Learning Objectives:
The reader is presumed to have a broad understanding of plastic surgical procedures and concepts. After studying this article, the participant should be able to:

1. Understand the basic science/physics of the equipment used in suction-assisted lipoplasty (SAL), including the cannula, tubing, suction pump, and the forces that affect suction efficiency.
2. Define the factors that determine design characteristics of SAL cannulas, such as port size, port number, cannula diameter, cannula length, tubing parameters, and suction machine factors.
3. Describe the clinical applications of this information and the experimental results that determine which variables are clinically significant in SAL.

Physicians may earn 1 CME credit by successfully completing the examination based on material covered in this article. The examination begins on page 247. ASAPS members can also complete this CME examination online by logging onto the ASAPS Members-Only Web site (http://www.surgery.org/members) and clicking on “Clinical Education” in the menu bar.

Background: Although suction-assisted lipoplasty (SAL) has been clinically practiced for more than 25 years, comparatively little investigation into fundamental physics of the instrumentation used in the procedure has been conducted. Moreover, relatively little is known about the clinical impact or merit of the wide variety of instrumentation currently available.

Objective: In this study, we examined the physics related to the various components of instrumentation used in lipoplasty, and developed means to optimize performance based on quantified bench and clinical data.

Methods: The components used to construct a lipoplasty system (vacuum pump, suction tubing, suction canister, and suction cannula) were first evaluated using methods of bench experimentation. A selected set of components/parameters were then evaluated in a clinical setting, and the results were correlated to the bench data. The following design parameters were analyzed: for cannulas—shaft length, shaft internal diameter, port size/pattern, and venting; for tubing—length, internal diameter, and collapsibility; for canisters—volume, pull-down speed, gradation precision, and splash-related issues; and for vacuum pumps—vacuum level and flow rate.

Results: Each of the system components can have a significant impact on the overall performance of the system. A simple calculation is presented that can be used to quantify the relative “resistance” and, therefore, speed of any selected cannula or tube. Port area is shown to be an important aspect of cannula design and clinical performance. Clinical data are shown to correlate reasonably with bench data, which imparts credibility to the bench data and provides a platform from which to extrapolate other bench data to the clinical setting.

Conclusions: With clinical objectives in mind, guidelines and recommendations are presented, based on the data we collected, to optimize a lipoplasty system with regard to choices of the vacuum pump, suction tubing, and canister. With the ideal system in place, the cannula becomes the only remaining variable. Cannula properties and performance were also studied and are discussed in detail. (Aesthetic Surg J 2005;25:234-246.)
Although lipoplasty has been performed for more than 25 years, comparatively little attention has been directed toward the fundamental physics of the equipment. Similarly, relatively few reports have appeared in the literature reviewing the clinical merit or impact of the wide variety of instrumentation now available. (An annotated bibliography of published works covering the history, design, and analysis of lipoplasty instrumentation is included in the reference section of this paper.)

Advances in all aspects of instrumentation have gained general acceptance through the evolution of the clinical practice of lipoplasty. For example, cannulas are now blunt-tipped to minimize possible puncture or perforation, and cannula diameters continue to decrease to reduce trauma and to maximize sculpting ability. Cannula port edges have been softened to avoid excessive bleeding, and for the most part, cannula ports have been placed along the sides of the distal cannula shaft to eliminate a curette-type effect. Vacuum pumps, suction tubing, and suction canisters are essential elements of a lipoplasty system and are usually viewed as “supply” items that do not quantifiably impact the course of the procedure.

A study of the performance of a lipoplasty system is complicated by at least 3 factors. First, the system parameters (tubing, cannula, suction pump, and canister) interact and therefore cannot be studied effectively in isolation. Second, the number of experiments required to achieve statistical significance in a purely clinical study is so high, given all the variables involved (such as patients, fat types, and surgeons) that it is impractical to conduct. Finally, practitioners generally do not have the inclination to undertake such time-consuming experiments.

