



OPEN ACCESS

EDITED BY

Kris Spaepen,
Vrije University Brussels, Belgium

REVIEWED BY

Tamorish Kole,
University of South Wales,
United Kingdom
Jan-Cedric Hansen,
Centre d'Hébergement et
d'Accompagnement Gériatrique
(CHAG), France

*CORRESPONDENCE

Takayuki Irahara
✉ iraira19@outlook.com

RECEIVED 11 October 2025
REVISED 11 February 2026
ACCEPTED 24 February 2026
PUBLISHED 30 March 2026

CITATION

Irahara T, Sakamoto T, Minamida T,
Shirokawa M, Kusaka A, Sakamoto Y,
Yamaguchi N and Watanabe E (2026)
Experimental evaluation of infusion
methods and administration speeds in
confined spaces during urban search and
rescue operations.
Front. Disaster Emerg. Med. 4:1722986.
doi: 10.3389/femer.2026.1722986

COPYRIGHT

© 2026 Irahara, Sakamoto, Minamida,
Shirokawa, Kusaka, Sakamoto,
Yamaguchi and Watanabe. This is an
open-access article distributed under the
terms of the [Creative Commons
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,
distribution or reproduction in other
forums is permitted, provided the
original author(s) and the copyright
owner(s) are credited and that the
original publication in this journal is
cited, in accordance with accepted
academic practice. No use, distribution
or reproduction is permitted which does
not comply with these terms.

Experimental evaluation of infusion methods and administration speeds in confined spaces during urban search and rescue operations

Takayuki Irahara^{1,2*}, Taigo Sakamoto^{1,3}, Teppei Minamida^{1,4},
Masamitsu Shirokawa^{1,5}, Akari Kusaka^{1,6}, Yoshiko Sakamoto^{1,7},
Naoki Yamaguchi^{1,8} and Eizo Watanabe²

¹Japan Disaster Relief (JDR) Rescue Team Medical Unit, Tokyo, Japan, ²Department of Emergency and Critical Care Medicine, Aichi Medical University Hospital, Nagakute, Aichi, Japan, ³Department of Emergency and Critical Care Medicine, Nippon Medical School Tama-Nagayama Hospital, Tama, Tokyo, Japan, ⁴Department of Emergency and Critical Care Medicine, Nara Medical University Hospital, Kashihara, Nara, Japan, ⁵Department of Emergency Care, Tokyo Metropolitan Hiroo Hospital, Shibuya-ku, Tokyo, Japan, ⁶Department of Emergency Medicine, Fukuoka Kinen Hospital, Sawara-ku, Fukuoka, Japan, ⁷Juntendo University Nerima Hospital Emergency Primary Care Center, Nerima-ku, Tokyo, Japan, ⁸Good Will Life Planning LLC, Osaka, Japan

Introduction: Confined space (CS) medicine is required for urban search and rescue operations, particularly for victims with crush syndrome. Adaptable infusion techniques are sometimes required for each rescue setting. However, the knowledge of infusion methods and speeds in CS is limited.

Aim: To evaluate infusion speeds of various methods using an infusion model based on *in vivo* data, aiming to inform rescue planning and training.

Methods: Peripheral venous pressure and infusion rates were measured in healthy male participants, aged 20–29 years ($n = 20$). An infusion model was established using a simulator arm based on these measurements. Seven infusion methods were tested, including spontaneous drip, manually pressurized bag + re-pressure, tube extension + pumping, and automated pressure devices (continuous or temporary by spring-loaded trays or batteries).

Results: Mean venous pressure of the participants was 19.8 cm H₂O, and 500 ml was infused over 16 min 25 s. An infusion model replicated this pressure gradient. Infusion speed varied among different methods. Compared with spontaneous drip, the time required for a 1 L infusion was significantly shorter when using tube extension + pumping ($P < 0.0001$), pressurized bag + re-pressurization ($P < 0.001$), and automated devices (continuous battery, $P < 0.001$ and temporary battery, $P < 0.05$).

Conclusions: A CS infusion model was developed based on *in vivo* experiments. Manual pressure with re-pressurization after 10 min may be the most reasonable. Although each method has its advantages and disadvantages, selection should prioritize efficacy and safety. Further research is required to confirm the findings.

