Microwave Oven: How to Use It as a Crystalloid Fluid Warmer

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Background: *Hypothermia is a common complication in the hypovolemic patient. Warm intravenous fluids have proven valuable at preventing this complication during volume replacement. The microwave oven is considered an applicable alternative method for warming fluids but no protocol has been established.*
Objective: *To evaluate the efficacy and affected variables of the microwave oven in warming crystalloid fluids and to determine the appropriate formula for calculating the warming duration.*
Results: *The important variables influencing the operation of the microwave oven include the difference between the crystalloid fluid and room temperature, the microwave oven's capability, variations in microwave irradiation, and fluid shaking. The appropriate formula for calculating warming duration is:*

$$\text{Duration (sec)} = \frac{\text{Volume (cc)} \times 4.2 j.g^{-1}.K^{-1} \times \text{Raised temperature } \Delta T \text{ (K)} \times 1.1 \text{ (Adjusted power)}}{\text{Microwave power (W)}}$$

Conclusion: *The microwave oven is a safe and practical method for warming crystalloid fluids.*

Keywords: *Heating, Hypothermia, Isotonic solutions, Microwaves, Resuscitation*

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Hypothermia is a common complication in the hypovolemic patient, causing an abnormal response to fluid resuscitation and coagulopathies. External warming devices, heat lamps, thermal caps, heated respiratory gasses, and warmed intravenous fluids have been advocated to prevent this complication.

Advance Trauma Life Support (ATLS) recommended heating the fluid to 39°C (102.2°F) before use(1). Many methods are demonstrated to warm intravenous fluids including a warm blanket, immersing coiled IV tubing in a warm water bath, and passing the IV tubing through heating blocks (dry heat technology). A microwave oven is considered an applicable alternative method for warming fluids. Many studies have been performed to evaluate the efficacy of this method, but the protocols for use have not been established, especially the appropriate warming duration(2-6).

The purpose of the present study is to evaluate the efficacy of a microwave oven and affected variables in warming crystalloid fluid, and to determine the appropriate formula for calculating warming duration.

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Material and Method

This research was an experimental study which was divided into three steps: 1) evaluating the variables influencing the operation, 2) determining the appropriate formula for calculating warming duration, and 3) applying the formula to the application. The authors used four brands of microwave oven that were labeled A, B, C and D (Table 1). Two types of crystalloid fluid, Normal saline solution (NSS), and Acetar and Lactated Ringer's solution (LRS) (Thai Otsuka Pharmaceutical Co. Ltd), were used in these experiments. Both types of fluid were contained in a polyethylene bag with a bromobutyl (non-metallic) stopper. All fluids were kept at room temperature for at least 24 hours. The authors measured the fluid temperature by a digital thermometer with a probe sensor and self calibration (Checktemp-1C Hanna instruments™). The level of temperature resolution was reported to within 0.1°C and the accuracy variability

Table 1. Types of microwave ovens

Microwave oven	A	B	C	D
Brand	Turbora	LG	LG	Sharp
Model	TRX-1981	MS-2342C	MS-2022C	R-240
Type	Digital	Digital	Analog	Digital
Capacity	19 L	23 L	20 L	22 L
Power	220v, 50Hz, 1200w	220v, 50Hz, 1000w	220v, 50Hz, 1200w	220v, 50Hz, 1200w
Frequency	2450MHz	2450MHz	2450MHz	2450MHz
Power output	600w	800w	800w	800w

about 0.3°C when measuring fluids between -20°C to 90°C. The time after warming the fluid was recorded by a Casio BG-153. The expected duration for target temperature can be achieved by the following theoretical calculation[3]:

$$\text{Duration (sec)} = \frac{\text{volume (mL) x 4.2 J.g}^{-1}\text{.K}^{-1}\text{ x raised temperature }\Delta\text{T (K)}}{\text{Microwave power (W)}\ \text{x}\ \dfrac{100 + \text{adjusted power (\%)}}{100}}$$

To evaluate the variables influencing the operation

Packet shaking

One thousand mL of water in a glass bowl was warmed in Microwave Oven A using the calculated duration. The expected temperature was 39°C. The bowl could not be removed from the oven. Measurement of the temperature at the center of the bowl was made every 5 seconds for the first 3 minutes and every 30 seconds for the next 2 minutes. The same sequence was repeated by starting the experiment with an equally room temperature water in the same cool down bowl as the previous experimental temperature, but measurement was made at the lateral part and center of the bowl after stirring the contents with a plastic spoon for 5 seconds. This test was carried out 3 times in each position, and the temperature was compared between each position.

