RECONSTRUCTIVE

Optimal Use of Surgical Drains: Evidence-Based Strategies

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Background: Closed-suction drains are widely used to reduce the incidence of seroma whenever potential spaces are surgically created. However, few studies have examined the parameters that affect drain efficacy.

Methods: An in vitro model was created to assess the effects of tubing length, tubing size, tubing type, fluid viscosity, fluid clotting, evacuator type, evacuator squeeze method, evacuator fill, and evacuator pressure on the performance of closed-suction drains.

Results: Fluid flow rate through the drain increases with increasing intracavitary tubing length, decreasing extracavitary tubing length, increasing tubing diameter, increasing negative pressure, decreasing fluid viscosity, and the use of perforated rather than fluted drains. Bulbs generate more effective suction when squeezed "side-to-side" than when squeezed "bottom-up," and evacuators were only able to generate half the maximal negative pressure when 25 percent full or greater. Stripping the drain tubing helped relieve obstruction caused by clotting.

Conclusions: The authors' findings have practical clinical implications for surgeons hoping to maximize the efficacy of closed-suction drains. Through this comprehensive review of the literature and in vitro analysis of relevant variables that affect drain function, the performance of closed-suction drains can be optimized by increasing intracavitary tubing length, decreasing extracavitary tubing length, increasing tubing diameter, increasing the pressure differential, using perforated drains, squeezing bulbs side-to-side, stripping drain tubing frequently, and evacuating containers whenever they are 25 percent full. (*Plast. Reconstr. Surg.* 141: 1542, 2018.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, V.

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THERAPEUTIC

Closed-suction drains play an essential role when large potential spaces are surgically created. In a surgical drain, the evacuator generates a negative pressure, which is transmitted by the tubing into the surgical cavity, which permits fluid evacuation, close apposition of tissue planes, and adherence.

A systematic review of seroma prevention when potential spaces are surgically created has demonstrated that drains reduce seroma formation.[1–3] It also demonstrated that drains removed on the basis of volume-dependent criteria rather than time-dependent criteria were more effective.[1] High negative drain pressure was found to be more effective at preventing seromas than low negative pressure, which highlights the fact that, for surgical drains to function properly, the negative pressure generated needs to be sufficient to ensure tissue plane apposition and to overcome fluid viscosity, which can impair fluid egress. According to the Hagen-Poiseuille equation, flow through a tube would be expected to follow the following equation:

$$Flow\ rate = \frac{\pi \times (pressure\ difference) \times (tube\ radius)^4}{8 \times (fluid\ viscosity) \times (tube\ length)}$$

with the pressure difference representing the difference between the two ends of the tube. In

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the case of a surgical drain, this pressure difference would be the negative pressure generated by the evacuator.

Few studies on optimizing parameters in surgical drains have been performed. Swartz et al. compared the flow rate achieved by flat and round Jackson-Pratt drains, qualitatively simulating various fluid viscosities using different types of soup, without actually measuring viscosity quantitatively.[4] They found that, using the highest fluid viscosity, the round drain was more efficient than the flat drain. Whitson et al. compared the negative pressure generated by four different types of bulbs.[5] They found that the Surgidyne (Aspen Surgical, Caledonia, Mich.) 100-cc bulb generated the highest amount of negative pressure, followed by the Jackson-Pratt 100-cc bulb (Cardinal Health, Dublin, Ohio), the Jackson-Pratt 400-cc bulb, and the HemoVac 400-cc evacuator (Zimmer Surgical, Dover, Ohio). They also found that most drain bulbs cannot generate adequate suction once they are approximately 50 percent full. Similar to the study by Whitson et al., Carruthers et al. also demonstrated that evacuators cannot generate adequate negative pressure once they are approximately 50 percent full.[6] They found that the 100-cc Jackson-Pratt bulb generated more initial negative pressure than the 400-cc Jackson-Pratt bulb (−117.6 mmHg versus −71.4 mmHg). Most importantly, they demonstrated that squeezing the bulb “bottom-up” rather than “side-to-side” generated no measurable negative pressure. Grobmyer et al. demonstrated that stripping drain tubing significantly increased the amount of negative pressure generated by the Jackson-Pratt bulb.[7] Williams et al. found that drain suction decreased by half when the drain was 25 percent full.[8]

