

## Original research

# Securing cannulas in combat: an *in vitro* study of three intravenous securement techniques

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## Abstract

**Introduction** Haemorrhage is the leading cause of preventable death in combat settings. Pre-hospital practice guidelines for shock advocate for intravenous (IV) access to enable the rapid delivery of blood products and adjunct treatments. However, peripheral intravenous catheter (PIVC) insertion and securement is challenging in the austere setting, and catheter failure is common. This study investigated dressing and securement methods to prevent PIVC dislodgement within an Australian Defence Force (ADF) tactical combat casualty care (TCCC) training course.

**Methods** A pragmatic *in vitro* design was used to compare the proportion of dislodged PIVCs using three securement techniques – the ruggedised field IV method (Ranger), the S-Wrap technique, and standard care (a Tegaderm™ dressing). The study was undertaken from February to May 2022 at the Australian Army School of Health (ASH) in Victoria, Australia. Pull-out force was simulated using a purpose-designed pulley system and measured with a digital forge gauge. The null hypothesis of no difference in average force between products was tested using one-way analysis of variance, followed by a post-hoc Bonferroni test. Statistical significance was determined at  $p \leq 0.05$ . This study is registered with the Australian New Zealand Clinical Trials Registry CTRN12621000314820.

**Results** Of the three methods of PIVC securement tested in this study (standard, Ranger, S-Wrap), the S-Wrap method demonstrated a significantly higher average pull-out force (66.1N; SD 7.1), and the lowest average pull-out force was associated with Tegaderm™ (9.7N; SD 2.2). The securements provided greater resistance against the pull-out force at 0° compared to 30°. The three Bonferroni-adjusted *p* values for the three null hypotheses between the three products were all  $< 0.001$ .

**Conclusion** PIVC securement is challenging in the austere or combat setting, and failure is common. The S-Wrap technique is an uncomplicated, feasible and safe PIVC securement dressing for use in high threat/austere pre-hospital settings.

## Background

The insertion of a peripheral intravenous catheter (PIVC, also called a cannula) is one of the most common clinical procedures performed<sup>1</sup>. About 30 million are used in Australia each year, with up to 70% of hospitalised patients requiring a PIVC<sup>2</sup>. However, it

is well documented that PIVCs often fail before the completion of intravenous (IV) treatment<sup>3</sup>, with an incidence as high as 69%<sup>4</sup>. Researchers have shown that this failure is, in part, a result of inadequate stabilisation or securement of the catheter to the skin<sup>3</sup>. Such failure is multifactorial; it may be due to poor initial

cannula securement, failure of dressings to remain adherent due to diaphoresis or, more commonly in a dynamic pre-hospital environment, due to inadvertent traction on an attached IV line. In addition to interruption of IV therapy, poor securement technique increases the risk of phlebitis and infection, and leads to patient pain, dislodgement of the catheter, occlusion or blockage of the catheter<sup>2</sup>.

Intra-osseous (IO) access has become a popular alternative to repeated PIVC access attempts, particularly in the shocked pre-hospital patient<sup>5</sup>. In the pre-hospital or austere setting, IO should be at the forefront of vascular access options because it provides rapid and high technical success, with the ability to administer any drugs and fluids that are traditionally administered via IV<sup>6</sup>. However, whilst success rates and repeatability in IO access is sound, comparison of flow rates between IV and IO is discrepant, with several studies showing that IO flow rates may be limited to approximately 60–100mls/hr, even with pressure applied<sup>7,8</sup>. Comparatively, flow rates for an 18G PIVC averaged approximately 200mls/hr, with up to 450mls/hr with a 16G PIVC<sup>9</sup>. Additionally, while generally safe, IO it is not without limitations, such as pain, inability to aspirate blood, and is associated with small risks of extravasation, compartment syndrome, technical difficulties, displacement and osteomyelitis<sup>10</sup>. Therefore, if rapid IV access is achievable in the pre-hospital environment, this is preferable and facilitates the rapid escalation of resuscitative methods once the patient reaches the next level of care.