Container

One thousand mL of water in a container was warmed in Microwave Oven A using the calculated duration. The expected temperature was 39°C. The container was removed from the oven and the contents stirred with a plastic spoon for 5 seconds. The water was transferred to a glass bowl or polyethylene bag. Measurement of the temperature was made every 5 seconds for the first 3 minutes, and every 30 seconds for the next 7 minutes. The test was carried out 3 times in each container, and the temperature was compared between each container.

Microwave irradiation variation

One thousand mL of NSS in a polyethylene bag were warmed in Microwave Oven A using the calculated duration. The expected temperature was 39°C. The package was removed from the oven and shaken for 5 seconds. A hole was bored in the center of the package. The temperature was measured every 5 seconds for the first 3 minutes, and every 30 seconds for the next 7 minutes. The test was carried out four times on two different days, and the temperature was compared between each time and day.

Type of crystalloid fluids

One thousand mL of crystalloid fluids (NSS, Acetar, LRS) in a polyethylene bag were warmed in Microwave Oven A using the calculated duration. The expected temperature was 39°C. The package was removed from the oven and shaken for 5 seconds. A hole was bored in the center of the package and the temperature was measured every 5 seconds for the first 3 minutes, and every 30 seconds for the next 7 minutes. The temperature was compared between each type of crystalloid fluid.

Difference between crystalloid fluid and room temperature

The temperatures of crystalloid fluids and room temperature were measured for many days by a thermometer. The differences between the crystalloid fluids and room temperature were compared.

To quantify the theoretical calculation

One thousand mL of NSS in a polyethylene bag was warmed in Microwave Ovens A, B and C. The warming duration was calculated from the adjusted theoretical formula, with 0, 5, 10, 15 and 20 percent added. The expected temperature of crystalloid fluids was 39°C. The test was carried out three times at each adjusted power level. To control the effect of varied microwave irradiation, the test was performed in accordance with the list in Table 2. The package was removed from the oven and shaken for 5 seconds. A hole was bored in the package and the temperature of the fluid was measured every 5 seconds for the first 3 minutes, and every 30 seconds for the next 7 minutes. The temperature was compared between each adjusted power level and between each microwave oven.

$$\text{Duration (sec)} = \frac{\text{volume (mL)} \times 4.2\ \text{J.g}^{-1}.\text{K}^{-1} \times \text{raised temperature } \Delta T\ \text{(K)}}{\text{Microwave power (W)} \dfrac{\times\ 100 + \text{adjusted power (\%)}}{100}}$$

To apply the theoretical calculation

One thousand mL of Acetar in a polyethylene bag was warmed in Microwave Oven D. The warming duration was retrieved from the adjusted theoretical calculation, with 10 percent added. The expected temperature of crystalloid fluids was 39°C. The test was carried out 10 times at each adjusted power level. The package was removed from the oven and shaken for 5 seconds. A hole was bored in the package and the temperature of the fluid was measured every 5 seconds for the first 3 minutes, and every 30 seconds for the next 7 minutes. Each temperature was compared.

Results

To evaluate the variables influencing the operation

Packet shaking

Without stirring or shaking, the temperature at the center of the container was highest at the 30^{th} second, and slowly decreased to the lowest temperature at the 2^{nd} minute (Fig. 1). After that, the temperature rose and remained stable until the 3^{rd} minute. The temperature at the lateral part of the container slowly rose and remained stable at 3 minutes 30 seconds. The stir water temperature was higher from the previous of center and lateral temperature might be from stirring effect and unequal stabilized power of microwave to warmed water.