KEYWORDS

confined spaces, crush syndrome, intravenous infusion, medical device, USAR

1 Introduction

On-site rescue and medical cooperation are recognized as necessary in urban search and rescue (USAR) missions during disaster relief operations. Confined space medicine is required, especially in patients with crush syndrome, where adequate fluid infusion before decompression is critical. Occasionally, unique infusion methods must be used in rescue operation settings where there is insufficient height difference between the ceiling and the ground. Rescue personnel and medical personnel must comprehend each other's technical procedures.

However, strong evidence for infusion therapy in confined space (CS) is lacking. The International Search and Rescue Advisory Group recommends an initial fluid load of 1–1.5 L/h in the first 2 h for adults to avoid hemodynamic collapse (1). Another review on crush syndrome suggests an isotonic saline rate of 1,000 ml/h (10–15 ml/kg/h) while the victim is trapped under rubble (2). The Japan disaster relief (JDR) Rescue Team Medical Unit advises completing at least 2,000 ml before decompression and continuing at 500–1,000 ml/h afterward (3).

Notably, even in times of disaster, the team operation must follow the laws of the affected country where the team belongs. During JDR operations, Japanese law currently prohibits the use of mechanical pumps by JDR paramedics. In addition, no infusion pump that is suitable for CS is currently approved in Japan. Therefore, any method other than spontaneous infusion must be carried out by nurses or medical doctors. These personnel are not extensively trained in CS operations as rescuers. Aiming for the reduction of time under CS decreases operational risks.

Knowledge regarding infusion methods and speed in CS is limited. Few studies exist on the speed of peripheral venous infusion (4) or venous pressure (5). The lack of data on field-adapted infusion therapy—especially in low clearance environments—has affected field rescue plans and safe medical care. The primary research question of this study is which infusion methods optimize speed and safety in confined spaces, where gravitational perfusion is ineffective and rescuer exposure must be minimized.

To simulate real-life conditions affecting infusion speed, venous pressure was replicated, and an intravenous infusion model was established based on experiments on healthy participants. An exploratory study was conducted to assess infusion rates. This study aimed to provide data on the infusion methods and administration speeds in CS required for on-site rescue and medical cooperation during USAR missions. This study was approved by the Ethical Review Board of the Aichi Medical University School of Medicine (Approval Number: 2022–018). Consent for the use of each device and data publication was obtained from each company.

2 Materials and methods

2.1 Human peripheral venous pressure and infusion speed

Healthy male participants aged 20–29 years were recruited from students of Aichi Medical University School of Medicine. Individuals with medical complications—especially

cardiovascular disease, upper limb vascular or lymphatic disease, or dialysis shunts—those who were severely underweight or obese (body mass index [BMI] <18 kg/m² or >30 kg/m²), or anyone deemed inappropriate by the investigators were excluded. Finally, 20 participants were enrolled in the study.

The procedures and risks were explained to all participants, and written informed consent was obtained. Information on age, height, weight, medical history, amount of water consumed within 12 h before the experiment, and the time of last fluid intake. Vital signs, central venous diameter and respiratory variation, peripheral venous diameter at the forearm, and blood flow velocity were measured by pulse Doppler method with ultrasonography (MicroMaxx[®] Ultrasound System; Sonosite, Inc., Bothell, WA, USA).

A peripheral forearm vein was cannulated with a 20 G needle (Surshield Surflo II[®] flush-type 20 G × 1, 1/4 inch; Terumo Corporation, Tokyo, Japan). Peripheral venous pressure was measured using a water manometer in the supine position. Infusion route for adults 125 cm (TI-U350; Terumo Corporation) and extension tube 50 cm (TS-WR1735L; Terumo Corporation) were connected with a total height of 90 cm. The time to administer 500 ml of Lactate Ringer Solution (SOLULACT[®] Infusion; Terumo Corporation) at full speed was measured. Results were statistically analyzed to assess the effect of age, height, weight, medical history, fluid intake 12 h prior, and the last time of water intake on infusion rate.

