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ORIGINAL RESEARCH

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Go with the flow: An experimental analysis with tubing alternative with irrigation

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Abstract

Background and Aims: Literature regarding alternative tubing for fluid delivery in irrigation and debridement procedures is lacking. The purpose of this study was to compare three different apparatuses with varying quantities of irrigation fluid to assess efficiency of administration and evaluate overall time for fluid administration.

Methods: This model was designed to compare available methods of gravity irrigation used in practice. Fluid flow time was measured for three types of tubing: single-lumen cystoscopy tubing, Y-type double-lumen cystoscopy tubing, and nonconductive suction tubing. Irrigation times were assessed for varying volumes of 3, 6, and 9 L to investigate the relationship between bag changes and irrigation time. Bag changes were not conducted for the 3 L trial, but were for 6 and 9 L trials. Dimensions of cystoscopy tubing consisted of 4.95 mm internal diameter and 2.1 m length in both single-lumen and Y-type double-lumen apparatus. Nonconduction suction tubing dimensions were 6.0 mm internal diameter and standard 3.7 m in length.

Results: The mean flow time for suction tubing was significantly faster than the cystoscopy tubing for the 3 and 9 L trials ($p < 0.001$). At 6 L, flow time for the suction tubing and the double lumen cystoscopy tubing were similar, 264 versus 260 s, respectively. At 9 L, the mean flow time for the suction tubing was 80 s faster (410 vs. 491 s) compared with single-lumen cystoscopy and was nearly 30 s faster compared with Y-type cystoscopy tubing.

Conclusion: The results of this study provide insight into a faster, widely available, and cost-efficient alternative to commonly used cystoscopy tubing.

KEYWORDS
debridement, flow, fluid, Irrigation, tubing

1 | INTRODUCTION

Wound irrigation serves a vital role in the management of open fractures and is critical in decreasing the bacterial load, which can ultimately have major impacts on patient outcomes.[1–3] There are many factors that are out of the surgeon's control when dealing with trauma injuries, but initial surgical wound management may be the most important single factor within the provider's control.[1] Historically, it has been recommended that patients with open fractures be taken to the operating room within 6 h for irrigation and debridement to reduce the risk of infection.[4] More recently, studies show the important of early antibiotic administration; however, the importance of irrigation and debridement cannot be discarded.[5–7] Surgeon preference as to what they choose to irrigate wounds may vary from provider to provider. Different factors to consider such as type of irrigation solution, tubing, height of bag solution, staff availability to exchange bags, all become pertinent in the efficiency of care in open traumatic orthopedic wounds. Current literature has evaluated varying methods of irrigation including the use of antiseptic solutions, flow velocity, and fluid volume.[1,8–10]

The Fluid Lavage of Open Wounds (FLOW) trial was integral in describing acceptable pressure variation and irrigant composition.[8] This trial consisted of 2447 patients demonstrated no significant difference in very low-, low-, or high-pressure irrigation. Additionally, it demonstrated improved outcomes with the use of normal saline in comparison to castile soap solution.[8] Along the same lines, antibiotic solutions have exhibited no advantage in decreasing infection rates when compared with nonsterile soap solutions and pose potential issues with wound healing.[1,9–11] Therefore, clinical evidence supports the discontinuation of antibiotic or surfactant containing solutions in favor of normal saline and sterile water.[12] The recommended amount of irrigant for irrigation in open fracture care typically increases with the severity of injury and the amount of contamination.[13] Anglen recommended a systematic increase in irrigation volume according to Gustilo classification I, II, IIIA-C with 3, 6, and 9 L, respectively.[1,14] Although popularized in the trauma community, there is little outcome data supporting specified amounts of irrigation.[13,14]

Irrigation can be administered with either bulb syringe and suction, gravity-administered fluid, or pulse lavage.[8] It is often difficult to efficiently administer large amounts of irrigant to open wounds with the use of bulb syringes. Due to this, often gravity administered, or pulsed lavage is used. One of the main points of discussion between nonpulsed and pulsed lavage is the impact on soft tissues.[15] Pulsed lavage systems introduce irrigation to the wound at 50–80 pounds per square inch.[16] Proponents of pulse lavage argue it is more effective in overall bacterial clearance and can assist in the clearance of unwanted debris.[17,18] Due to the high-pressure nature, it has been found that these systems interfere with bone healing and ultimately cause the damage to soft tissue and osseous structures.[1,19–21] Additionally, high-pressure systems and introduce unwanted bacteria deeper into the soft tissues.[22] To avoid undesirable damage to the tissues, gravity irrigation is often recommended in the management of open fractures.[1,8,15,19–23]