Consequently, we have taken a different approach to the study of this topic. First, quantitative bench data were developed to provide insight into interactions, trends, and other performance parameters of the components of the system. Selected clinical measurements were then obtained and compared to the bench data trends or ratios. Clinical data were always generated using a contralateral study model to eliminate patient-to-patient variations as much as possible. Using this approach, we were able to correlate the more accurate and repeatable bench findings with clinical findings and generate clinically meaningful observations, without having to conduct studies on a very large number of patients.

**Bench Data Methodology and Results**

A series of bench experiments was designed to measure the changes in aspiration rate for various combinations of vacuum level, suction tubing diameter and length, and cannula diameter and length. The experiments were then extended to examine the role of cannula port area and the presence or lack of a cannula vent. For all experiments, a mixture of 800 mL of store-purchased applesauce with 400 mL of tap water was used as the model of tissue with fluids. This combination has a viscosity higher than water, yet it flows and pours easily. The volume of diluted applesauce aspirated in 60 seconds was used to determine the aspiration rate for all experiments. A precision canister (VentX 1250, Sound Surgical Technologies, Louisville, CO) was used to accurately measure volumes of aspiration.

**Vacuum level, cannula diameter, and suction tubing diameter**

This experiment examined variation in vacuum level with 3 cannula diameters (3.0 mm, 3.7 mm, and 4.6 mm; all 26-cm length) and 2 internal diameters (ID) of suction tubing (1/4 in = 6.4 mm, and 3/8 in = 9.5 mm; both 12-ft length). Vacuum ranged from 16 in Hg to 28 in Hg. The results are shown in Figure 1.

The data in Figure 1 show that small changes in vacuum (2-3 in Hg) do not appreciably impact aspiration rate, especially when the system includes either a smaller diameter cannula or the smaller diameter (1/4 in) suction tubing. The most significant effect is the tubing ID. For example, the 3/8-in ID tubing attached to a 3.0-mm cannula had a slightly higher aspiration rate than the 1/4-in ID tubing without any cannula attached to it. When using the smaller 1/4-in ID tubing, the variation in aspiration rate for the different diameter cannulas was small, showing that the tubing diameter dominated flow rates.

**Cannula diameter and length, suction tubing diameter and length**

This experiment examined variations in cannula and suction tubing lengths in combination with 2 different IDs of suction tubing (1/4 in = 6.4 mm, and 3/8 in = 9.5 mm). A single diameter cannula, 3.7 mm, was used throughout this portion of the study. The results are shown in Figure 2.

The data in Figure 2 quantify the differences in cannula length (shorter is faster), tubing length (shorter is faster), and tubing ID (larger is faster) for the selected vacuum pump, applesauce viscosity, and tubing/cannula combinations. While the figure shows meaningful trends for the conditions tested, what is needed is a simple method to characterize each cannula and/or tubing in
such a way that its relative impact on aspiration rate could be predicted for any situation.

Based on the data presented above, we can characterize the “resistance” (R) of any cannula or tubing using its length (L) and ID with the following relationship: $R = \frac{L}{ID^{1.5}}$. In this formula, which was determined empirically from the data in Figures 1 and 2, the ID is the actual dimension of the internal lumen of the cannula or tubing, not the common designation of diameter, such as 3.0 mm or 3.7 mm. When using this calculation, it is necessary that a consistent set of units be used to measure length and ID for each item.

The value of this formula is that it can be used to determine the resistance of any cannula, or any tube relative to any other cannula or tube, using the common characteristics of diameter and length. The formula can also be used to estimate the performance of combinations of any tube with any cannula. The performance of combinations is simply the sum of the 2 resistance values. In clinically meaningful terms, the aspiration rate is proportional to the inverse of the total resistance. For example, the resistance values (using inches for units) of all the cannulas and tubes evaluated in this study, and a few other commonly used cannula and tubing combinations, are shown for reference in Table 1. In the last column, the inverse of resistance (speed) is calculated and normalized using the 12-ft 1/4-in ID tube as the basis.