Optimal dressing and securement of PIVCs in the pre-hospital setting is a crucial practice strategy to reduce complications and failure; however, variations in practice are widespread<sup>11</sup>. PIVC dressing and securement are two inter-related interventions<sup>4</sup>. A PIVC dressing should cover the insertion site, keeping it clean and dry, be comfortable for the patient and offer protection from external contamination or trauma<sup>12</sup>. Further, PIVCs should be secured to the skin and stabilise the PIVC hub to minimise catheter movement. PIVC dressings should be cost-effective and easy to remove<sup>13</sup>. A recent, secondary analysis of over 40,000 PIVCs revealed that dressing and two-step securement combinations (tape dressing combined with tape or a tubular bandage) – termed ‘methods’ in this study – were significantly associated with decreased catheter site complications compared with a reference combination (simple polyurethane plus non-sterile tape over the dressing<sup>14</sup>. Specifically, these two-step securement approaches were associated with fewer phlebitis symptoms, less bruising, and reduced ‘micro-movement’ of the device within the vein<sup>12</sup>.

PIVC are essential during pre-hospital trauma resuscitation because both civilian and military guidelines recommend administration of blood products, IV fluids and medications<sup>15,16</sup>. However, patient outcomes can be negatively impacted if the PIVC fails before treatment completion<sup>17,18</sup>. Disaster or high

threat conditions such as treating a trauma patient during a domestic terrorist event or in combat pose an even greater risk of accidental PIVC dislodgement (e.g., during extraction via helicopter or movement over rough terrain)<sup>19</sup>. Further, loss of vascular access in these austere settings may delay crucial fluid resuscitation or lead to missed treatment as limited opportunity or limited catheters or trained medics may prevent repeated PIVC insertion attempts<sup>20</sup>.

One way in which the United States (US) military has addressed the dislodgement risk in combat is to develop a securement intervention known as the ruggedised field (Ranger) IV method<sup>21</sup>. Army medics in the Australian Defence Force (ADF) have also developed a novel two-part securement method termed the S-Wrap to reduce the chance of PIVCs being dislodged during casualty evacuation. However, the effectiveness of combat PIVC securement methods remains unclear, and we could find no studies that evaluated cannula securement in the austere, combat or disaster context.

Researching in a disaster or combat setting has numerous inherent risks, including physical harm to researchers, breach of confidentiality, legal action, or psychological discomfort<sup>22</sup>. When real-life situations preclude research opportunities, high fidelity simulations present an alternative option. High fidelity simulations are defined as a healthcare education methodology that involves sophisticated life-like manikins<sup>23</sup>. The ADF conducts high fidelity simulated combat casualty care training, termed tactical combat casualty care (TCCC). The TCCC training is mandated in the ADF for all healthcare professionals (HCPs), including defence medics, paramedics, nurses and physicians; thus, simulated TCCC training in the ADF affords a unique opportunity to evaluate the effectiveness of dressing and securement practices in the austere setting. The aim of this study was to address cannula failure due to inadvertent traction on an attached IV line by comparing the pull-out force of three PIVC securement methods and inform future securement practices.

## Methods

### Study design

A pragmatic *in vitro* design was utilised to compare the dislodgements with the Ranger technique, the S-Wrap technique, and standard PIVC dressings on an attached IV line during TCCC simulations<sup>24</sup>. The assessment of pull-out force was used to determine the effectiveness of each PIVC securement method to prevent cannula dislodgement *in vitro* against a control. This study formed part of the larger multi-method S2C study, and the protocol has previously been published<sup>25</sup>.

### Setting

The study was undertaken at the Australian Army School of Health (ASH) in Victoria, Australia. The ASH has world-class facilities, particularly simulation that affords realistic medical training to support military operations using simulated casualties.