Each of these studied evaluated the effect of one or two variables on drain function. No study to date has evaluated the effects of drain size, tubing length, or quantitative fluid viscosity. Our purpose in this study was to perform a comprehensive analysis of all factors affecting the function of surgical drains. By performing one large in vitro study in which each variable is controlled independently, we hope to be able to paint a clear picture of how to optimize drain performance. Our hypotheses were the following:

1. That fluid flow rate would increase with longer drain tubing inside the body cavity, larger tube diameter, and stronger negative pressure.
2. That fluid flow rate would decrease with longer drain tubing outside the body cavity, higher fluid viscosity, and more drain tube clotting.
3. That fluid flow rate would be unaffected by drain tube type and evacuator type.
4. That pressure generated would be unaffected by evacuator type.
5. That pressure generated would decrease when the drain bulb was squeezed bottom-up, and when the drain bulb was 50 percent full.

MATERIALS AND METHODS

An in vitro model was constructed, consisting of a fluid container, with an opening for a closed suction drain to pass into the container. The external end of the closed suction drain was connected to a drain bulb. The weight of fluid in the bulb was measured using a tared digital scale. To determine the fluid flow rate into the bulb, the following formula was used:

$$\mathit{Flow\,rate}\ (ml/\mathrm{sec}) = \frac{\mathit{Fluid\,volume}(ml)}{\mathit{Time}\ (\mathrm{sec})} = \frac{\mathit{Fluid\,weight}(g)}{\mathit{Fluid\,density}\ (g/ml)\times \mathit{Time}\ (\mathrm{sec})}$$

To determine the pressure generated by the bulb, a digital manometer was applied to the bulb-emptying port. A diagram of the experimental setup is shown in Figure 1. Variables that were studied were as follows:

1. Intracavitary drain tube length (length of drain tubing inside the fluid container): Repeated measurements were performed with intracavitary drain lengths of 25, 15, and 5 cm.
2. Extracavitary drain tube length (length of drain tubing outside the fluid container): Repeated measurements were performed with extracavitary drain lengths of 70, 50, and 30 cm.
3. Drain tube size: Repeated measurements were performed with drain tube sizes of 10, 15, and 19 French.
4. Fluid viscosity: Four sets of fluids of different viscosities were produced by mixing distilled water with a starch-based fluid thickener. Fluid dynamic viscosities were 1, 2, 4, and 5.5 cP (centipoise). These dynamic viscosities were selected to encompass the common range of physiologic fluids. For reference, the dynamic viscosity of distilled water is 1 cp, and the dynamic viscosity of pure blood ranges between 4.7 and 5.4 cP, depending on gender and hydration status.[9] Fluid