One factor that can influence the rate of irrigant demonstrated to the wound in open fracture surgery in the height of the bag in gravity-administered fluid. This can be simply explained by the gravitation pull on the water; however, Mundy et al. showed faster emptying of irrigant for gravity-administered fluid compared with pulse lavage at increasing hanging height.[24] Along the same lines, Muscatelli et al. described a decrease in flow time with increasing height.[25] It is recommended that the highest possible position of bag height be used to help administer the fluid.[24,25]

Currently, cystoscopy tubing is the most commonly used gravity irrigation method to deliver the irrigant to the wound.[25] There is a paucity of literature evaluating alternative gravity pressure methods.[25] The purpose of this study is to compare alternative methods of wound irrigation to the current standards. The hypothesis is that wider diameter tubing will provide a decreased flow time for a constant fluid volume at a specified height.

2 | METHODS

This ex-vivo study was designed to compare flow time for commonly available methods of gravity irrigation in an experimental setup, mimicking their typical clinical application. Fluid flow time was measured for three different types of tubing. Cystoscopy tubing with standard 4.95 mm internal diameter and 2.1 m length in both single lumen and Y-type TUR/bladder irrigation double lumen (Baxter International) was used. The third delivery method consisted of 6.0 mm internal diameter and standard 3.7 m length, nonconductive suction tubing (Cardinal Health). This type of tubing typically is used for suction. Fluid reservoirs consisted of 3 L bags of normal saline solution (Baxter International). Cystoscopy tubing include a plastic spike to allow connection with fluid bags. A bag decanter (Advance Medical Design) was utilized to connect suction tubing to saline bag reservoirs.

Bag height has been shown to affect fluid flow rates; therefore, both bag height and fluid delivery height were standardized in this study.[24,25] Stryker Neptune 3 (Stryker) suction devices include an intravenous pole, which can be raised to a maximum height of approximately 259 cm. This height was utilized for all fluid bags. The delivery height of tubing apparatuses was set at 81.2 cm (32 inches) from the ground as to approximate the height of a typical OSI Jackson table at its lowest setting, resulting in 178 cm between the base of the saline bag and the fluid delivery location. The Neptune IV pole was positioned at 91.4 cm (36 inches) from the fluid delivery point to mimic a typical clinical scenario (Figures 1 and 2). Irrigation times, utilizing stopwatches manually monitored, were assessed for varying volumes of 3, 6, and 9 L to investigate the relationship between bag changes and irrigation time. Bag-changing techniques were performed by the authors involved for the 6 and 9 L legs of the trial by lowering the Neptune IV pole down completely, removing the empty saline bag, replacing with a new saline bag, and subsequently raising the IV pole again before continuation of the simulated irrigation.

Seven trials were performed for each variable, creating a 3 × 3 design (three volumes for single lumen cystoscopy tubing, Y-type cystoscopy tubing, and suction tubing) for a total of 63 data points. New bags of fluid were utilized for each trial. Refilling of bags was avoided to eliminate concern for inequitable fluid volumes. Time required to lower the IV pole, change bags, and raise the IV pole again was recorded for all trials involving multiple bags of saline. During bag changes, tubing was clamped until the newly connected bag was raised to maximum height on the IV pole and then the bag was unclamped. This was done by a single investigator. Run time began when the fluid first exited the end of the tubing and stopped as soon as the fluid stopped exiting the tubing.

FIGURE 1 Simulation setup for irrigation trials consisting of canisters set at appropriate height to simulate patient height on flat top operating table and Stryker Neptune IV pole at a set height and distance from the canister.

$$Q = \frac{\pi P r^4}{8\eta l}$$

FIGURE 2 The Hagen–Poiseuille equation for laminar flow. Q, flow; P, pressure drop along the tube; r, radius of the tube; η, viscosity of the fluid; l, length of the tube.

Statistical analysis was performed using Microsoft Excel software (Microsoft). The flow times were summarized for each irrigation method and volume using means and 95% confidence intervals. Standard deviations were calculated. Analysis of variance (ANOVA) tests were performed to compare the mean flow times between irrigation methods for each volume. Independent sample student's t tests were utilized for comparisons across continuous variables. Significance was set at $p < 0.050$ a prior.

3 | RESULTS

The mean flow times for each of the seven trials are listed in Table 1. Volume trials consisting of 3 L demonstrated a significant effect for tubing type. When assessing single-lumen cystoscopy, double-lumen cystoscopy, and suction tubing in the 3 L group, there were statistically significant differences, with suction tubing shown to be 25 s faster. Flow times for single-lumen cystoscopy tubing, Y-type cystoscopy tubing, and suction tubing were significantly different from each other ($p < 0.001$). Of note, there were no bag changes for the 3 L saline bags during this part of the trial.