Table 1 lists the various components in order of lowest resistance to highest resistance. As expected, a short larger-diameter cannula had the lowest resistance. The impact of the tubing was surprising. The 12-ft long tubing, in both diameters studied, contributed the largest elements of resistance (continuous flow), even more than a 34-cm, 3.0-mm cannula. The larger ID tubing (3/8-in ID) was about 1.8 times faster (1.8/1.0) than the 1/4-in ID tubing. The ratio of speeds for the 3.0-mm, 3.7-mm, and 4.6-mm cannulas, relative to the 3.0-mm diameter (standard 26-cm length), was 1.0 to 1.5 to 2.2, providing an approximate clinical guideline for the difference in the aspiration speed of these 3 cannula diameters.

The data in Table 1 should be considered to be performance-bounding data. This means that the ratio of any one item relative to any other item in the table represents the maximum possible difference. In clinical practice, these differences will be reduced rather than enhanced because of the in/out and stop/go nature of surgery, as opposed to the continuous and uniform nature of the laboratory experiments. For example, a change from a 12-ft
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1/4-in ID suction tube to a 12-ft 3/8-in ID suction tube will improve performance up to a maximum of 80% (1.8/1.0), relative to the 1/4-in ID tube. In actual clinical application, the impact of the suction tubing diameter will be less, especially if the volumes to be removed are relatively small. As the volume to be removed increases,

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**Table 1. Resistance and speed of cannulas and suction tubing**

<table>
<thead>
<tr>
<th>Component</th>
<th>Length (in)</th>
<th>Internal diameter (in)</th>
<th>Resistance L/ID$^{1.5}$</th>
<th>Normalized speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannulas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.6 mm, 16 cm</td>
<td>6.30</td>
<td>0.151</td>
<td>107</td>
<td>10.7</td>
</tr>
<tr>
<td>3.7 mm, 16 cm</td>
<td>6.30</td>
<td>0.116</td>
<td>160</td>
<td>7.2</td>
</tr>
<tr>
<td>4.6 mm, 26 cm</td>
<td>10.47</td>
<td>0.151</td>
<td>178</td>
<td>6.5</td>
</tr>
<tr>
<td>4.6 mm, 34 cm</td>
<td>13.39</td>
<td>0.151</td>
<td>228</td>
<td>5.1</td>
</tr>
<tr>
<td>3.0 mm, 16 cm</td>
<td>6.30</td>
<td>0.088</td>
<td>241</td>
<td>4.8</td>
</tr>
<tr>
<td>3.7 mm, 26 cm</td>
<td>10.47</td>
<td>0.116</td>
<td>266</td>
<td>4.3</td>
</tr>
<tr>
<td>3.7 mm, 34 cm</td>
<td>13.39</td>
<td>0.116</td>
<td>340</td>
<td>3.4</td>
</tr>
<tr>
<td>2.4 mm, 16 cm</td>
<td>6.30</td>
<td>0.068</td>
<td>351</td>
<td>3.3</td>
</tr>
<tr>
<td>3.0 mm, 26 cm</td>
<td>10.47</td>
<td>0.088</td>
<td>400</td>
<td>2.9</td>
</tr>
<tr>
<td>3.0 mm, 34 cm</td>
<td>13.39</td>
<td>0.088</td>
<td>512</td>
<td>2.3</td>
</tr>
<tr>
<td>Suction tubing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.375” tube, 10’</td>
<td>120.00</td>
<td>0.375</td>
<td>523</td>
<td>2.2</td>
</tr>
<tr>
<td>.375” tube, 12’</td>
<td>144.00</td>
<td>0.375</td>
<td>627</td>
<td>1.8</td>
</tr>
<tr>
<td>.25” tube, 10’</td>
<td>120.00</td>
<td>0.250</td>
<td>960</td>
<td>1.2</td>
</tr>
<tr>
<td>.25” tube, 12’</td>
<td>144.00</td>
<td>0.250</td>
<td>1152</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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**Figure 2.** Flow rates for combinations of cannulas and suction tubing lengths. Labeling is as follows: the first item is the cannula diameter in millimeters, the second item is the tubing internal diameter in inches, the third item is the suction tubing length in feet, and the last item is the cannula length. “Short” refers to a cannula length of 16 cm; “med” refers to a cannula length of 26 cm, and “long” refers to a cannula length of 34 cm.
the importance of the suction tubing diameter becomes more pertinent. The larger-diameter tubing may be viewed as an extension of the volume of the canister toward the cannula. This has the effect of shortening the distance between the cannula and the canister, relative to the smaller-diameter tube.