2.2 Establishing the infusion model using a simulator arm

Based on the human experiment results, we established an experimental model with the same height and tube length. The differences between the infusion line's lower end and the top of the cylinder was set to 19.8 cm on a vascular access simulator arm (V-Line[®]; Kyoto Kagaku Co., Ltd., Kyoto, Japan), as shown in Figure 1.

2.3 Infusion experiment with various methods

Using the established infusion model, the administration speed was measured using various infusion methods, as shown in Figure 2. Measurements were performed seven times for each method.

2.3.1 Spontaneous dripping

The infusion route for adults (125 cm) and extension tube (50 cm) were connected 90 cm high (same as in the human experiment).

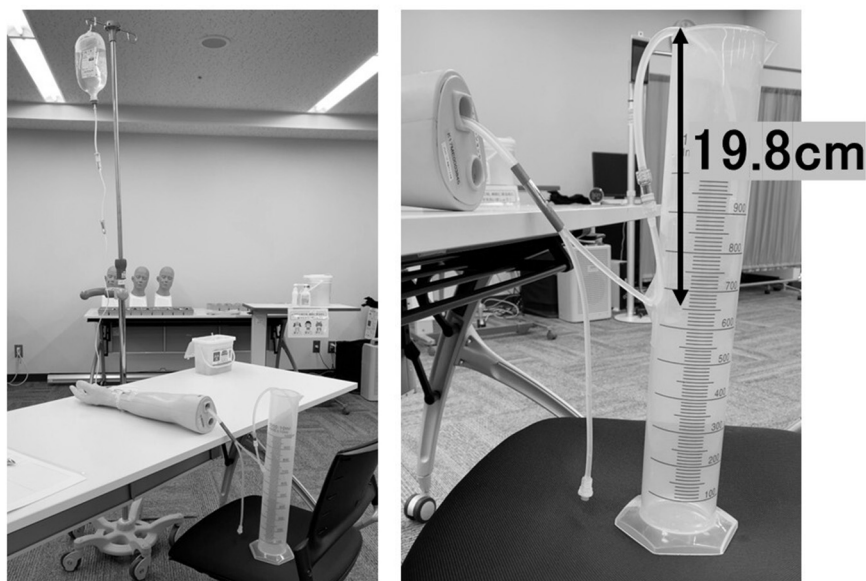


FIGURE 1

The height difference between the infusion line's lower end and the cylinder top was set to 19.8 cm (same as human peripheral venous pressure) on a vascular access simulator arm.

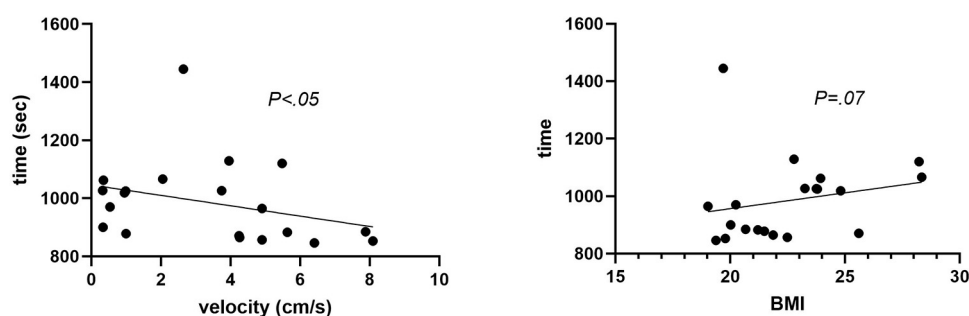


FIGURE 2

Various infusion methods were used, including spontaneous dripping (125 + 50 cm tube with 90 cm height); manually pressurized bag + re-pressure (pressurized bag for 1,000 ml followed by re-pressure after 10 min); tube extension + pumping (125 + 50 cm × 10 = 625 cm with 50 cm height + pumping with 20 ml syringe); Droper (spring-loaded automated pressure device); AutoCuff (continuous battery pressure); Terumo and Nipro devices (battery-powered temporary pressure, with re-pressure after 10 min).