With stirring, the temperature reached the highest level at the 10^{th} second, then slowly decreased to the lowest level at the 1^{st} minute before rising again to remain stable at 1 minute 20 seconds.

Container

Using a glass bowl, the temperature rapidly decreased in the first 2 minutes and then decreased slowly (Fig. 2). When using a polyethylene bag, the temperature decreased rapidly only in the first 5 seconds before slowly decreasing.

Microwave irradiation variation

In both experimental days, the highest temperature reached in warming NSS was at the 20^{th} second (Fig. 3). The temperature measured in day 2 was higher than in day12.

Type of crystalloid fluids

The temperatures measured in each type of crystalloid fluid were not different and reached the highest level in 20 seconds (Fig. 4). The decreasing rate of all temperatures measured was the same.

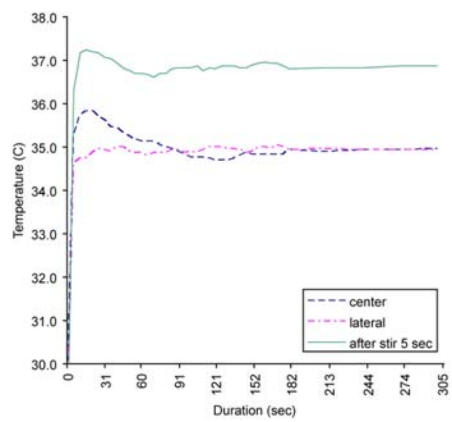

Fig. 1 Comparison between each position of the container

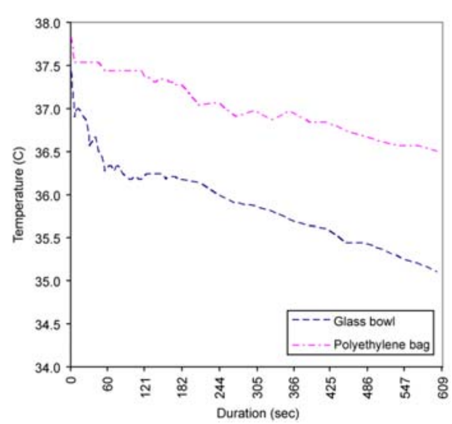

Fig. 2 Comparison between each type of container

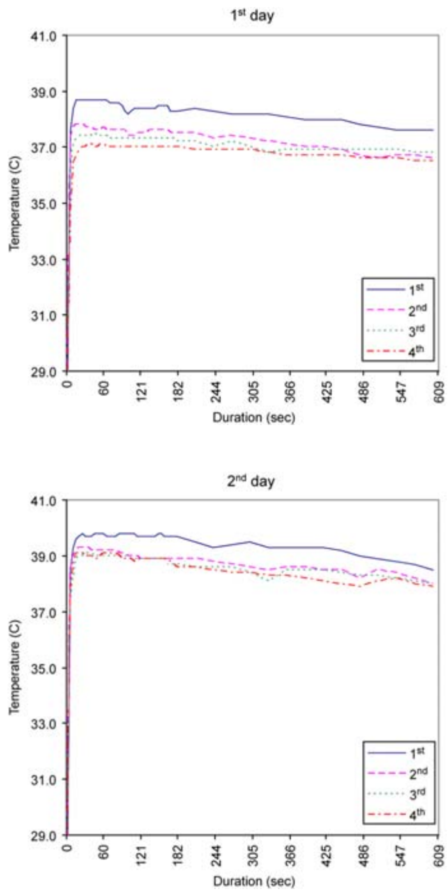

Fig. 3 Comparison between each operation in the 1st and 2nd days

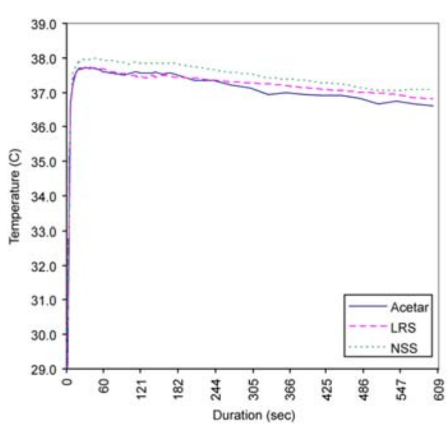

Fig. 4 Comparison between each type of crystalloid fluids

Difference between crystalloid fluid temperature and room temperature

Always, the room temperature was higher than the temperature of the crystalloid fluid (Fig. 5). However, the difference was varied on each day and mean difference was 0.5 ± 0.26°C.

To determine the appropriate formula for calculating warming duration

According to the order of experiments, every fluid tested reached its highest temperature the first time it was warmed (Fig. 6). The maximum differences in temperature from maximum to equilibrium were 0.7, 1.1 and 0.6°C in Microwave Ovens A, B and C, respectively.

The differences were lower in the second warming for all ovens. The average temperatures measured at 20 seconds after warming were 36.7, 37.2, 37.6, 38.1 and 38.8°C respectively when adding 0%, 5%, 10%, 15% and 20% duration. The authors found that the safety temperature level of 39°C was at 10 percent of added duration.