### Vented cannula

The term “vented cannula” refers to a particular cannula design that includes a very small continuous leak in the cannula just proximal to the location where the cannula shaft joins the cannula handle. This venting design is to be clearly differentiated from a “thumb-hole” type of vent that allows the surgeon to occlude or open a hole in the cannula handle to release the vacuum lock in the system.

The purpose of the vented cannula design is to reduce the relative viscosity of the tissue and fluids in the suction tubing so that they move faster and continuously in the tubing. The effect is most pronounced for smaller-diameter tubes, where the venting greatly improves the flow rates in the tubing. Larger-diameter tubing does not show as significant an effect because of its inherently superior flow characteristics. Venting also has a secondary beneficial effect, in that it reduces the canister splash caused by large volumes of tissue/fluids splashing into the canister when the cannula is removed from the patient.

Effective venting requires precise control of the leak. If the leak is not sufficient, then the cannula and tubing will behave essentially as a standard suction system. If the leak is too large, then the vacuum level available at the cannula may be overly compromised. A properly designed vented cannula should drop no more than 0.5 in Hg of vacuum at the level of the cannula.

An experiment was designed to compare the effect of the vented design to that achieved with a nonvented cannula. Cannulas of 3 different diameters (3.0 mm, 3.7 mm, and 4.6 mm), with and without venting, and 2 diameters of suction tubing (1/4 in and 3/8 in) were studied. The results are shown in Figure 3.

The data in Figure 3 show an improvement in aspiration rate for the vented cannulas in all cases. Note that the percentage improvement is always larger with the smaller-diameter suction tubing, indicating that the primary impact of the venting is to decrease the resistance to flow in the suction tubing. Thus, a vented cannula increases performance, not because the cannula is faster, but rather because the vented cannula improves the flow in the tubing by decreasing the average viscosity of the tissue and fluids in the tubing.
flow. Also note that the change in suction tubing ID has a more significant effect on performance than venting.

The clinical impact of the vented cannula design will be most apparent when removing larger volumes and when suction is uninterrupted for longer periods of time. In effect, the venting continually empties the suction tubing without reducing the time required to reach a working vacuum or the maximum vacuum level by more than 0.5 in Hg.

**Cannula port areas**

The significance of the actual area of each port in a cannula design has not been meaningfully studied. Generally speaking, the cannula diameter has been considered to be the most important parameter. However, it is the area of the port that determines the size of avulsed particles of fat and the actual “vacuum force” applied to the tissues. The following experimental design was used to study cannula diameter, total port area, and the area of each single port. The setup consisted of a vacuum pump connected to a 1250-mL canister and 2 ft of silicone 3/8-in bore tubing between the canister and the cannula to minimize the impact of the tubing. Cannula diameters of 3.0 mm, 3.7 mm, and 4.6 mm were used, all with a length of 26 cm. Table 2 shows the individual port areas and the lumen areas of the designs tested.