## Intervention (PIVC securement methods)

### Control method

A standard PIVC securement method involved the use of a PIVC (Becton Dickinson [BD] Insite™ Autoguard 18 GA, 1.16 IN 1.3x30mm) and connected IV saline lock (Baxter Clearlink™ Luer Activated Valve) covered with a bordered IV transparent film dressing (3M Tegaderm™ IV 7x8.5cm) (Figure 1).

### Ranger method

This securement method involved the use of PIVC (BD Insite™ Autoguard 18 GA, 1.16 IN 1.3x30mm) and connected IV saline lock (Baxter IV Bung Interlink™ Injection Site) that is established and covered with a bordered polyurethane dressing (Plastod HYPOR Film® 10x12.5cm). The subsequent step used the IV catheter (BD Insite™ Autoguard 18 GA, 1.16 IN 1.3x30mm) inserted through the polyurethane dressing into the Baxter IV Bung Interlink™ Injection Site, leaving the plastic cannula *insitu* and connecting the IV administration tubing (Baxter Clearlink™ Solution Set) to the cannula and securing the line with the Raptor™ IV Securing Device (NA Rescue®). The Raptor IV securing device is a tapeless, secondary securement device that holds IV tubing in place with a secured hook and loop velcro closure (Figure 2).

### S-Wrap method

A PIVC was inserted using the previously described method for the Ranger. The IV administration tubing (Baxter Clearlink™ Solution Set) was connected to the cannula and then looped in an S shape between several layers of non-elastic cotton crepe bandage (BSN Handy Crepe® 10cmx1.5m) secured with 3M Transpore™ Tape 2.5cm (Figure 3).

## Study procedures

The study investigated the pull-out force *in vitro* of two PIVC securement methods against the control (standard care) method. Pull-out force was defined in this study as the tensile force measured in Newtons (N) required to produce PIVC dislodgement or PIVC equipment failure against the different securement methods. PIVC dislodgement was defined as the IV cannulae being partially removed from the vessel. Previous studies and the protocol have recommended pigskin as a surrogate for human skin; however, for pragmatic reasons in this study for comparative testing, each securement method was completed using a MEDIQUIP® Surgical Cut Suit component – sleeve. The Hyper-Realistic™ interchangeable sleeve is used routinely at the ASH in simulation because it benefits training by replicating the look and feel of skin or other wounds in Moulage (mock injuries) to practise actual procedures in the application of combat healthcare.

Under the sleeve was a padded plastic and rubber replica of a muscle. The design team inserted two 0.5mm clear plastic tubing between the muscle and the Hyper-Realistic™ interchangeable

sleeve to simulate vessels that were used for the cannulation. This setup was then positioned on a study team member's upper arm in the cubital fossa area.

Following PIVC securement, the IV administration tubing (Baxter Clearlink™ Solution Set) was connected to the cannula according to the type of securement method. The IV administration tubing was then passed through a purpose-designed and built pulley system that achieved constant angles of 0° or 30° to the positive x-axis (Figure 4). These angles were selected because they attempt to replicate how IV administration tubing may become caught on a fixed object from any angle (e.g., tree branch, stretcher, body armour) in an austere combat setting.

The IV administration tubing was attached to a calibrated handheld digital force gauge (ADM Instruments™ Lutron FG). This is a measuring instrument used across industries to measure the force during a push or pull test and aligns with previous studies examining PIVC dressing securement<sup>17</sup>.

Sixteen PIVCs using the control method were inserted and tested at angles of 0° (eight times) and 30° (eight times) until PIVC dislodgment. Sixteen (eight at each angle) were replicated for the S-Wrap method and again for the Ranger method until PIVC dislodgment or IV equipment failure. The peak force occurring before dislodgment or equipment failure was measured on the digital force gauge and recorded.

A study team member (CW) experienced in cannulation performed the control and the two different securement methods, while another member (BM/BT) of the study team observed their practice to ensure consistency and accuracy. A third study member (DA) performed the pull-out force tests by continuously increasing tension on the catheter securement method at the designated angle through the pulley system. Each item utilised for cannulation and the different securement methods were in date, used only once, and correctly applied as per the manufacturer's instructions.