2.3.2 Manually pressurized bag + re-pressure

Inspiron[®] pressurized bag for 1,000 ml (IN9,000K; MC Medical Inc., Ponce, Puerto Rico), followed by re-pressure after 10 min (because infusion speed decreases by half in 10 min).

2.3.3 Tube extension + pumping

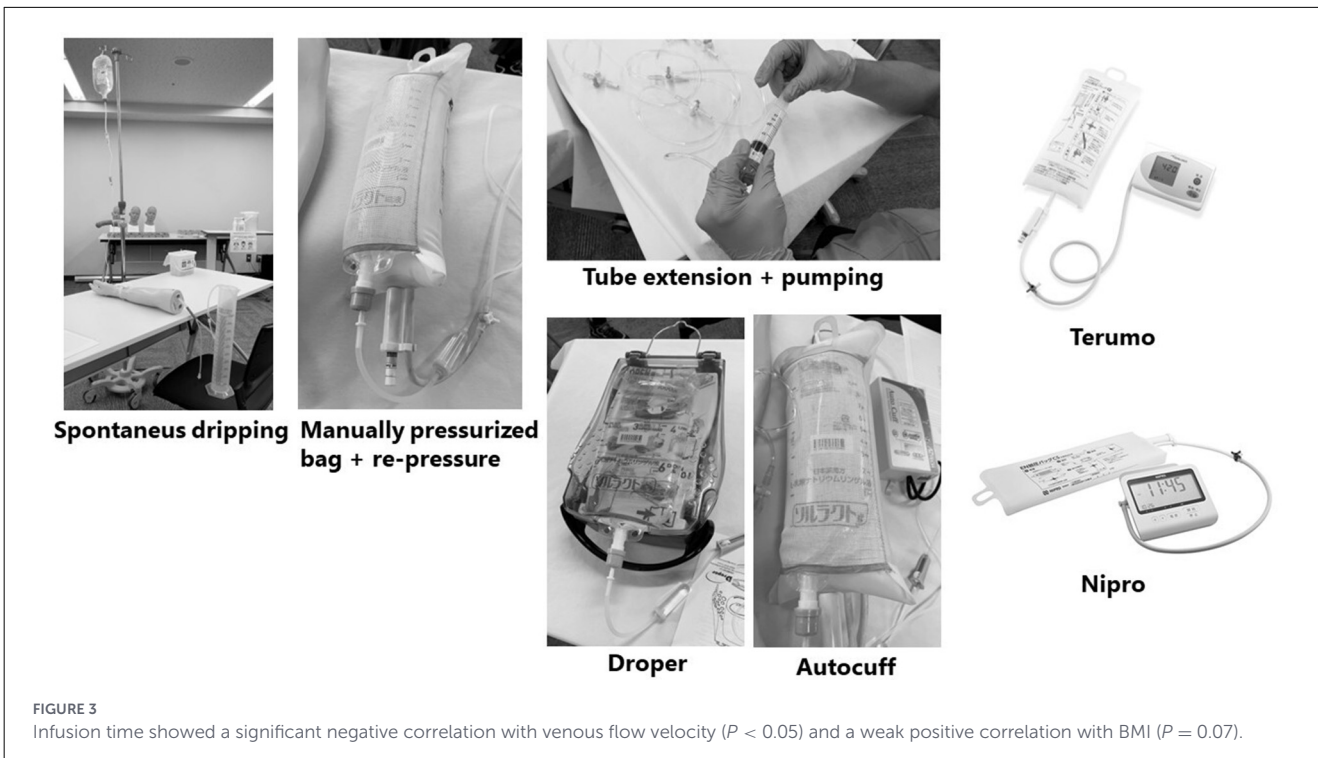
Infusion route for adults 125 cm and extension tube 50 × 10 cm = 625 cm connected with 50 cm height + pumping (repeating manual bolus with 20 ml syringe).

2.3.4 Droper

Automated pressure device with continuous pressure by spring-loaded tray (Droper[®]; Promovet SARL, Givet, France).

2.3.5 AutoCuff

Automated pressure device with continuous pressure by battery (AutoCuff[®]; Aztech Co., Ltd., Tokyo, Japan).