The flow rates for the various configurations are shown in Figure 4. From this figure we can deduce the following general trends. First, when the total port area exceeds about 1.5 times the cross-sectional area of the lumen of the cannula, there is no additional benefit with regard to speed. This means that more ports or larger ports will not further increase speed once the total port area is in excess of 1.5 times the lumen area. Second, when the area of a single port is less than about half the area of the lumen, there is a significant reduction in speed. Third, when the area of a single port exceeds the area of the lumen, there is no additional benefit with regard to flow rate. These last 2 observations indicate

![Figure 4](https://academic.oup.com/asj/article-abstract/25/3/234/227466)

**Table 2. Single port areas and lumen areas for tested cannula designs**

<table>
<thead>
<tr>
<th>Cannula diameter</th>
<th>Single port area (in²)</th>
<th>Lumen area (in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 mm</td>
<td>.0109</td>
<td>.0077</td>
</tr>
<tr>
<td>3.7 mm</td>
<td>.0048</td>
<td>.0129</td>
</tr>
<tr>
<td>3.7 mm</td>
<td>.0138</td>
<td>.0129</td>
</tr>
<tr>
<td>3.7 mm</td>
<td>.0196</td>
<td>.0133</td>
</tr>
<tr>
<td>4.6 mm</td>
<td>.0087</td>
<td>.0186</td>
</tr>
<tr>
<td>4.6 mm</td>
<td>.0201</td>
<td>.0186</td>
</tr>
</tbody>
</table>
that the actual port area is optimized (for speed considerations) when the port area is at least larger than half the lumen area but not much larger than the lumen area. These observations led to the design of the small-holed cannulas that are discussed in the clinical section of this paper.

**Discussion of Components**

**Suction tubing**

Suction tubing suitable for use in a lipoplasty aspiration system is available in multiple lengths, diameters, and in 2 primary materials (clear polyvinylchloride [PVC] and silicone) from a number of suppliers. PVC tubes cannot be easily resterilized and are generally single-use items. PVC is available in many durometers, a measure of the hardness of the material usually expressed using the Shore A scale. Soft PVC has a durometer of approximately Shore A 55 and is softer and more flexible, somewhat similar to silicone. Medium PVC has a durometer of approximately Shore A 65 and is harder and less flexible. Most PVC tubing uses the medium durometer Shore A 65 material; only a limited number of suction tubes are available in the softer Shore A 55 material. Typical silicone tubing has a durometer of Shore A 50, which is the reason this tubing material feels softer and more flexible than PVC. Silicone tubing can be cleaned and resterilized if proper procedures are followed. Silicone tubes are semi-opaque white or light brown in color. Because silicone is a softer material, the thickness of the tubing wall is usually greater than for an equivalent PVC tube.

**Table 3** shows the physical characteristics of commonly available tubing, including dimensions, a measure of collapsibility, and sterilization options. The collapsibility of each tube configuration was assessed by forming the tube into a 3-in-diameter circle to approximate the bends and curves on the operating table, and then applying a vacuum of 28 in Hg with the other end of the tube plugged. If the tube showed a marked tendency to neck down in the bent part of the tube, it was considered collapsed, even if the collapse did not completely occlude the tube. Testing was only completed at the 28-in Hg level; tubing that collapsed at 28 in Hg may not collapse at lower levels of vacuum.

The choice of suction tube is a trade-off between performance and price. Larger diameter tubing (3/8-in ID) provides improved aspiration performance by a factor of approximately 1.8 (nearly double) over 1/4-in ID tubing for continuous flow (12-ft lengths), and is generally more expensive and not as flexible as the smaller-diameter tubing. The 3/8-in ID tubing should be used for moderate to large volumes of aspiration, when operating room time is of the essence, and with cannula diameters of 3.7 mm and larger. Tubing with 1/4-in ID is widely available and is appropriate when aspiration volumes are small to moderate, when tubing weight and flexibility are important, and with cannula diameters 3.0 mm or smaller. Tubing with IDs smaller than 1/4 in are not recommended because of their severe impact on flow rates. There are many 1/4-in ID tubes designed for general surgical use that will collapse when subjected to the vacuum of a lipoplasty pump (which is significantly stronger than wall suction) and should not be used in a lipoplasty system. The weight and flexibility of the suction tubing play a role in the effort expended by the surgeon, as does the weight of the cannula itself. Again, there is a trade-off between lighter weight/more flexibility (smaller ID) and improved aspiration efficiency (larger ID).