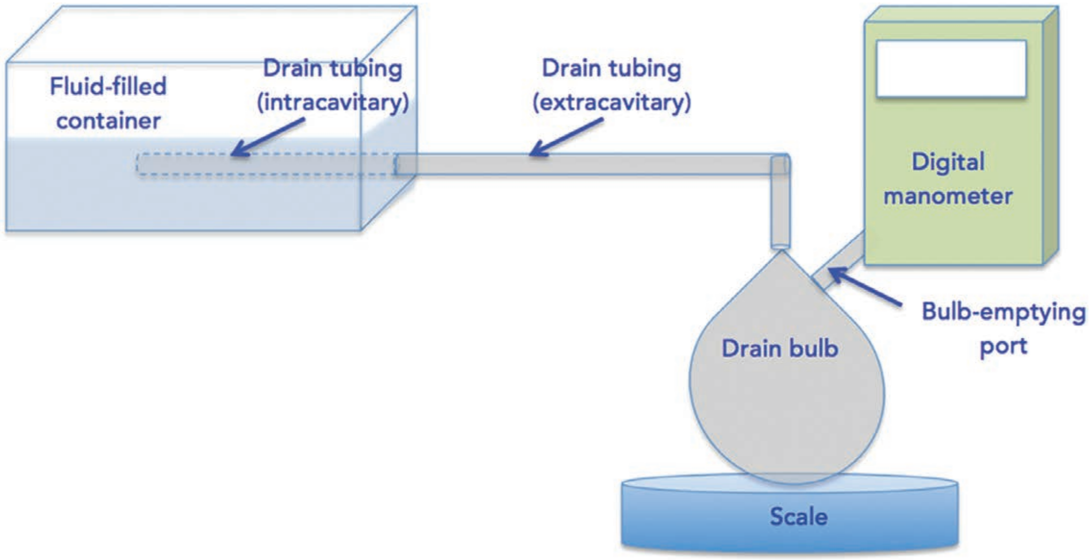

Fig. 1. Diagram of the experimental setup.

viscosities were measured using a glass capillary Cannon-Fenske viscometer (Cannon Instrument Company, State College, Pa.).

5. Drain tube type: Repeated measurements were performed with silicone round fluted-channel drain tubes and silicone flat perforated drain tubes.
6. Clotting: For the perforated drain tubes, glue was used to occlude 25, 50, or 75 percent of the perforations, or the drain tubing itself. For the fluted drain tubes, glue was used to occlude 25, 50, or 75 percent of the flutes, or the drain tubing itself.
7. Evacuator type: Repeated pressure measurements were performed with 100-cc silicone Jackson-Pratt bulbs, 400-cc silicone bulbs (Cardinal Health), and 400-cc three-spring evacuators (Zimmer Biomet, Warsaw, Ind.).
8. Evacuator squeeze method (for Jackson-Pratt bulbs only): Repeated pressure measurements were performed with the bulbs squeezed side-to-side versus bottom-up.
9. Evacuator fill: Repeated pressure measurements were performed with each evacuator empty or 25 percent filled with fluid.
10. Pressure versus flow: Fluid flow rate was measured at different evacuator negative pressures.

For each variable, 50 distinct measurements were made to obtain sufficient power. The effect of each variable was then evaluated using the t test, with values of $p < 0.05$ representing statistical significance.

RESULTS

Intracavitary Drain Tube Length

We found that when the intracavitary drain tube length decreased from 25 cm to 15 cm, fluid flow rate decreased by 6.60 percent ($p = 0.05$). Between 15 and 5 cm, fluid flow rate did not change. Overall, between 25 and 5 cm, the fluid flow rate decreased by 6.60 percent ($p = 0.05$) (Fig. 2, *above, left*).

Extracavitary Drain Tube Length

We found that when the extracavitary drain tube length decreased from 70 cm to 50 cm, fluid flow rate increased by 12.4 percent ($p = 0.13$). Between 50 and 30 cm, fluid flow rate increased by 5.40 percent ($p = 0.1$). Between 30 and 15 cm, fluid flow rate increased by 18.7 percent ($p = 0.005$). Overall, decreasing the extracavitary drain tube length from 70 cm to 15 cm increased the fluid flow rate by 40.6 percent ($p < 0.001$) (Fig. 2, *above, right*).

Drain Tube Diameter

We found that when the drain tube diameter increased from 10 French to 15 French, the fluid flow rate increased by 124 percent ($p < 0.001$). Between the 15- and 19-French drain tubes, the fluid flow rate increased by 61.0 percent ($p < 0.001$). Overall, between the 10- and 19-French drain tubes, the fluid flow rate increased by 260 percent ($p < 0.001$) (Fig. 2, *center, left*).

Fluid Viscosity

When viscosity increased from 1 cP to 2 cP, fluid flow rate decreased by 17.3 percent