## Data analysis

The pull-out forces by product and direction of force were presented with means and standard deviations (SD) and on a scatter plots. The null hypothesis of no difference in average force between products was tested using one-way analysis of variance, followed by a post-hoc Bonferroni test. Statistical significance was determined at  $p \leq 0.05$ . Data was using Stata 16 (StataCorp LLC, College Station, Texas, USA).

## Ethics

This study was endorsed by the Australian Army Health Services Working Group, and reviewed by the Departments of Defence and Veterans' Affairs Human Research Ethics Committee (DDVA HREC) and deemed to be an evaluation activity. This study is registered with the Australian New Zealand Clinical Trials Registry, CTRN12621000314820.



Figure 1. Standard IV securement technique



Figure 3. S-Wrap IV securement technique – to preview a full video of this technique, go to: <https://vimeo.com/754161768>

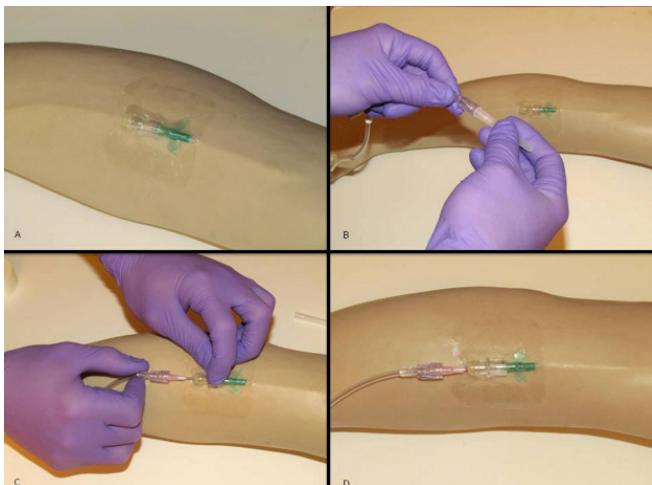


Figure 2. Ranger IV securement technique – to preview a video of this technique, go to: <https://www.youtube.com/watch?v=VP8QMhMGxe8>

## Results

The average pull-out force was lowest using Tegaderm™ (9.7N; SD 2.2) and highest with S-Wrap (66.1N; SD 7.1). The securements provided greater resistance against the pull-out force at 0° compared to 30° (Table 1; Figure 5). The three Bonferroni-adjusted p values for the three null hypotheses between the three products were all <0.001. Dislodgment of the PIVC occurred

using Tegaderm™, while equipment failure occurred consistently with S-Wrap (i.e., line breaking) and Ranger (i.e., second line dislodged) in achieving peak force measurement.

## Discussion

This is the first study to evaluate PIVC securement in a simulated austere, combat context. Of the three methods of securement tested in this study (standard, Ranger, S-Wrap), the S-Wrap method demonstrated a significantly higher pull-out force. Further, our study found that the S-Wrap is reliable, safe and provides a greater securement benefit than the next best alternative, the Ranger approach. Figure 5 demonstrates that, across all angles, the peak force measurement for S-Wrap was over twice as high when compared to Ranger.

Vascular access in the austere or disaster environment is often complex as the environment can be volatile and/or uncertain, which may require prolonged care in the field<sup>26,27</sup>. The integrity of the IV dressing at the site is therefore paramount, regardless of line securement technique. Dressing integrity may be impacted by diaphoresis, haemoserous ooze or leaking IV fluid from the insertion site, as well as rolling or lifting of the dressing edges. A major contributing factor to device failure is inadequate fixation of the PIVC to the patient's skin, causing not just dislodgement but also micromotion, leading to vein irritation