**Suction pumps**

Suction pumps for lipoplasty are characterized by 2 performance parameters: maximum vacuum and maximum flow rate. Most lipoplasty suction pumps have adjustable vacuum, with a maximum vacuum between 27.0 and 29.5 in Hg at sea level. Maximum flow rates range from 2.0 to 8.5 cubic feet per minute (CFM). Various pump technologies include rotary vane, rocking piston, diaphragm, and liquid ring, each having different characteristics of reliability, noise, ease of repair, and required maintenance. It is important that the suction pump have sufficient vacuum and flow, but it is not necessary to achieve the often quoted “negative one atmosphere” capability only available with special pump
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Technologies (see vacuum level trends in Figure 1). Almost any lipoplasty suction pump that is first and foremost “quiet” will provide sufficient performance, provided that it is used in combination with appropriate tubing, canisters, and cannulas. For aspiration systems that are used at high altitudes, a higher maximum vacuum capability is recommended. A rule of thumb is that a suction pump loses approximately 1 in Hg per 1000 feet of altitude.

The role of maximum flow rate is related directly (and only) to the time it takes the aspiration system to reach working vacuum. Pumps with higher flow rates will reach working vacuum faster than systems with lower flow rates because they empty the canister and tubing faster. Therefore, larger-volume canisters (2000-3000 mL capacity) ideally require a higher flow rate pump. Pumps with low maximum flow rates that are used with the larger-volume canisters will result in noticeable delays before the cannula reaches working vacuum (see canister speeds in Table 4).

Suction pumps should include a vacuum gauge that is easily viewed, a vacuum level adjustment, and a means to turn the pump on and off during the procedure, usually accomplished with a foot switch. All suction pumps should be protected by an in-line filter that prevents canister splash from reaching the pump’s moving parts. If left unprotected, fat and fluids will corrode and may completely destroy the pump’s working parts over time. Optimally, the filter should be a high-flow high-vacuum type, with a hydrophobic filter media.

Most commercially available suction pumps designed for lipoplasty provide more than adequate maximum vacuum and maximum flow rate. As a result, the most important criteria in the choice of the suction pump are the noise of the pump, the proven reliability of the

### Table 4. Commercially available suction canisters

<table>
<thead>
<tr>
<th>Canister mfr</th>
<th>Volume (mL)</th>
<th>Gradation (mL)</th>
<th>Canister speed (s)</th>
<th>Splash protection</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Surgical</td>
<td>250</td>
<td>2</td>
<td>2.0</td>
<td>Deflector baffle + splash shield</td>
<td>Disposable</td>
</tr>
<tr>
<td>Sound Surgical</td>
<td>1250</td>
<td>10</td>
<td>5.0</td>
<td>Deflector baffle + splash shield</td>
<td>Disposable</td>
</tr>
<tr>
<td>Bemis</td>
<td>1200</td>
<td>50</td>
<td>5.8</td>
<td>Mechanical float + fiber washer</td>
<td>Disposable</td>
</tr>
<tr>
<td>Baxter</td>
<td>1500</td>
<td>50</td>
<td>6.2</td>
<td>Mechanical float + fiber washer</td>
<td>Disposable liner with shell</td>
</tr>
<tr>
<td>Abbott</td>
<td>1900</td>
<td>25</td>
<td>7.8</td>
<td>None</td>
<td>Disposable liner with shell</td>
</tr>
<tr>
<td>Bemis</td>
<td>2000</td>
<td>50</td>
<td>8.2</td>
<td>Mechanical float + fiber washer</td>
<td>Disposable</td>
</tr>
<tr>
<td>Dornoch</td>
<td>2400</td>
<td>50</td>
<td>12.0</td>
<td>Foam barrier</td>
<td>Reusable base, disposable lid</td>
</tr>
<tr>
<td>Korean</td>
<td>3000</td>
<td>100</td>
<td>13.0</td>
<td>Mechanical float</td>
<td>Reusable</td>
</tr>
</tbody>
</table>

*Figure 5. Commercially available suction canisters.*
design, the pump’s ease of use, and required maintenance.

