Microwave Oven vs Level-1 Rapid Fluid Warmer: A Comparative Efficacy Study of Fluid Warming in the ATLS Protocol (MOLEWA Study)

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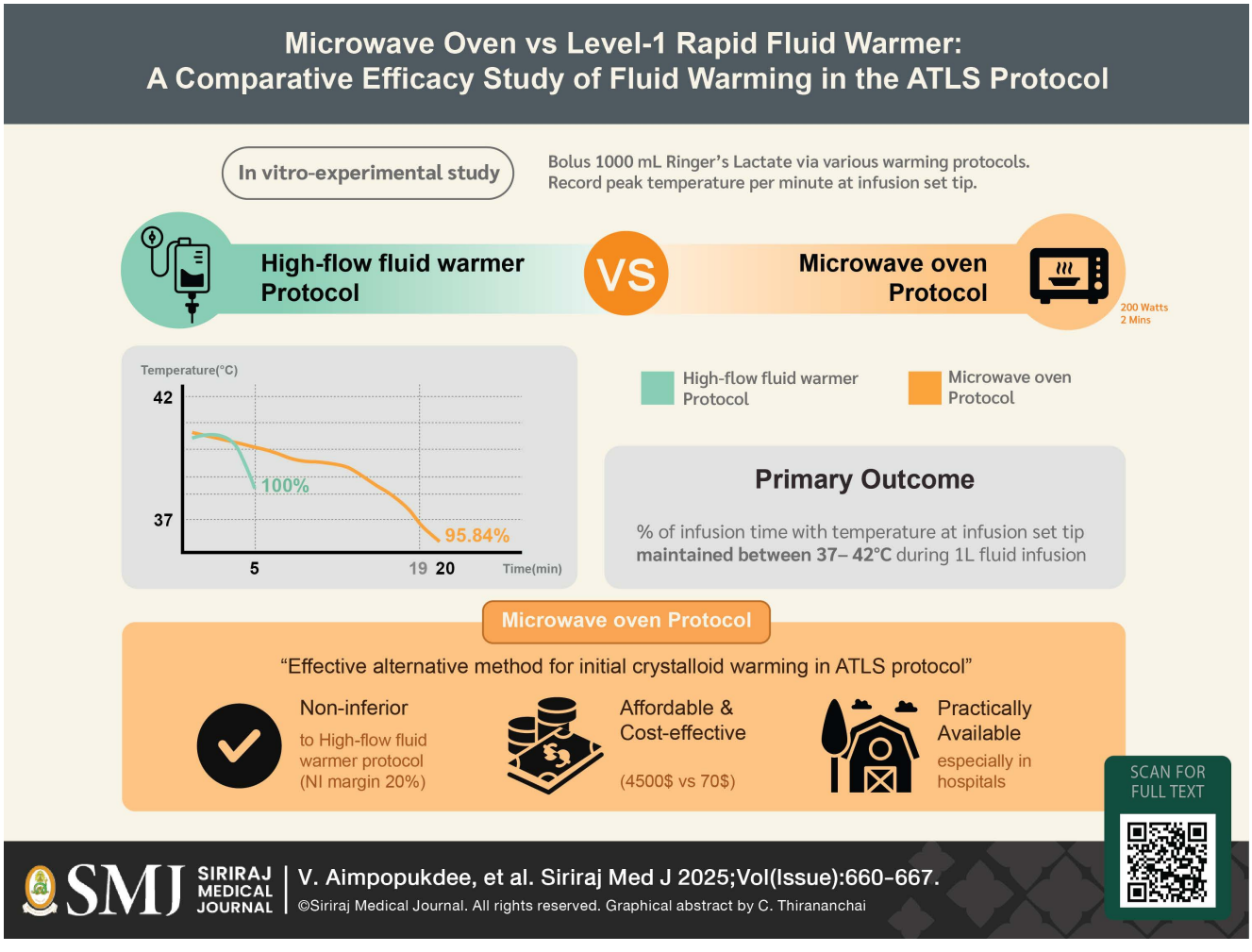

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ABSTRACT

Objective: Although the use of a microwave for fluid warming has been proposed, standardized protocols for its clinical application remain limited. The purpose of this study is to evaluate the effectiveness of microwave-based fluid warming compared to conventional fluid warming equipment.