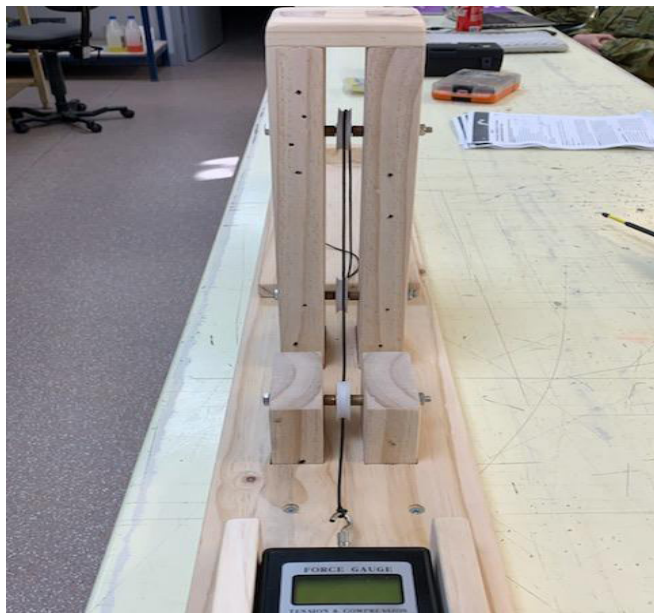


Figure 4. The digital force gauge and pulley system

(phlebitis or occlusion) and entry of skin bacteria into the entry site (infection)<sup>3</sup>.

Establishing the ideal PIVC securement technique is essential to guide formal training for military health practitioners, particularly as consumables (e.g., catheter and dressings), and equipment (e.g., administration sets and IV fluids) are often limited in this setting compared to civilian pre-hospital settings<sup>28</sup>. Military clinicians must optimise their available resources, and our findings demonstrated the S-Wrap technique required minimal

stock and was therefore more effective at preventing PIVC dislodgement compared to a transparent dressing (standard care) and PIVCs secured with the Ranger approach.

In the austere/tactical and pre-hospital setting there has been support to secure PIVC using the Ranger approach<sup>29</sup>. However, in 2014 an observational study highlighted that using the Ranger securement system can significantly delay fluid bolus administration rates, which could potentially delay resuscitation efforts<sup>21</sup>. Haemorrhage from the injured extremity is the primary cause of preventable death in military settings, and TCCC guidelines advocate for the rapid delivery of IV fluid for the hypovolaemic trauma patient in the tactical environment<sup>21,30</sup>. In these dynamic environments, IO access provides an effective vascular access alternative to PIVC<sup>6</sup>. However, with discordant flow rates between IV and IO access, if IV access is rapidly achieved it is preferable for resuscitation, and requires appropriate securement<sup>7,31-33</sup>.

In the austere/tactical setting military medics, nurses and physicians must feel confident that the PIVC securement approach they employ can withstand the additional demands

Table 1. Descriptive statistics of pull-out force outcomes by product

Angle	No. tests	Force in N (SD)		
		Tegaderm™	Ranger	S-Wrap
0°	8	11.8 (4.1)	34.7 (10.0)	68.2 (9.3)
30°	8	7.5 (2.2)	15.7 (6.6)	64.0 (11.2)
Average	8	9.7 (2.2)	25.2 (3.9)	66.1 (7.1)