To apply the formula in the application

The room temperature was 27.6°C, while the Acetar temperature was 27.1°C. The difference between crystalloid fluid and room temperature was 0.5°C. After warming, the highest temperature of warm Acetar was 37.5°C for the first time of operation, and the temperature in the previous operation was higher than in the later one.

Discussion

It is already known that glucose is caramelized at 60°C. Therefore, heating glucose is a potential threat to patient safety[7] and many authors did not recommend using a microwave to warm blood due to the fear of local over heating[5,8-11].

The stability of the polyethylene container and bromobutyl rubber has been established[12], although complete screening of all compounds that might leach has not been undertaken.

The center of the container is the point where maximum energy is obtained by the microwave oven. Then the heat spreads to the periphery. Stirring or shaking is suggested for rapid equilibrium. The container has an influential effect. It absorbs some of the microwave's energy and the heat from the fluid.

The microwave oven gives the maximum output on the first use and it is less on the next use. The different results between each use are

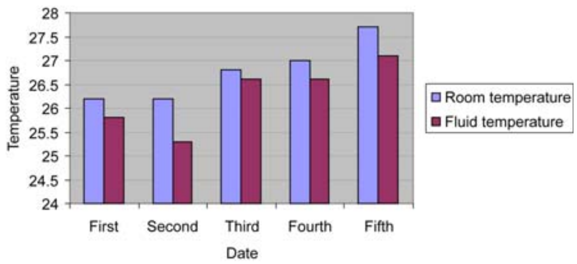

Fig. 5 The difference between crystalloid fluid and room temperature in each experimental day

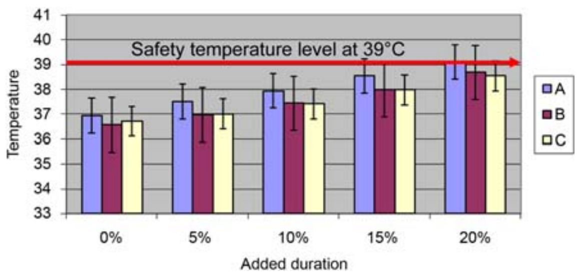

Fig. 6 The relationship between increasing temperatures in Microwave Ovens A, B and C and the added duration

unpredictable, but those obtained from a new microwave oven are likely to be less varied.

Different types of crystalloid fluids contain the same water volume but are different in electrolyte volume. Microwaves energy was transmitted to water molecules but not electrolyte molecules, so the theoretical calculation for fluid warming is 1 mL of water uses 4.2 joule of energy to raise 1 Kelvin. According to this theory, differences between each type of crystalloid fluid could not be found.

