Temporal|	Threshold	Score
Odelga ISO 9001	0.4	0.4	1	60
Tuttnauer Stera 120	1.8	1.8	1	0
MMM selection Lokal	0.1	0.1	1	90
TRIDENT MEDICAL EA-632	0.2	0.2	1	80

The local MMM selection shows the highest stability with a temporal variation of 0.1°C (score 90), while the Tuttnauer Stera 120 has the highest fluctuation (1.8°C) resulting in a score of 0 and indicating a need for improvement in the temperature control system.

Calculation of Total Variation Criteria Score.

Total variation is a combination of spatial and temporal variations that describes the uniformity of sterilization conditions overall. This criterion has a threshold of 2°C. Calculations for other types of high-temperature sterilizers are carried out according to the calculations above so that the results shown in Table 11 are obtained.

Table 11. Total Variation Criteria

High temperature sterilizer	Total	|Total|	Threshold	Score
Odelga ISO 9001	0.5	0.5	2	75
Tuttnauer Stera 120	2	2	2	0
MMM selection Lokal	0.3	0.3	2	85
TRIDENT MEDICAL EA-632	0.3	0.3	2	85

MMM Lokal selection and TRIDENT MEDICAL EA-632 achieved the highest score (score 85) with a total variation of only 0.3°C, indicating a good control system for low-temperature sterilization. Tuttnauer Stera 120 showed the worst performance with a variation of 2°C, reaching the maximum threshold limit.

a. Calculation of the Uncertainty Criterion Score U95.

Measurement uncertainty (U95) indicates the level of reliability and precision of the sensor system as well as the high-temperature Sterilizer data acquisition. The threshold is set at 1°C. Calculations for other types of high-temperature Sterilizers are carried out according to the calculations above, resulting in the results shown in Table 12.

Table 12. U95 Uncertainty Criteria

High temperature sterilizer	U95(°C)	Threshold	Score
Odelga ISO 9001	0.7	2	65
Tuttnauer Stera 120	2.2	2	0
MMM selection Lokal	0.4	2	80
TRIDENT MEDICAL EA-632	0.2	2	90

TRIDENT MEDICAL EA-632 shows the lowest uncertainty (0.2°C, score 80) indicating a reliable measurement system. In contrast, the Tuttnauer Stera 120 has the highest uncertainty (2.2) which exceeds the threshold and receives a score of 0.

Ranking Based on AHP Score.

The final stage is to calculate the final score of each alternative by multiplying the score on each criterion by the predetermined priority weight, and then summing the results. The ranking is arranged based on the highest total score, which reflects the overall effectiveness of sterilization quality, and can be shown in Table 13.

Table 13. Final Ranking Based on AHP Score

High temperature sterilizer	Calculation (Score × Weight)	Types of Sterilizers	Rank
MMM selection Lokal	75.25	Steam Prevacuum	1
Odelga ISO 9001	63.65	Steam Gravity	2
TRIDENT MEDICAL EA-632	62.55	Steam Prevacuum	3
Tuttnauer Stera 120	45.93	Steam Gravity	4

The calculation for the local MMM selection tool according to Table 4.20 is explained as follows.

AHP Score = Σ (Criteria Score × Criteria Weight)
= (C1×0.30) + (C2×0.20) + (C3×0.13) + (C4×0.13) + (C5×0.13) + (C6×0.06) + (C7×0.03) + (C8×0.02)

Thus obtained,

AHP Score = (40×0.30) + (95×0.20) + (90×0.13) + (90×0.13) + (85×0.13) + (80×0.06) + (100×0.03) + (100×0.02)
= 12.00 + 19.00 + 11.70 + 11.70 + 11.05 + 4.80 + 3.00 + 2.00
= 75.25

Calculations for other types of high-temperature Sterilizers are carried out according to the calculation above. The ranking results show that the local MMM selection ranks first with a score of 75.25, indicating optimal performance in the majority of criteria with the best performance in terms of time accuracy and sterilization stability using Steam Prevacuum. Odelga ISO 9001 ranks second with a score of 63.65, showing good performance with simpler yet reliable Steam Gravity technology in meeting international sterilization standards. TRIDENT MEDICAL EA-632 is ranked third with a score of 62.55, also using Steam Prevacuum technology but with slightly lower performance compared to the local MMM selection in several testing criteria. Meanwhile, the Tuttnauer Stera 120 occupies the fourth rank with a score of 45.93, indicating that although it uses Steam Gravity technology, this high-temperature sterilizer has limitations in several critical parameters that affect its final score. This ranking confirms that Steam Prevacuum technology (MMM local selection and TRIDENT MEDICAL) generally provides better performance compared to Steam Gravity brands Odelga ISO 9001 and Tuttnauer Stera 120.

5. Conclusions

Based on the results of the research on the determination of sterilization quality in high-temperature sterilizers, this study can be concluded as follows: (a) Based on the results of the study on determining sterilization quality in high-temperature sterilizers, this study can be concluded as follows: a. Factors affecting the determination of sterilization quality priorities in high-temperature sterilizers are temperature, time, and type of sterilizer. The three high-temperature sterilizers (Odelga ISO 9001, Tuttnauer Stera 120, and MMM Selection Local) showed temperature deviations within the tolerance limit of ±2°C, with deviations of +1.4°C, +1°C, and +1.2°C, respectively. However, the TRIDENT MEDICAL EA-632 showed a significant deviation of +4.1°C, which exceeded the limit. Spatial temperature variation in the four high-temperature sterilizers tested was 0.2°C < ±2°C, indicating a homogeneous steam distribution. Temporal temperature variation ranged from 0.0°C to 1.8°C, with 3 out of 4 units requiring a variation of ±1°C. Sterilization time accuracy showed that 3 out of 4 units had deviations of less than 1 minute, although the Tuttnauer Stera 120 experienced a deviation of 1. minutes that potentially cause sterilization failure.

(b) The types of high-temperature sterilizers affect sterilization quality based on different operational characteristics. The Steam Pressure Gravity Displacement shows an operating temperature profile of 127-142°C with a holding time of 15-20 minutes. The Odelga ISO 9001 brand shows stable performance with a set temperature of 127°C reaching 128.4°C, a holding time of 15 minutes with a deviation of 0.3 minutes, and controlled spatial-temporal variation (0.2°C and 0.4°C). Steam Prevacuum High Pressure operates at a temperature of 135-146°C with a shorter holding time (3-4 minutes), with MMM selection Lokal showing the best stability with a set temperature of 134°C reaching 135.2°C (deviation +1.2°C), a holding time of only 4 minutes with minimal deviation (0.15 minutes), and the lowest temporal variation (0.1°C). Measurement uncertainty shows that high-temperature gravity sterilizers have a lower average value (±0.45°C) compared to prevacuum type (±1.3°C).

(c)The Analytical Hierarchy Process can be used to determine the priority of sterilization quality in high-temperature sterilizers, as indicated by MMM Local selection ranking first with an AHP score of 75.25. The AHP hierarchy structure sets temperature accuracy (30%) as the top criterion, followed by time accuracy (20%), total variation (13%), spatial and temporal variation (each 13%), measurement uncertainty (6%), physical inspection (3%), and electrical safety (2%). A Consistency Ratio of 2.3% indicates the validity of the criteria weighting.

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