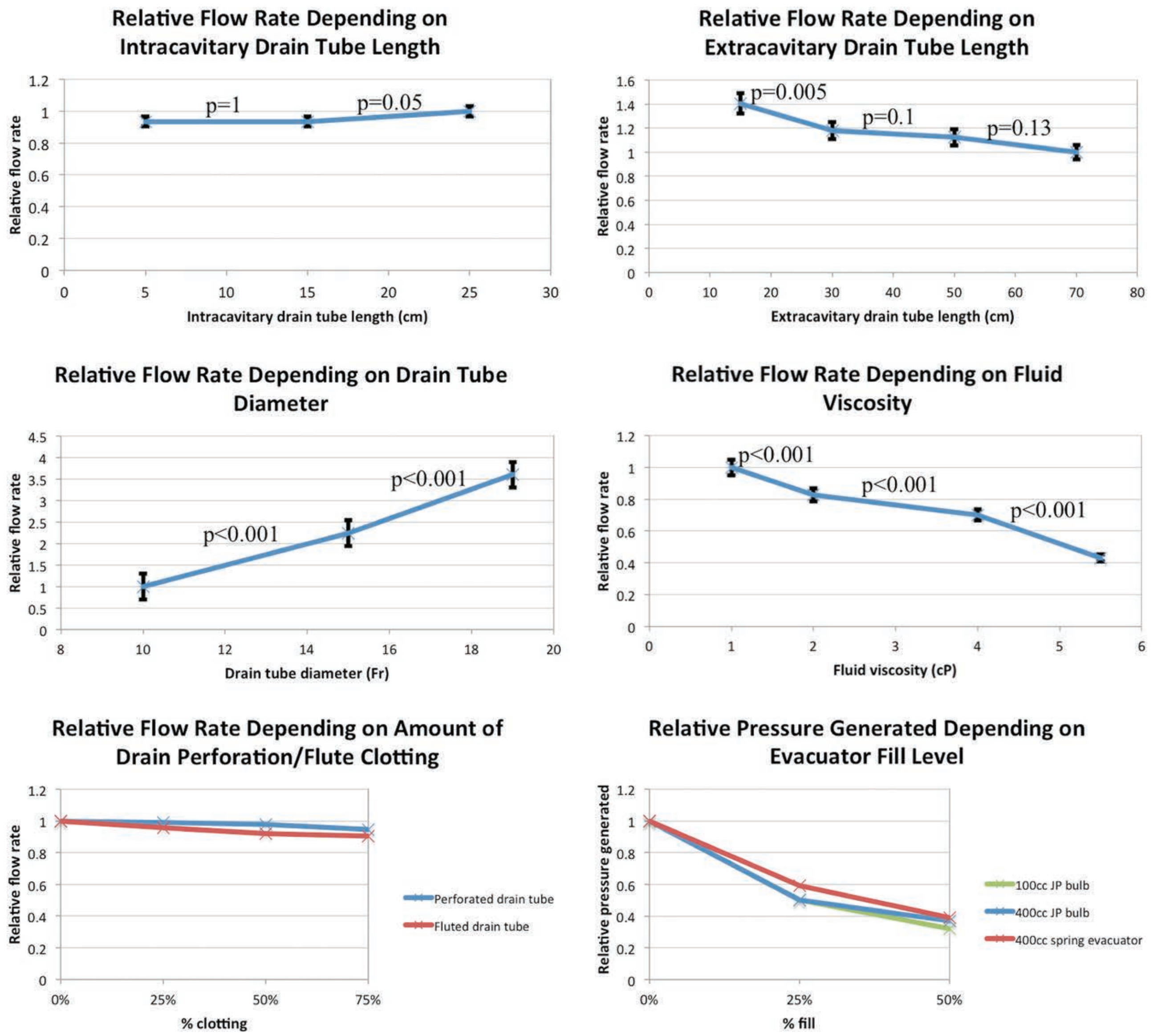

Fig. 2. (*Above*, *left*) Relative flow rate depending on intracavitary drain tube length. (*Above*, *right*) Relative flow rate depending on extracavitary drain tube length. (*Center*, *left*) Relative flow rate depending on drain tube diameter. (*Center*, *right*) Relative flow rate depending on fluid viscosity. (*Below*, *left*) Relative flow rate depending on amount of drain perforation/flute clotting. (*Below*, *right*) Relative pressure generated depending on evacuator fill level. *JP*, Jackson-Pratt.

($p < 0.001$). Between 2 and 4 cP, fluid flow rate decreased by 15.2 percent ($p < 0.001$). Between 4 and 5.5 cP, fluid flow rate decreased by 16.3 percent ($p < 0.001$). Overall, when viscosity increased from 1 cP to 5.5 cP, fluid flow rate decreased by 56.9 percent ($p < 0.001$) (Fig. 2, *center*, *right*).