Comparison of larger volumes (6 and 9 L) weighed two competing variables against one another: larger-diameter tubing and bag change time. Table 2 demonstrates the bag change times for each of the trials. A mean time of 36 s was required for bag changes, averaged across all trials. Trials of 6 L required bag changes for only single-lumen cystoscopy tubing and suction tubing apparatuses; the Y-type lumen cystoscopy tubing did not require a bag change. At 6 L trials, the Y-type cystoscopy tubing was an average of 4.01 s faster than the single-lumen suction tubing. Single-lumen cystoscopy was significantly slower than both alternatives ($p < 0.001$); however, there was no statistically significant difference between Y-type cystoscopy tubing and suction tubing ($p = 0.017$). When the timing of the bag change is removed for the flow time, the suction tubing delivers the irrigant faster than the cystoscopy tubing as demonstrated in Table 3.

Trials with 9 L of fluid volume demonstrated statistically significant differences for all irrigation methods ($p < 0.001$). Once

TABLE 1 Mean total flow times listed in seconds for each of the seven trials for the respective volumes.

Apparatus	3 L	6 L	9 L
Single-lumen cystoscopy tubing	140.14 s ± 0.90 (139–142)	322.12 s ± 1.86 (320–325)	491.57 s ± 2.34 (488–491)
Double-lumen cystoscopy	131.57 s ± 1.62 (129–134)	260.86 s ± 1.95 (257–263)	438.43 s ± 3.69 (434–444)
Nonconductive suction tubing	115.43 s ± 2.37 (112–120)	264.86 s ± 3.29 (261–271)	410.00 s ± 7.26 (400–418)

Note: Noncategorical variables are given as mean values ± standard deviations, with ranges in parentheses.

TABLE 2 Mean bag change times for each of the seven trials for the respective volumes, listed in seconds.

Apparatus	3 L	6 L	9 L
Single-lumen cystoscopy tubing	N/A	36.29 s	65.43 s
Double-lumen cystoscopy	N/A	N/A	34.71 s
Nonconductive suction tubing	N/A	36.00 s	66.29 s

TABLE 3 Mean flow times for each of the seven trials with timing for bag change removed, listed in seconds.

Apparatus	3 L	6 L	9 L
Single-lumen cystoscopy tubing	140.14 s	285.83 s	426.14 s
Double-lumen cystoscopy	131.57 s	260.86 s	403.72 s
Nonconductive suction tubing	115.43 s	228.86 s	343.71 s

again, it is important to note that these trials involved two bag changes for single-lumen cystoscopy tubing and suction tubing, while only requiring a single bag change for Y-type cystoscopy tubing. Bag change time can be seen in Table 2. Independent sample t-tests were calculated to assess the differences between individual apparatuses. Flow times for 9 L trials demonstrated statistically significant differences for all irrigation methods ($p < 0.001$). There was a significant difference between the single lumen and double lumen at a ($p < 0.001$). Additionally, between the single-lumen cystoscopy tubing and suction tubing, and between the double-lumen cystoscopy and the suction tubing there were significant differences with $p < 0.001$ in both cases.

4 | DISCUSSION

This experimental study demonstrates a good alternative tubing to the traditional cystoscopy tubing for irrigation and debridement procedures for open fracture care. The potential benefit of using nonconductive suction tubing as the preferred tubing during over the use of cystoscopy tubing is most pronounced for procedures when compared with single-lumen cystoscopy tubing. Y-type cystoscopy tubing showed comparable results to suction tubing if 6 L of fluid is planned.

The Hagen–Poiseulle equation governs the modern concept of fluid dynamics and laminar flow (Figure 2). In accordance with this law, flow velocity of a liquid within a confined tube should proportionately increase as the tube diameter expands (to the fourth power). This is likely much of the reason that the suction tube was found to be faster than the cystoscopy tubing. Suction tubing was shown to have the fastest flow time for both 3 and 9 L irrigation volumes; however, Y-type cystoscopy tubing was faster for 6 L trials. This is due to the suction tubing having to undergo a bag change. If the bag change time is not recorded, then the suction tubing delivers the irrigant much faster compared with the cystoscopy tubing (Table 3).

While this methodology has been validated countless times in perfectly controlled experimental models, it cannot be seen as a rigid mandate for how we understand the irrigation methods of this study. First, the apparatuses used in this study are not all simple tubes; the Y-type cystoscopy tubing joins two fluid sources, resulting in a potential bottle-neck effect. In addition, the concept of bag changes introduces a truly significant variable when contemplating which irrigation method may be preferred. In a clinical setting, staff having to retrieve additional saline bags for continuous irrigation at surgeon preference would invariably add more time to the overall procedure. This was not taken in account during this study analysis as this was a controlled environment with the needed materials in the same room.