Materials and Methods: This in-vitro experimental study was conducted in two phases. In the pilot trial, we compared five groups using different combinations of container types, infusion rates, and warming techniques. In the second phase, a non-inferiority trial, two groups of 18 1-liter isotonic crystalloid bottles were compared: one using the Level-1 H-1200 fluid warmer and the other employing a microwave oven warming protocol (800W, two minutes at maximum power). The primary outcome was the percentage of infusion time during which the fluid temperature at the tip of the infusion set remained within the target range of 37°C to 42°C.

Results: The warming cabinet and microwave oven achieved mean infusion durations of 5.0 and 19.5 minutes, respectively. The Level-1 group maintained the target temperature for 100% of the infusion duration, while the microwave group achieved a rate of 95.84% [95.82%-95.86%], demonstrating non-inferiority to the Level-1 method.

Conclusion: Microwave fluid warming is a feasible, practical, and cost-effective alternative to conventional fluid warming equipment. Its comparable warming efficiency and wide availability support its potential use in rural areas with limited resources.

Keywords: Microwave; fluid warming; trauma; initial management (Siriraj Med J 2025; 77: 660-667)

Abbreviation

ATLS - Advanced Trauma Life Support

INTRODUCTION

Advanced Trauma Life Support (ATLS) and other trauma care standards emphasize the importance of administering warm intravenous (IV) fluids to avoid the lethal triad of acidosis, coagulopathy, and hypothermia. High-flow fluid warmers are effective in maintaining the recommended fluid temperature of 39°C, particularly in geriatric patients.[1,2] However, their high cost and logistical challenges may limit their practicality, especially in resource-constrained settings. As a result, microwave ovens are being investigated as a potential alternative for fluid warming. They offer a practical, low-cost option that may simplify trauma care.

The concept of using microwave ovens to warm crystalloid fluids emerged in 1984[3], with subsequent in vitro studies examining various parameters including microwave models, power settings, heating durations, and flow rates.[4-8] Research has confirmed the safety of microwaving crystalloid fluids packaged in polypropylene, as its melting point exceeds 130°C and is FDA-approved for microwave food contact.[9,10] However, microwave ovens are not FDA-approved for warming IV fluids, as they are not designed to ensure uniform heating or prevent overheating, which can lead to patient harm. The FDA advises against microwave use for fluid warming due to risks such as hot spots, bag rupture, and unpredictable temperature control. However, in resource-limited or emergency settings where approved fluid warmers are unavailable, a general-use microwave may be used with extreme caution, following strict protocol. For this reason, the ATLS guidelines suggest that a microwave may be considered as an alternative method for fluid warming when standard fluid warmers are unavailable, provided appropriate safety precautions are followed. However, this method is exclusively recommended for crystalloid fluids. Blood products are not suitable for microwave warming, as hemolysis can occur at temperatures above 42-43°C.[11] Additionally, some studies have reported complications, such as burns and venous thrombosis, associated with overheated fluids.[12,13]

This study aims to address the lack of established protocols and limited evidence by rigorously comparing microwave-based fluid warming with conventional high-flow fluid warmer methods. Using a two-phase approach — beginning with a pilot trial to explore various warming techniques, followed by a non-inferiority trial — the research evaluates effectiveness, infusion time, and cost considerations. The primary outcome is the maintenance of target fluid temperatures throughout administration.

MATERIALS AND METHODS

This study employed an in-vitro experimental design to comprehensively assess the efficacy of microwave oven fluid warming compared to the high-flow fluid warmer

systems in the context of trauma care. The study was conducted at a Level 1 trauma center equipped with multiple types of fluid warming machines and equipment.

Sample size calculation:

The sample size for the non-inferiority trial was determined based on the following parameters: *Pilot Study Sample Size* (from a prior microwave protocol infusion study; six participants per arm, *Significance Level* (alpha, one-sided): 0.025 (corresponding to a 2.5% significance level), *Standard Proportion* (from pilot data): 0.99, *Equivalence Limit Difference (Margin of Non-Inferiority)*: -0.2, *Expected Proportion*: 0.95, and the *Expected Difference* (difference to detect): -0.04. We set the power at 80% (corresponding to a beta of 0.20). Using these values, along with the provided proportions: the sample size was 18 for each group.