Drain Tube Type

We found that, among drain tubes of the same size, perforated drains had a 22.5 percent higher flow rate than fluted drains ($p < 0.001$).

Clotting

For the fluted drains, as clotting increased from 0 percent to 25 percent of the flutes, fluid flow rate decreased by 4.20 percent. Between 25 and 50 percent clotting, fluid flow rate decreased by 4.00 percent. Between 50 and 75 percent clotting, fluid flow rate decreased by 1.00 percent. Overall, when clotting increased from 0 percent to 75 percent of the flutes, fluid flow rate decreased by 9.50 percent.

For the perforated drains, as clotting increased from 0 percent to 25 percent of the perforations, fluid flow rate decreased by 1.10 percent.

Between 25 and 50 percent clotting, fluid flow rate decreased by 1.30 percent. Between 50 and 75 percent clotting, fluid flow rate decreased by 2.90 percent. Overall, when clotting increased from 0 percent to 75 percent of the perforations, fluid flow rate decreased by 5.40 percent (Fig. 2, *below, left*).

When the drain tubing itself was occluded with glue, there was no flow in any drain. Flow could only be reinstated when the occlusion was moved into the bulb using drain stripping.

Drain Evacuator Type

The spring evacuator generated the weakest initial negative pressure (−91.3 mmHg), followed by the 100-cc Jackson-Pratt bulb (−111.6 mmHg; $p = 0.05$) and the 400-cc Jackson-Pratt bulb (−112.2 mmHg; $p = 0.01$ versus spring evacuator, $p = 0.5$ versus 100-cc Jackson-Pratt bulb).

Evacuator Squeeze Method

For the 100-cc Jackson-Pratt bulb, we found that squeezing the bulb bottom-up generated significantly weaker negative pressure than squeezing it side-to-side (−3.00 mmHg versus −111.6 mmHg; $p < 0.001$). Similarly, for the 400-cc Jackson-Pratt bulb, squeezing the bulb bottom-up generated significantly weaker negative pressure than squeezing it side-to-side (−31.0 mmHg versus −112.2 mmHg; $p < 0.001$).

Evacuator Fill

We found that compared to an empty evacuator, an evacuator that was 25 percent full generated 50 percent less negative pressure for both the 100-cc Jackson-Pratt and 400-cc Jackson-Pratt bulbs, and 40.8 percent less negative pressure for the spring evacuator. An evacuator that was 50 percent full generated 68 percent less negative pressure for the 100-cc Jackson-Pratt bulb, 63 percent less negative pressure for the 400-cc Jackson-Pratt bulb, and 61 percent less negative pressure for the spring evacuator (Fig. 2, *below, right*).

Pressure versus Flow

We found that the fluid flow rate increased proportionately to the absolute value of the negative pressure generated by the evacuator. The findings of our study are summarized in Table 1.

Table 1. Summary of the Study Findings

Variable	Effect on Drain Flow
Intracavitary drain tube length	↑
Extracavitary drain tube length	↓
Drain tube diameter	↑↑
Fluid viscosity	↓
Drain tube type	
Perforated	↑
Fluted	↓
Clotting	
At the perforations or flutes	Minimal
In the drain tubing	↓↓
Drain evacuator type	
100-cc bulb	↑
400-cc bulb	↑
400-cc spring evacuator	↓
Evacuator squeeze method	
Bottom-up	↓↓
Side-to-side	↑↑
Evacuator fill >25%	↓
Pressure differential	↑

DISCUSSION

Despite the advent of novel techniques such as progressive-tension sutures that have made drainless abdominoplasty possible,[10] closed-suction drains still play a fundamental role in most reconstructive and cosmetic operations where tissue planes are developed and potential spaces are created. Because of the lack of existing studies, the optimal parameters for closed-suction drains have not been determined, and the manner in which drains are used varies widely among surgeons and institutions. Moreover, drain care by patients, caregivers, and nurses tends to be inconsistent. Despite at least one previous study showing that squeezing Jackson-Pratt bulbs bottom-up generates very little negative pressure,[6] this is still a common practice. Our purpose was to evaluate the effect of all possible parameters governing drain choice and use, to optimize drain efficacy.