Crystalloid fluids kept in room conditions might have the same temperature as room temperature; however, a difference was found. This result was probably from a difference in heat released among fluid and air. Fluid temperature changes more slowly than room temperature during daytime. In practice, room temperature was used as the baseline temperature, not fluid temperature, because the authors could not measure the fluid temperature before warming with a microwave oven due to sterility measure. A greater difference was shown and more errors occurred as a result. This problem can be corrected by controlling room temperature with air conditioners or by leaving some fluid in an open system at room temperature for measurement as a calibrator.

For safety, the fluid used must not be warmed higher 39°C. Due to variations in microwave irradiation, the appropriate adjustment of the power level was that of the highest temperature plus the higher difference among warming times, nearest to but not exceeding than 39°C. At 10% duration added level, the microwave oven provided the safest temperature level that did not exceed the temperature threshold. Therefore, the appropriate adjustment of the power level was to add 10% into the theoretical calculation.

Applying the calculation to this application, the authors obtained the highest temperatures of warm Acetar, 37.5°C, in the first time of operation. The difference between room and fluid temperature was 0.5°C. If the room and fluid temperature were equal, the result must have been 37.5 + 0.5 = 38°C, which was 1°C lower than the expected temperature. This was very safe and there was no overheating.

Conclusion

The authors conclude that the microwave oven is a safe and practical method for warming crystalloid fluids, especially in rural hospitals where a standard warmer is not available. Safe use requires a narrow difference between crystalloid fluid and room temperature, an accurate room temperature thermometer, an accurate stopwatch, and a pretest for microwave ovens.

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การใช้เตาอบไมโครเวฟเพื่ออุ่นสารละลายคริสตัลลอยด์

กวีศักดิ์ จิตตวัฒนรัตน์, ศิริวสันต์ อกนิษฐาภิชาติ

ภูมิหลัง*: อุณหภูมิกายต่ำเป็นภาวะแทรกซ้อนที่พบได้บ่อยในผู้ป่วยที่มีการสูญเสียสารน้ำ ซึ่งการอุ่นสารน้ำก่อนที่จะให้ทางหลอดเลือดดำจะช่วยป้องกันภาวะแทรกซ้อนนี้ได้ เตาอบไมโครเวฟก็เป็นอีกทางเลือกหนึ่งซึ่งสามารถใช้ได้แต่ยังไม่มีแนวทางการใช้ที่ชัดเจน*

วัตถุประสงค์*: เพื่อประเมินดูประสิทธิภาพของเตาอบไมโครเวฟในการอุ่นสารละลายคริสตัลลอยด์ วิเคราะห์ปัจจัยที่มีผลต่อการใช้เตาอบไมโครเวฟ และหาสูตรเพื่อใช้คำนวณระยะเวลาที่เหมาะสมในการอุ่นสารละลายคริสตัลลอยด์*

ผลการศึกษา*: ปัจจัยสำคัญที่มีผลต่อการใช้เตาอบไมโครเวฟได้แก่ ความแตกต่างระหว่างอุณหภูมิของสารน้ำคริสตัลลอยด์และอุณหภูมิห้อง ประสิทธิภาพของเตาอบไมโครเวฟ การให้พลังงานที่ไม่เท่ากันในแต่ละครั้งของเตาอบไมโครเวฟ และการเขย่าสารน้ำให้ทั่วหลังการอุ่น สูตรที่เหมาะสมในการอุ่นสารละลายคริสตัลลอยด์คือ*

$$\text{เวลาที่ใช้อุ่น} = \frac{\text{ปริมาตรสารน้ำ (มล.)} \times 4.2\ \text{จูล.กรัม}^{-1}\text{.เคลวิน}^{-1} \times \text{อุณหภูมิที่ต้องการเพิ่ม (เคลวิน)} \times 1.1\ \text{(ระดับพลังงานที่ปรับเพิ่ม)}}{\text{กำลังของเตาอบไมโครเวฟ (วัตต์)}}$$

สรุป*: เตาอบไมโครเวฟเป็นอีกวิธีหนึ่งที่ปลอดภัยและสามารถนำไปใช้ในการอุ่นสารละลายคริสตัลลอยด์*