A 20% non-inferiority margin was established to determine acceptable differences in the proportion of time fluid temperature remained within the target range (37°C-42°C). This margin was considered clinically acceptable given the potential advantages of the alternative warming device, including cost-effectiveness, portability, and reduced setup time. The selected margin aligns with previous studies of perioperative warming technologies, which have employed non-inferiority thresholds of 10-20% for devices with comparable safety profiles.[14,15] Additionally, NICE guideline NG65 endorses practical, cost-efficient warming methods when thermal performance is equivalent across devices.[16] The 20% margin was therefore deemed clinically and operationally appropriate for this device comparison.

Study design and setting

Initial phase:

The initial phase of the study consisted of a pilot trial designed to explore a variety of fluid warming techniques and identify optimal conditions for subsequent evaluation. Seven distinct groups were formed, each characterized by differences in container types, infusion techniques, and temperature maintenance strategies. These included four microwave oven methods, two warm cabinet methods, and one high-flow fluid warmer method. The study investigated 1-liter of Ringer lactate solution containers made of standard polypropylene, including both rigid and soft intravenous bags. Infusion techniques ranged from free-flow infusion to syringe-push delivery using an 18-gauge Cathlon catheter, simulating different clinical scenarios with varying urgency of fluid administration. Temperature maintenance strategies included microwave-based warming and the warm cabinet approach.

Non-inferiority trial:

Informed by the pilot trial findings, a non-inferiority trial was subsequently designed to compare the performance of microwave fluid warming to the established high-flow fluid warming protocol. A total of 36 bottles of 1-liter isotonic crystalloid solution were used — 18 for each method. For the high-flow warming group, the Smith Medical Level 1 H-1200 fluid warmer was used, which is a widely accepted device known for its precision in maintaining fluid temperature during infusion.

For the microwave warming group, a standardized protocol was developed. In this protocol, each fluid bottle was heated in a microwave oven, calibrated to 800W, for a duration of two minutes. The temperature at the tip of the infusion set was measured using a digital thermometer.

Outcome measures:

The primary outcome measure of this study was the percentage of infusion time during which the temperature at the tip of the infusion set remained within the optimal range of 37-42°C. Temperature readings were obtained using a Fluke 179 RMS Multimeter, with the probe positioned at the tip of the infusion set, representing the point of connection to the patients. This measure served as a critical indicator of each warming protocol's ability to deliver warm IV fluids as mandated by the ATLS protocol.

Data collection and analysis:

Data collection was conducted by a team of trained healthcare professionals to ensure precision and consistency. Temperature measurements were recorded at one-minute intervals throughout the administration of each 1-liter fluid unit, allowing for the calculation of the percentage of infusion time that fell within the target temperature range.

Descriptive statistics, including means, standard deviations, and confidence intervals, were calculated to summarize the performance of each warming protocol. Inferential statistical analyses, including t-tests and non-inferiority testing, were conducted to compare the two methods and determine non-inferiority based on a predetermined margin derived from the pilot trial. All data were collected and analyzed using IBM SPSS Statistics 28 (IBM Corporation, Armonk, NY).

Ethical considerations:

Ethical exemption for this in-vitro experimental study was obtained from the Institutional Review Board. The study adhered to all relevant ethical guidelines and

regulations to ensure the responsible and respectful conduct of research.

RESULTS

Pilot trial:

The pilot trial evaluated a range of fluid warming techniques, each characterized by variations in container types, infusion rates, and temperature maintenance strategies. The average warming efficacy across the various protocols is illustrated in Fig 1.

Among the tested methods, protocols 1, 2, 3, and 5 demonstrated efficacy rates of 96.71%, 85.12%, 100%, and 25%, respectively. However, protocols 4 and 6 were terminated prematurely due to critical safety concerns: fluid temperatures exceeded the upper safety limit of 42°C within the initial minutes of operation, often reaching 44-46°C. This overheating necessitated discontinuation of these protocols.

Given the practicality and efficacy of protocol 1, it was selected for further investigation in the non-inferiority study against the established high-flow fluid warming protocol. In contrast, although protocol 3 exhibited the highest efficacy, it required rapid infusion of an entire 1-liter crystalloid solution, a condition deemed impractical for real-world application. These results underscore the importance of evaluating not only the efficacy but also the safety of fluid warming protocols, particularly in high-stakes trauma care scenarios.