2.3.6 Terumo

Automated pressure device with temporary pressure by battery (PG pressure Q series[®] pressurized bag + electric pump PE-PR40DP PE-PR40DPB; Terumo Corporation) followed by re-pressure after 10 min.

2.3.7 Nipro

Automated pressure device with temporary pressure by battery (Nipro pressure pump EN pressurized bag CS[®]; Nipro Corporation, Osaka, Japan) followed by re-pressure after 10 min.

2.4 Statistical analysis

Values are presented as median (interquartile range). Data were analyzed using the *Mann-Whitney U*-test between two groups, and the *Kruskal-Wallis*-test with Dunn's multiple comparison test between more than three groups. Spearman's rank correlation coefficient was used for the correlation analysis. Statistical analyses were performed using GraphPad Prism 9 (GraphPad Inc., San Diego, CA, USA), with significance set at $P < 0.05$.

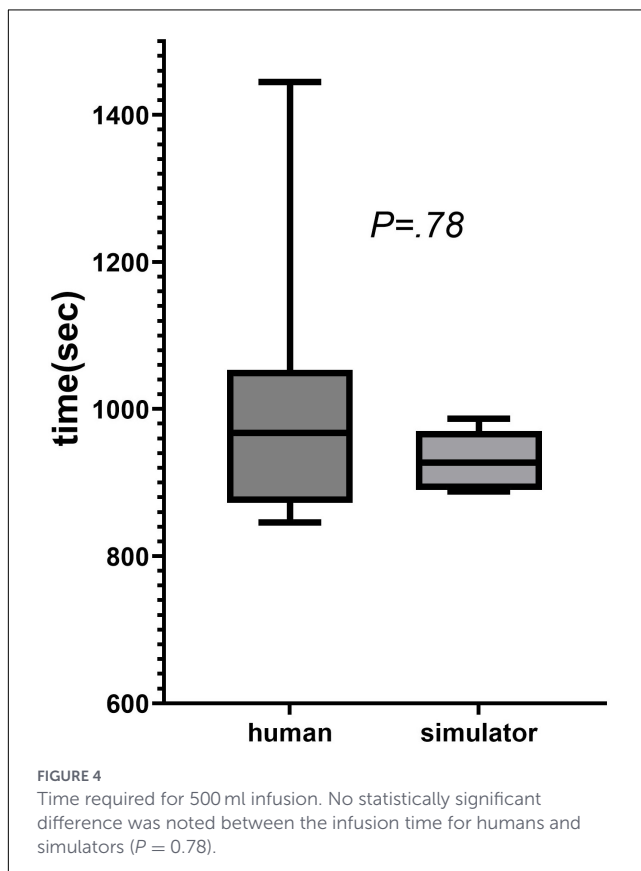


FIGURE 4 Time required for 500 ml infusion. No statistically significant difference was noted between the infusion time for humans and simulators ($P = 0.78$).

TABLE 1 Time required to administer 1 L of infusion solution via each administration method.

| Method | Infusion time for 1 L | P-value |
|---|---------------------------------------|---------|
| Spontaneous dripping (90 cm height) | 29 min (28 min 48 s–29 min 17 s) | – |
| Manually pressurized bag + re-pressure after 10 min | 15 min 35 s (14 min 32 s–16 min 20 s) | 0.0009 |
| Tube extension (625 cm, 50 cm height) + pumping | 13 min 16 s (11 min 27 s–14 min 47 s) | <0.0001 |
| Droper | 29 min (25 min–29 min) | >0.9999 |
| AutoCuff | 14 min (14 min–18 min) | 0.0004 |
| Terumo | 19 min (18 min–22 min) | 0.2805 |
| Nipro | 18 min (16 min–18 min) | 0.0359 |