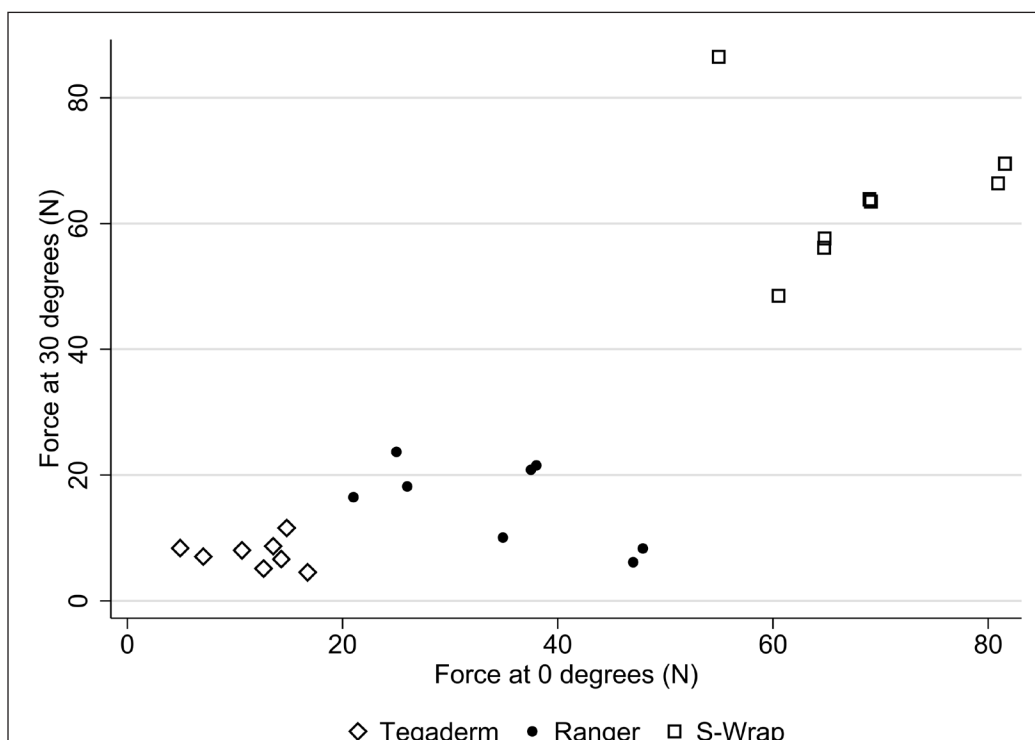


Figure 5. Results of pull-out forces by product

that these dynamic environments realise<sup>28</sup>. The findings from this study will inform military medical training and pre-hospital emergency care, and ensure best PIVC dressing and securement practices are embedded into future training to reduce catheter failure and any resultant patient harm.

## Strengths and limitations

A limitation to this study was that the use of a simulated setting may not adequately represent a real-life disaster or combat setting. However, high-fidelity simulations afford a pragmatic alternative option. In addition, the pragmatic nature of this study meant that dressings and securements were only attached for a short period of time before the pulling force was applied. Therefore, the PIVC site (e.g., cubital fossa, hand) and the effects of soiling, sweat, blood or moisture were not taken into account. Further, the impact of different dressing options on IV flow rates was beyond the scope of this study. The acceptability of the S-Wrap method was also not explored; however, this study formed part of larger mixed method study, and phase two aims to explore the real-world experiences of PIVC insertion and securement practices of ADF members during TCCC<sup>25</sup>.

## Conclusion

PIVC securement is challenging in the austere or combat setting. The increasing use of damage control resuscitation in combat and austere settings has mandated the need for reliable, secure IV access. The initial step of a secure adherent dressing on the skin at the cannula entry site remains paramount. Results from this study support the use of the S-Wrap technique to augment the initial dressing and prevent PIVC dislodgement. Further research, including clinical trials, is needed to establish the benefit of the S-Wrap for preventing other PIVC complications including occlusion and infiltration.

## Author contribution

BM, CW, DA, BT: manuscript write-up and collection of data. GM, JD, GW: manuscript write-up and data synthesis. GM, JD, GW: manuscript write-up and study supervisors.

## Disclaimer

The views expressed in this presentation are those of the author(s) and do not necessarily reflect the official policy of the ADF or ASH. The use of trademark names do not imply endorsement by the ADF but is intended only to assist in the identification of a specific product.

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## Conflict of interest

NM: Griffith University and the University of Queensland have received on her behalf speaker fees from 3M and investigator-initiated research grants from 3M, Becton Dickinson, Eloquest and Cardinal Health, unrelated to the current project.

GRB: reports consultancy payments provided to her previous employer (Griffith University) by product manufacturers (3M, Becton Dickinson) and education providers (Ausmed, Wolters Kluwer, Continulus), unrelated to this project.

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