This experimental study reflects the time required for bag changes in an ideal scenario, but it cannot account for a busy circulating nurse who may not be immediately available to perform this duty. An investigation comparing irrigation methods using the uncommonly available 5-L fluid bags would be interesting to pursue to extrapolate flow time differences across a larger volume without bag changes. This would likely produce similar results to the data seen in Table 3, where the bag change times are removed.

This is the first known study to quantify flow times for three gravity-administered tubing. The FLOW trial definitively championed gravity pressure lavage as the superior method of fluid delivery in open fractures.[8] There is currently a paucity in literature regarding gravity irrigation methods since the FLOW trial. Muscatelli et al. compared pulsatile lavage, Y-type cystoscopy tubing and nonconductive tubing using a proprietary connective device at varying fluid source heights.[25] Their findings supported faster flow rates with higher fluid source heights and larger diameter tubing. While the data from Muscatelli et al. supports the benefits of further investigating alternative, larger-diameter tubing, the proprietary connective attachment used in their study is not widely available in all facilities. In contrast, this study utilized nonconductive suction tubing along with a standard bag decanter, both of which are widely available in hospitals.

Irrigation methods can greatly affect the outcome of open fracture treatments. Decreasing operative time is known to correlate to decreased complication rates, anesthetic risks, and recovery time. In this study, using suction tubing compared with single-lumen cystoscopy tubing saved an average of 80 s (410 compared with 491) when using 9 L of irrigation. Along the same lines, suction tubing took nearly 30 s less to deliver 9 L to the surgical field when compared with Y-type cystoscopy tubing, with an additional bag change. It is well known that increased operative times can lead to increased complications.[26] Longer operative times have been associated with higher readmission rates, higher reoperation rates, increased surgical site infections, wound dehiscence, and need for postoperative blood transfusion.[27] While this may seem miniscule for a single procedure, over time the benefits can add up at a large trauma center where these procedures are routinely performed.

The economic effects are also important to consider. A more efficient operation leads to decreased anesthesia costs, decreased staff costs, and higher patient throughput. At the facility of the senior author, the prices for each irrigation method were evaluated. Single-lumen cystoscopy tubing costs $4.58, Y-type cystoscopy tubing costs $9.62, and suction tubing and decanter costs a combined $1.62. With all factors considered, suction tubing provides a tremendous benefit as an irrigation method. A formal cost analysis would be beneficial in quantifying a system-wide effect, considering the fact that irrigation is extremely common procedure in most trauma centers. However, a cost analysis was beyond the scope of this study.

There are limitations to this study. Trials were conducted in a simulated environment and did not include clinical wounds on patients, but instead were simulated using approximate heights and distances. Bag changes in this study were performed immediately and in an efficient manner, which may not always be the case in a busy operating room. Additionally, the tubing was held in the same place and there was no movement, while throughout an actual irrigation and debridement procedure the lumen of the tube will be moved over the wound. Lastly, there is the nature of human error in relation to the timing; however, this is likely reduced by multiple trials with very little difference between times. Human interobserver effect is one of greatest limitations as described in conjunction with variability of institution resource availability, protocols. Clinical relevance may be criticized as multiple factors could ultimately lead to longer procedural times such as wound size, degree of wound contamination, and extent of debridement. However, in spite of these clinical ramifications, the current analysis attempts to provide an objective comparison between irrigation alternatives to negate these variables. The choice of tubing may also be criticized as clinically irrelevant as long as the saline bags are elevated to maximum height on IV pole, the number of needed bags are readily available in the operating room suite, and staff is nearby for quick and efficient bag changes.

In conclusion, gravity irrigation is known to be the safest and most efficient method of irrigation in open fracture management. This study demonstrates the use of nonconducting suction tubing as an alternative to cystoscopy tubing for irrigation and debridement procedures can be beneficial. It can lead to a reduction in operating room times and can also be cost-effective, as cost has become more of a priority in assessing financial burden in the healthcare community. Future cost analyses would be beneficial to further quantify implications depending on apparatuses used. Overall, the authors recommend to use of nonconducting suction tubing as the primary tubing in irrigation procedures for open fractures to provide a faster, widely available, and more cost-efficient alternative to commonly used cystoscopy tubing.

AUTHOR CONTRIBUTIONS

Scott S. Hyland: Data curation; formal analysis; investigation; methodology; writing—original draft. **Daniel T. DeGenova**: Data curation; investigation; methodology; writing—original draft. **Joseph P. Scheschuk**: Conceptualization; supervision; writing—review and editing. **Benjamin C. Taylor**: Supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

All authors have read and approved the final version of the manuscript, Scott S. Hyland, the corresponding author had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

The lead author Scott S. Hyland affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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