3 Results

3.1 Human peripheral venous pressure and infusion speed

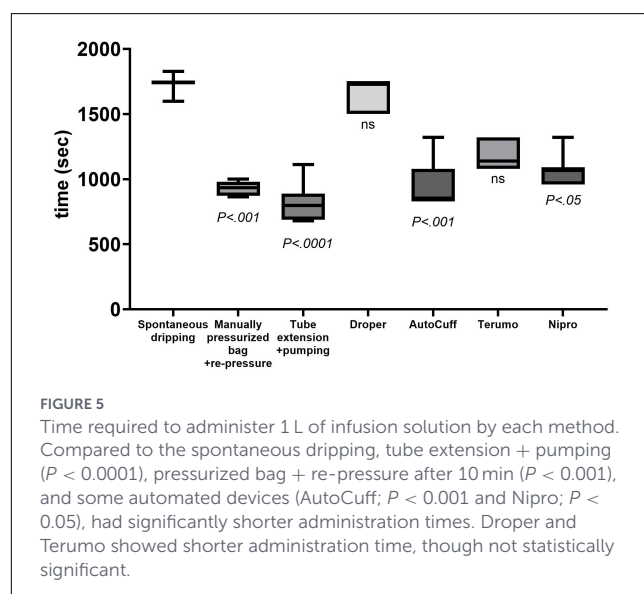
The median time to administer 500 ml lactated Ringer's solution in 20 participants was 16 min 8 s (14 min 33 s–17 min 33 s). Peripheral venous pressure was 21.5 (16.5–26.1) cm H₂O, and flow velocity was 3.85 (0.96–5.34) cm/s. Infusion time was significantly negatively correlated with flow velocity ($P < 0.05$) and weakly positively correlated with BMI ($P = 0.07$) (Figure 3). No correlations were found with other parameters (venous pressure, fluid intake, time of last drinking, venous diameter, and central venous respiratory variation).

3.2 Establishing infusion model using a simulator arm

The results of preliminary measurements on seven simulators showed that there was no statistically significant difference between the 500 ml infusion time of 15 min 27 s (14 min 50 s–16 min 10 s) and that of human infusion, and the model was considered adequate (Figure 4).

3.3 Infusion experiment with various methods

The time to administer 1 L of infusion solution was measured using the model; results are shown in Table 1 and Figure 5. Compared to spontaneous dripping, tube extension + pumping ($P < 0.0001$), pressurized bag + re-pressurization after 10 min, and automated devices, such as AutoCuff ($P < 0.001$) and Nipro ($P < 0.05$), had significantly shorter administration times. Other automated pressure devices, such as Droper and Terumo, tended to have shorter administration times; however, the difference was not significant.



4 Discussion

In USAR operations during disaster relief, rescue and medical cooperation are critical to save lives. One such common case is crush syndrome, caused by muscle compression from heavy debris, especially during earthquakes. This can result in serious conditions such as hypovolemic shock or kidney injury after decompression (2). In Japan, where earthquakes often occur, many victims suffered from crush syndrome during the 1995 Hanshin-Awaji earthquake (6). Several reports highlighted treatments such as infusions and dialysis (7); with early massive infusion is especially important for preventing renal failure and avoiding dialysis (8, 9). Usuda et al. emphasized the importance of fluid infusion before decompression (10).

In CS, gravity-dependent rapid dripping is ineffective due to height, and techniques such as pressurized bags or pumping to shorten the medical personnel's working time. Experimental studies have been conducted on pressurized infusion and velocity in CS (11, 12). White et al. demonstrated that pressure infusers more than doubled IV flow rates and clearly outperformed all other field methods. Shirokawa et al. demonstrated that infusion using pressure bags or body weight pressure is effective during disasters.

TABLE 2 Advantages and disadvantages of each infusion method.

| Method | Advantage | Disadvantage |
|---|---|--|
| Spontaneous dripping (90 cm height) | No device or power supply | Not enough height in CS; Slowest |
| Manually pressurized bag + re-pressure after 10 min | No power supply; 2nd fastest | Safety concern – requires re-entry to CS |
| Tube extension (625 cm, 50 cm high) + pumping | No device or power supply; fastest | Safety concern – requires staying in CS |
| Dropper | Continuous pressure by spring-loaded tray | Device concern – size |
| AutoCuff | Continuous pressure by battery | Device concern – power supply or environmental failure |
| Terumo | Temporary pressure by battery | Device concern – power supply or environmental failure Safety concern – requires re-entry to CS |
| Nipro | Temporary pressure by battery | Device concern - power supply or environmental failure Safety concern – requires re-entry to CS |

CS, confined space.