We found that fluid flow rate decreased slightly as the length of drain tubing inside the body cavity decreased. This is an expected finding, because decreasing the tubing length inside the patient decreases the surface of interaction between the fluid and the flutes or perforations. Obviously, the length of tubing that is placed inside the patient usually depends on the size of the cavity. The take-home point is that one should choose an intracavitary drain tubing length that fits the cavity (rather than curl up redundant drain tubing or make the intracavitary drain length too short).

As the length of drain tubing outside the cavity increased, fluid flow rate decreased. This is a direct effect of increasing resistance to flow, as dictated by the Hagen-Poiseuille equation. Theoretically, flow would be proportional to $1/\textit{tubing length}$. In reality, we found the flow rate to be proportional to $1/\textit{tubing length}^{0.2}$. The conclusion here is to make the extracavitary drain length as short as possible, balancing the needs of convenience to the patient.

As expected, flow rate increased as the diameter of the tubing increased because of decreasing flow resistance. Theoretically, flow should be proportional to tubing diameter to the fourth power. In reality, we found the flow rate to be proportional to tubing diameter to the second power.

As expected, we found that, as fluid viscosity increased, flow rate decreased. Theoretically, flow should be proportional to 1/fluid viscosity. In reality, we found the flow rate to be proportional to 1/fluid viscosity$^{0.5}$. Taking our findings on tubing diameter and fluid viscosity into consideration, when one expects a more sanguinous (and viscous) character to the drainage, using a larger diameter tube would be more prudent.

Flat perforated drain tubes had a 22.5 percent higher flow rate than round fluted tubes, despite having the same inner diameter. This is an unexpected finding and may help guide surgeons' choice of drains. However, this needs to be balanced against the fact that one disadvantage of flat perforated drains is that they tend to have a hub that has a larger diameter than the tubing, causing significant patient discomfort during drain removal.[11] In addition, tissue ingrowth into the perforations may cause an increased chance of difficult (or painful) drain removal.

Both perforated and fluted drains performed surprisingly well in the face of clotting of the flutes and perforations. This may be because there are more flutes/perforations than necessary for maximal flow. It seems likely that the bottleneck where most of the resistance occurs resides in the tubing itself, so that even when only 25 percent of flutes or perforations were available, the flow rate decreased only minimally. In contrast, clotting of the drain tube itself led to complete cessation of flow, which did not resume until the clot was displaced into the drain bulb by stripping of the drain tubing. This highlights the importance of frequent drain stripping to keep drains functional. Drain stripping should be more frequent in the early days after surgery, when a large proportion of the fluid is sanguinous with a higher chance of clotting. With time, as the character of the effluent becomes more serous, the fluid is less prone to clotting, and stripping can be performed less frequently. Although there are no studies evaluating the frequency of drain stripping, we typically strip surgical drains every 2 hours in the first 2 postoperative days, then decrease the frequency to every 4 hours, provided that the fluid is mostly serous. Often, the importance of this is visible in the clot of blood, fibrin, or proteinaceous coagulum that can be expressed into the evacuator, which otherwise might occlude the tubing and impair drain output. Clot and debris in the drain tubing can fully impede drain function, leading to seroma formation. Our study demonstrates that frequent drain stripping can help maintain drain function when debris is present or when the output has a high chance of clotting (i.e., when there is a significant sanguinous component). Another practical conclusion that may be drawn from this is the fact that a drain stitch that is placed to secure the tubing can partially compress the tubing without significant decrease in flow, provided that it is stripped enough to prevent clot formation. We use the modified Roman sandal suture technique that has been demonstrated to be the most effective means of drain fixation in mechanical studies.[12]

Both the 100-cc and 400-cc Jackson-Pratt bulbs generated the same amount of negative pressure, which was significantly stronger than the three-spring evacuator. This is different from previous studies that found greater negative pressure in the 100-cc bulbs than in the 400-cc bulbs.[6] This is likely because of differences in the way the bulbs were evacuated of air. In our study, special attention was afforded to fully squeezing the bulbs side-to-side with both hands, leaving practically no air in them.