Non-inferiority trial:

In the non-inferiority trial, each fluid method was meticulously evaluated for its ability to maintain the target temperature range during the infusion of isotonic crystalloid solutions. The high-flow fluid warmer group achieved a 100% maintenance rate, ensuring that the temperature at the tip of the infusion set remained within the optimal range of 37-42°C throughout the entire fluid administration process. This consistent robust performance reaffirmed the high-flow fluid warmer's effectiveness in precise temperature control.

Conversely, the microwave oven warming protocol, using rigid polypropylene crystalloid solution containers heated at 800W for two minutes, also demonstrated remarkable ability to rapidly attain the desired temperature. The mean warming time for the microwave method was 19.43 minutes, and the temperature maintenance rate was 95.84% (95.82-95.86, SD 0.04), indicating reliable performance. The standard deviation of temperature measurements was 0.04°C. Detailed results are illustrated in Fig 2.

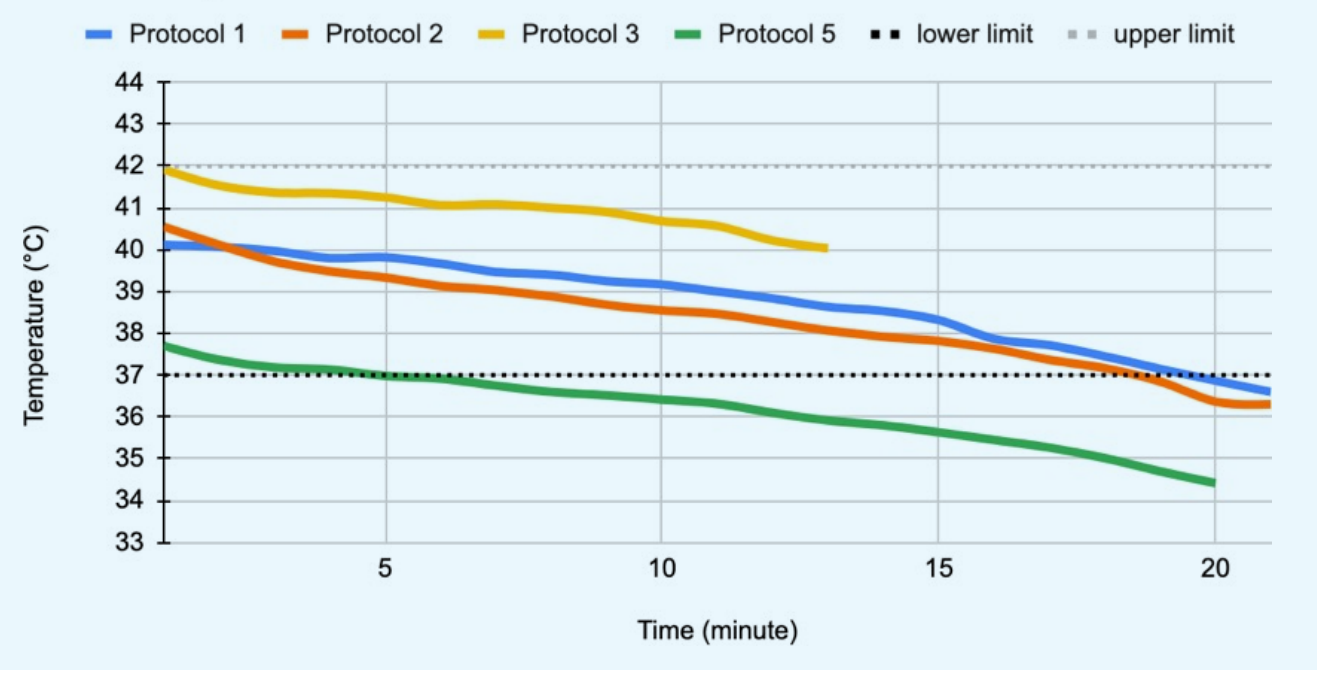

Fig 1. Temperature control comparison across different warming protocols
Protocol 1: Microwave oven, 800 W for 2 mins, rigid 1-liter RLS package, free- flow via Cathlon No.18
Protocol 2: Microwave oven, 800 W for 2 mins, soft 1-liter RLS package, free-flow via Cathlon No.18
Protocol 3: Microwave oven, 800 W for 2 mins, rigid 1-liter RLS package, syringe push via Cathlon No.18
Protocol 4: Microwave oven, 800 W for 3 mins, rigid 1- liter RLS package, free-flow via Cathlon No.18, Prematurely terminated
Protocol 5: Warm cabinet preheated to 40°C for 8 hours, rigid 1-liter RLS package, free-flow via Cathlon No.18
Protocol 6: Warm cabinet preheated to 50°C for 8 hours, rigid 1-liter RLS package, free-flow via Cathlon No.18, Prematurely terminated

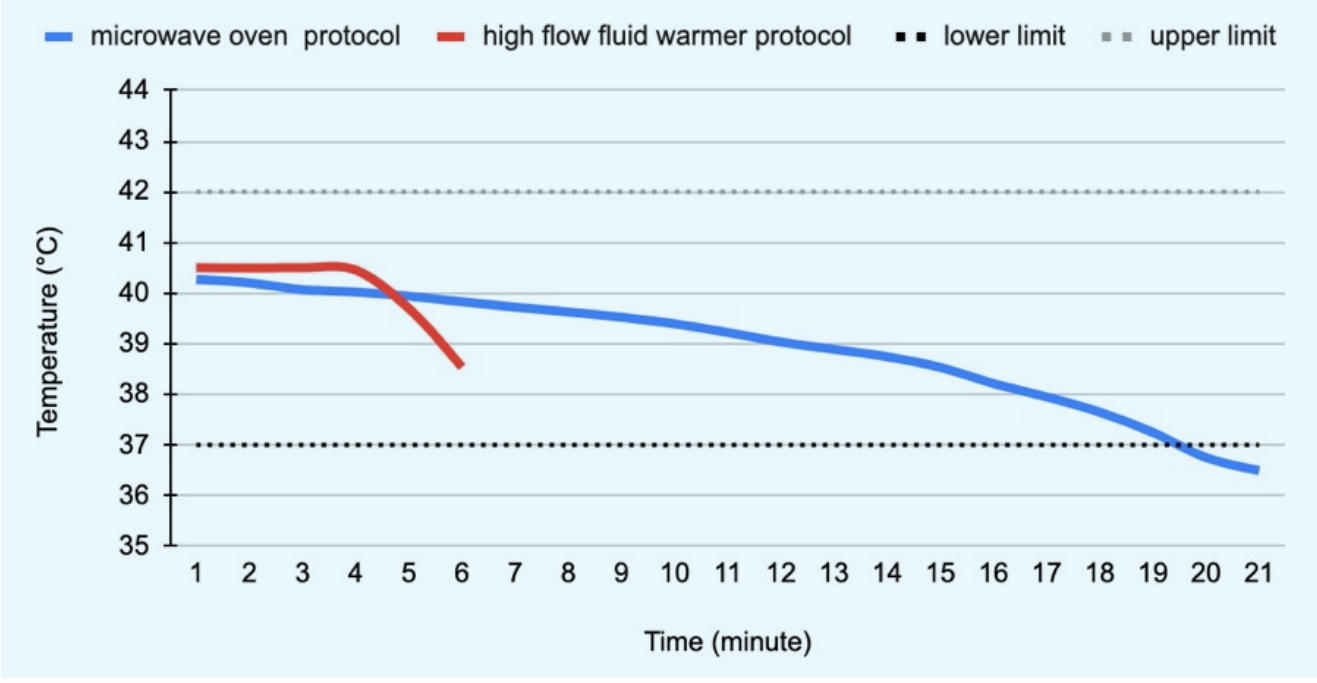

Fig 2. Temperature control comparison between oven protocol and high-flow fluid warmer protocol.