Although previous studies have examined pressurized infusion, many used open-air models lacking venous resistance, limiting clinical relevance.

Given the limited knowledge about infusion methods and speed in CS, an exploratory study on the administration speed of various infusion methods was conducted using an infusion model based on healthy human participants. Each method was evaluated based on the concept of victim survival and rescuer safety. Shortening the time spent working in CS can reduce the risk of secondary damage and increase the chance of victims' survival. This is a novel approach in that the infusion model was established based on *in vivo* experiments.

Data from *in vivo* experiments showed a weak correlation between infusion time, peripheral venous flow velocity, and BMI—likely reflecting the resistance in the peripheral veins, and suggesting that body size affects infusion speed.

Although Franklin et al. experimented with spontaneous dripping and pressurized bags *in vivo* (13), our study assessed various infusion methods and found meaningful differences in administration speed.

Significant reductions in the administration time for tube extension + pumping, manually pressurized bags + re-pressure after 10 min, and automated pressure devices (continuous and temporary by battery). These methods should be selected based on effectiveness and the safety field conditions.

However, practical challenges remain with automated devices, including the size, necessity of power supply, environmental durability, training requirements and device portability (Table 2). Although the safety concern requiring re-entry into confined spaces exists, manually pressurized bag + re-pressure after 10 min strikes a balance between safety of pumping, and is actively used by JDR Rescue Team Medical Unit.

There are some limitations regarding this study. The infusion time may vary depending on anatomical factors not replicable in simulator models, such as venous branches, valves, collapsibility, tissue edema, or patient movement and the victim's physiological state. Such systematic biases (e.g., lack of tissue resistance or dynamic venous collapse) might affect real-world applicability.

Besides, it is experimental and performed on a group of young, healthy male participants, who may differ from actual crush syndrome victims who may be hypovolemic, acidotic, or shock. Additionally, other administration methods (e.g., intraosseous infusion) and needle sizes other than 20 G were not evaluated due to cost and device limitations. Finally, larger sample sizes or testing under simulated stress conditions (e.g., vibrations, dust) could further validate the findings.

While our study focused on intravenous infusion methods, international guidelines such as those from INSARAG (2023) and the WHO emphasize intraosseous (IO) access as a critical alternative when IV access is unfeasible (1). IO infusion offers several advantages in confined spaces, including rapid deployment, minimal training requirements, and reliability in hypotensive patients (14). Future studies should compare IV and IO methods in simulated confined space environments to determine optimal protocols for USAR teams. Our exclusion of IO access reflects a limitation of the current study, as it may represent the most viable option in scenarios where IV cannulation is impossible (e.g., complete limb entrapment or severe vasoconstriction).

Despite these limitations, this study is worth presenting as evidence from the JDR rescue team medical unit and has a potential to be integrated into USAR training programs or standardized protocols (e.g., INSARAG's technical guidance notes), especially given the lack of international studies on infusion methods and rates in CS. Further research is required; this study will continue to collect more relevant evidence. Studies involving trauma patients or IO access would require additional ethical considerations (e.g., informed consent in austere environments).

This exploratory study evaluated the infusion speeds using an infusion model based on the results from healthy human participants. based on *in vivo* experiments novel approach in the infusion model was established. Among the methods tested, the manual pressurized bag with re-pressurization after 10 minutes emerged as a promising balance between speed and practicality. However, the optimal method may vary depending on field conditions, and further validation in real-world USAR scenarios is warranted. Although each method has its advantages and

disadvantages in terms of power supply and safety, selection should be based on careful evaluation. Further research is required to determine the optimal method for each rescue scenario.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethical Review Board of the Aichi Medical University School of Medicine. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TI: Conceptualization, Funding acquisition, Formal analysis, Writing – original draft. TS: Conceptualization, Writing – review & editing, Methodology. TM: Writing – review & editing, Conceptualization, Methodology. MS: Writing – review & editing. AK: Writing – review & editing, Investigation. YS: Investigation, Writing – review & editing. NY: Investigation, Writing – review & editing. EW: Supervision, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This study was funded by the Foundation for Ambulance Service Development as a Research Project for Emergency Medical Services in 2022.