As in previous studies,[6] we found that squeezing drains bottom-up generated significantly weaker pressure than squeezing them side-to-side. The negative pressure generated by bulbs is predicated on bulb elasticity counteracting the deformational forces. Squeezing a bulb side-to-side essentially creates potential energy as the bulb slowly returns to its original shape. Jackson-Pratt bulbs that are squeezed bottom-up have very little tendency to return to their original shape, and therefore the potential energy generated is very low. Clinically, we often encounter drain bulbs that have been squeezed bottom-up, and our study has provided us with objective data to recommend a change in management.

We expected that the negative pressure generated by an evacuator would decrease significantly, as the evacuator was approximately half full.[5,6] However, we found that the negative pressure dropped by half when the evacuator was only 25 percent full, as in the findings by Williams et al.[8] During this experiment, we noted that diligently squeezing the bulbs with both hands and paying particular attention to evacuating practically all the air from the bulbs resulted in much greater negative pressure than casually squeezing the bulbs with one hand, as is typically done in clinical practice. Our findings have led us to change our drain management protocol, and evacuators are now emptied whenever they are 25 percent full, rather than 50 percent, and nurses are asked to squeeze the bulbs diligently with both hands. From that perspective, the 400-cc Jackson-Pratt bulb has an advantage over the 100-cc Jackson-Pratt bulb, as both bulbs generate similar initial negative pressure, but the 400-cc bulb can be filled with as much as 100 cc of fluid (25 percent) before its negative pressure decreases by half. One disadvantage of 400-cc bulbs, however, is that they are large and heavy, making them awkward for patients to carry.

The Hagen-Poiseuille equation assumes ideal conditions, and would not be expected to apply perfectly to our surgical drain model. Instead, we found the following formula to be a better representation of fluid flow rate, based on our model:

$$\mathit{Flow\ rate} \propto \frac{\mathit{Pressure\ difference} \times \mathit{Tube\ radius}^{2}}{\mathit{Fluid\ viscosity}^{0.5} \times \mathit{Tube\ length}^{0.2}}$$

where $\propto$ indicates proportionality.

Our practical version of the Hagen-Poiseuille equation differs from the theoretical equation for several reasons: The theoretical Hagen-Poiseuille equation applies only to Newtonian fluids (whose viscosity does not change with velocity), flowing in a laminar fashion.[13] Like blood, our experimental solution is a non-Newtonian fluid, where the viscosity of the fluid depends on its velocity, because of the presence of particles. (In the case of blood, these particles consist of red blood cells and others. In our experimental fluid, the particles consist of starch corpuscles.) In addition, as with blood, the flow in our experiment is more turbulent than laminar, leading to further deviation from the theoretical Hagen-Poiseuille equation.

Our study is not without limitations. For instance, we used an in vitro model, and body fluids were simulated with water thickened with a starch-based fluid thickener, which may not apply perfectly in vivo. However, to our knowledge, this is the most comprehensive study on the variables affecting surgical drain performance. An in vivo clinical study would likely add valuable information. However, unlike our study, it would not allow full control over every variable. Our experiments result in specific, tangible findings that surgeons can use to improve the effectiveness of closed-suction drains. These include increasing intracavitary tubing length, decreasing extracavitary tubing length, increasing tubing diameter, increasing the pressure differential, using perforated drains, squeezing bulbs side-to-side, stripping drain tubing frequently, and evacuating containers whenever they are 25 percent full.

CONCLUSIONS

In this study, we found that fluid flow rate through a drain increased when the length of tubing outside the cavity decreased, when the drain tube diameter increased, when perforated drains were used instead of fluted drains, and when the strength of the negative pressure generated increased, and that the flow rate decreased when the length of tubing inside the cavity decreased and when fluid viscosity increased. We also found that the negative pressure generated was strongest with the 100-cc and 400-cc Jackson-Pratt bulbs, when the bulbs were squeezed side-to-side, and when the evacuator was less than 25 percent full.

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