Non-inferiority analysis:

The primary focus of the non-inferiority analysis was to determine whether the microwave fluid warming protocol was non-inferior to the high-flow fluid warming protocol, using a pre-determined non-inferiority margin of 20%, as defined in the pilot trial. Statistical evaluation was performed using appropriate methods, including t-tests and non-inferiority testing. The results demonstrated that the microwave method was non-inferior to the Level-1 method (95.84% vs 100%)

Secondary outcome measures:

Infusion Time: Infusion time was assessed as a key secondary outcome. In the microwave oven warming group, using a free-flowing technique, the mean infusion time was 19.5 minutes. In contrast, the high-flow fluid warming group achieved significantly faster infusion times, averaging 5 minutes per liter.

Overall cost analysis:

An economic comparison of factors associated with each warming protocol was carried out, accounting for initial equipment costs and the cost of disposable infusion sets. The findings revealed a substantial cost difference between the two groups (Table 1). The microwave warming protocol, which encompassed the cost of the microwave oven and disposable infusion sets, had an average procedural cost of approximately $70 per procedure. In contrast, the high-flow fluid warming group incurred considerably higher costs, with an estimated $4,500 per procedure. This substantial cost disparity highlights the significant economic advantage of the microwave oven method.

TABLE 1. Comparative cost analysis of common fluid warming methods in clinical settings.

Device	Estimated unit cost (USD)	Lifespan (Years)	Estimated uses per year	Per-use cost estimate (USD)
Level-1 fluid warmer	$8,000 - $12,000	5 - 7	1,500 - 2,000	~$1.00 - $1.60
Warming cabinet	$3,000 - $5,000	7 - 10	2,000 - 3,000	~$0.20 - $0.40
Microwave	$100 - $300	3 - 5	1,000 - 1,500	~$0.03 - $0.10

DISCUSSION

This study provides a comprehensive evaluation of the viability and effectiveness of microwave fluid warming in trauma care, compared with the well-established high-flow fluid warming technique. The discussion focuses on the implications of these findings on patient outcomes, trauma management procedures, and broader healthcare systems.

Regarding fluid-warming efficacy, the high-flow Level-1 is known for its precision and ability to maintain target temperatures. Hence, it serves as the benchmark against which microwave fluid warming is evaluated. The Level-1 method's ability to consistently achieve a 100% target temperature maintenance underscores its effectiveness in ensuring optimal IV fluid temperatures. This aligns with existing literature supporting the use of specialized fluid warming equipment to prevent the lethal triad in trauma patients. Although the microwave method did not reach the same level of temperature maintenance as the Level-1 method, it demonstrated substantial promise. The microwave technique warmed fluids in just an average of two minutes, highlighting its capacity to swiftly elevate fluid temperatures. This speed may be especially valuable in time-sensitive scenarios, potentially accelerating the initiation of warm fluid administration. Moreover, its ability to maintain the target temperature for 95.84% of the infusion duration indicates the method's clinical utility and effectiveness in ensuring warm fluid delivery for the majority of infusion duration.

To further improve temperature maintenance, several strategies warrant consideration, including insulation of crystalloid packages to mitigate thermal loss and modifying infusion parameters. For example, the use of larger-bore needles or simultaneous infusion of two 500 mL packages may decrease total free-flow infusion time, provided warming protocols are adjusted accordingly. These suggestions could enhance both the efficacy and infusion rate of microwave-based fluid warming, ultimately increasing its clinical applicability in time-critical trauma care settings. Further research and refinement of these strategies could lead to more effective fluid warming techniques and enhance patient care in high-stake medical situations.

Our study emphasized the practical clinical implementation of IV fluid warming. In contrast to Chittawattanarat et al., who investigated optimal microwave parameters under controlled laboratory conditions using various fluids and containers[4], we replicated actual clinical practice by utilizing standard IV fluid bottles connected to infusion sets with needles. This approach accounts for potential heat loss along the IV line, and we measured temperature at the needle tip to reflect the final temperature delivered to the patient. In addition to microwave warming, we compared the efficacy of other commonly used warming protocols. Notably, warming cabinets, despite their widespread use in trauma settings, may be ineffective if fluids are not delivered rapidly (e.g., 1 liter in 5 minutes). This highlights the need to determine optimal cabinet temperature settings that maintain adequate warming without causing overheating or underheating during slower infusions.