References

- International Search and Rescue Advisory Group (INSARAG). The medical management of the entrapped patient with crush syndrome. Medical Technical Reference Note. (2023).
- Sever MS, Vanholder R, Lameire N. Management of crush-related injuries after disasters. *N Engl J Med.* (2006) 354:1052–63. doi: 10.1056/NEJMra054329
- Standard Operating Procedure of JAPAN Disaster Relief (JDR) Rescue Team Medical Unit, 2022.
- Foor JS, Moureau NL, Gibbons D, Gibson SM. Investigative study of hemodilution ratio: 4Vs for vein diameter, valve, velocity, and volumetric blood flow as factors for optimal forearm vein selection for intravenous infusion. *J Vasc Access.* (2024) 25:140–8. doi: 10.1177/11297298221095287
- Sperry BW, Campbell J, Yanavitski M, Kapadia S, Tang WHW, Hanna M. Peripheral venous pressure measurements in patients with acute decompensated heart failure (PVP-HF). *Circ Heart Fail.* (2017) 10:e004130. doi: 10.1161/CIRCHEARTFAILURE.117.004130
- Oda J, Tanaka H, Yoshioka T, Iwai A, Yamamura H, Ishikawa K, et al. Analysis of 372 patients with Crush syndrome caused by the Hanshin-Awaji earthquake. *J Trauma* (1997) 42:470–5. Discussion: 475–476. doi: 10.1097/00005373-199703000-00015
- Oda Y, Shindoh M, Yukioka H, Nishi S, Fujimori M, Asada A. Crush syndrome sustained in the 1995 Kobe, Japan, earthquake; treatment and outcome. *Ann Emerg Med.* (1997) 30:507–12. doi: 10.1016/s0196-0644(97)70011-8
- Gunal AI, Celiker H, Dogukan A, Ozalp G, Kirciman E, Simsekli H, et al. Early and vigorous fluid resuscitation prevents acute renal failure in the crush victims of catastrophic earthquakes. *J Am Soc Nephrol.* (2004) 15:1862–67. doi: 10.1097/01.ASN.0000129336.09976.73
- Iraj N, Saeed S, Mostafa H, Houshang S, Ali S, Farin RF, et al. Prophylactic fluid therapy in crushed victims of Bam earthquake. *Am J Emerg Med.* (2011) 29:738–42. doi: 10.1016/j.ajem.2010.02.018
- Usuda D, Shimozawa S, Takami H, Kako Y, Sakamoto T, Shimazaki J, et al. Crush syndrome: a review for prehospital providers and emergency clinicians. *J Transl Med.* (2023) 21:584. doi: 10.1186/s12967-023-04416-9

Acknowledgments

The authors thank JDR Rescue Team Medical Unit members, and Aichi Medical University medical students for their participation. We also thank Editage (<http://www.editage.jp>) for English editing.

Conflict of interest

NY was employed by Good Will Life Planning LLC.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest”

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

11. White SJ, Hamilton WA, Veronesi JF. A comparison of field techniques used to pressure-infuse intravenous fluids. *Prehosp Disaster Med.* (1991) 6:429–34. doi: 10.1017/S1049023X00038917
12. Shirokawa M, Nakajima M, Goto H. Comparison of maximum infusion rate by body weight pressure infusion techniques with difficulties in securing a supporting frame and verification of a measure for controlling infusion rate during disaster. *J J Disast Med.* (2016) 21:253–58.
13. Franklin WE, Patterson J, Kulick M, Sexton J. A new method for rapid fluid bolus infusion into a peripheral vein. *Prehosp Emerg Care.* (1997) 1:273–76. doi: 10.1080/10903129708958823
14. Wang D, Deng L, Zhang R, Zhou Y, Zeng J, Jiang H. Efficacy of intraosseous access for trauma resuscitation: a systematic review and meta-analysis. *World J Emerg Surg.* (2023) 18:17. doi: 10.1186/s13017-023-00487-7