From an economic standpoint, the microwave warming approach presents a strong value proposition to medical facilities looking for less expensive options that meet the clinical criteria for trauma resuscitation. A significant cost disparity has major implications for resource allocation, especially at facilities with tight budgets. Furthermore, when compared to specialized fluid warming equipment, microwave ovens — which are widely available in both clinical and residential settings — are more cost-effective and ubiquitous. This can democratize access to fluid warming capabilities across a range of healthcare environments. Future research should explore the cost-utility ratio of both warming approaches and assess how feasible each is for application in different clinical settings, especially in situations with low resource environments, such as rural areas, or in mass casualty situations where access to specialized equipment may be limited.

While the focus of this study was temperature maintenance, it is important to acknowledge safety considerations. The risk of overheating remains a potential concern with microwave fluid warming. It poses a risk of hot spots and overheating, especially at the center of the container, where microwave energy is most concentrated.[4] This can lead to thermal injury, hemolysis, or fluid degradation. The container material also influences heating by absorbing microwave energy unevenly. To reduce risk, fluids should be gently shaken or inverted and allowed to rest briefly after microwaving to promote even heat distribution.[4] Consider verifying that the final temperature is below 42°C before infusion, where feasible. Future research should examine not only temperature maintenance but also patient safety and the incidence of adverse events.

In addition to the risk of overheating, the potential release of microplastics should be considered. Although polypropylene, commonly used in IV bags and tubing, has a high melting point (>130°C) and is FDA-approved for microwave food contact, recent studies have raised concerns. Hussain et al. reported the release of micro-

and nanoplastics from microwaved dairy products in polypropylene containers.[17] More recently, Tarafdar et al. demonstrated microplastic release from standard IV infusion systems, with increased levels observed when infusion pumps were used.[18] These findings suggest that microwave warming of IV fluids may further promote microplastic release. However, no studies have directly examined this risk in the context of IV fluid warming, and the clinical implications remain unknown. Further research is warranted.

As with any study, this investigation is not without limitations. While the present study demonstrates the feasibility and thermal efficiency of microwave-based fluid warming under controlled in-vitro conditions, it is important to acknowledge the limitations in translating these findings directly into clinical practice. Our results indicate that, when all parameters are precisely controlled, microwave warming can deliver fluids within the target temperature range recommended for trauma resuscitation. However, in real-world clinical settings, variables such as ambient temperature, infusion tubing length, flow rates, patient core temperature, and individual thermoregulatory responses may significantly affect the temperature of the infused fluid at the point of delivery. Additionally, we acknowledge that the Level 1 system includes both warming and pressurized infusion, while the microwave method relied on free-flow alone. This flow difference may have affected temperature maintenance, potentially disadvantaging the microwave group, though it was not found to be inferior. Our model also excluded vascular resistance, which in clinical settings may slow flow further. If 1 liter cannot be delivered within 19 minutes, the fluid may not reach the target temperature. Moreover, microwave warming of IV fluids is not currently recommended by the FDA due to limited evidence and concerns about overheating from inconsistent temperature control. While existing data may be outdated and high-quality studies are lacking, the potential for harm prevents formal recommendation of this method. As such, further in-vivo investigations are warranted to assess the clinical efficacy, safety, and practicality of this technique before it can be recommended for routine use in patient care.

CONCLUSION

In conclusion, using a microwave to warm fluids is non-inferior to a conventional high-flow fluid warming device. Microwave fluid warming during early trauma resuscitation is feasible, especially in remote areas with limited resources. Additionally, this method costs less. However, further in-vivo studies are warranted to evaluate the efficacy and assess outcomes.

Data Availability Statement

Data supporting this study is available from the corresponding author upon reasonable request.

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DECLARATIONS

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Conflict of Interest

The authors (VA, SM, AB, TW, CS, RC, and NO) have no conflicts of interest or disclosures of funding to declare.

Registration Number of Clinical Trial

None.

Author Contribution

Conceptualization and methodology: VA, SM, NO; Investigation: VA, SM, NO; Data analysis: VA, AB, NO; Visualization and writing–original draft: VA, SM, NO; Writing–review and editing: VA, SM, RC, NO; Supervision: RC, NO.; Essentially Intellectual Contributor: SM. All the authors read and agreed with the final version of the manuscript.

Use of Artificial Intelligence

The authors used ChatGPT (OpenAI) to assist with grammar correction and sentence refinement.

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