**Canisters**

Canisters suitable for lipoplasty are available in volumes from 250 mL to 3000 mL and in disposable and reusable forms. While seemingly a relatively unimportant component of the lipoplasty system, canisters are unfortunately the source of much consternation when fittings, tubing, and canister nipples do not form good sealing connections. Figure 5 shows a selection of commercially available canisters in a wide variety of volumes and designs. Most suction canisters are designed for general surgical use, not specifically for lipoplasty, and may not be rated for the full vacuum of a lipoplasty vacuum pump (they may implode). Further, the precision of these types of canisters is usually less than would be optimal for most lipoplasty surgery. An important role of canisters is to measure, quickly and easily, volumes of aspirate. Commonly available canister systems are often out of the field of vision of the surgeon, and it is difficult for the staff to discern volume measurements. Identical canisters are available from many distribution sources with different names and labels.

Two performance parameters usually determine the choice of canister: volume and precision. Larger-volume canisters take longer to evacuate to the working vacuum level and usually have lower precision gradations. The lid of the canister may or may not incorporate anti-splash or anti-spill features.

Table 4 shows the volume, gradation precision, relative canister speed, presence or absence of splash protection, and type (reusable or disposable) for 8 commercially available canisters. Relative canister speed was determined by measuring the time required to evacuate each of the canisters to 90% of full vacuum using the same vacuum pump. The canister speed changes with different flow rates available from different pumps, but the ratio of one canister to another does not.

In general, canisters should be readily interchangeable and have precise resolution for small volumes of removal in areas such as the inner knees, inner thighs, or neck, with a volume of 500 mL or less. For larger volumes of aspirate, the precision of the gradation may increase along with the volume per canister (1 to 2 L). In general, 3-L canisters provide plenty of volume, but the gradation accuracy is too coarse to be of any real value. In addition, it is helpful if the canisters are paired for aspiration of symmetric body regions to facilitate accurate aspirate volume comparisons.

**Suction cannulas**

There are a wide variety of cannula choices. Most incorporate design features commonly accepted as standard, such as blunt tips, no ports at the very tip, and no sharp edges. Others depart from this general design and are usually for specific indications, such as superficial suction, treatment of fibrotic body regions, and others. The impact of diameter, length, single port area, total port area, and venting on performance has been discussed in detail previously. In general terms, shorter cannulas afford the surgeon better control at the expense of a larger number of access incisions. A large internal diameter translates into faster flow at the expense of larger incisions and, possibly, increased tissue trauma. Large-bore cannulas are less suitable for sculpting, and the aspirate is less suitable for autologous fat transfer (AFT). As discussed previously, venting can increase aspiration speed, particularly when larger volumes are being extracted. Smaller-holed cannulas have been shown to be faster than larger-holed ones and are believed to cause less tissue trauma (see following clinical results). Once the components of a lipoplasty system are ideally chosen and integrated for optimal performance, the choice of suction cannula becomes the only remaining variable. Ultimately, surgeons develop a cannula preference, not unlike the preference of a musician for a particular instrument.

**Clinical Data Methodology and Results**

Two sets of clinical experiments were completed. The first experiment was a comparison of aspiration rate with a change from high to low vacuum. The second experiment was a comparison of aspiration rates using a cannula with multiple small holes versus a cannula with fewer large holes, with both cannulas having the same diameter and equivalent total port areas. To make the experiments more meaningful, patient data were collected from contralateral symmetric body areas. In addition, data were only compared on a percentage or ratio basis. Using this approach, the data from different patients could be averaged and compared with trends in the bench data.

**Variation in vacuum**

Data from 3 different patients and 6 anatomic sites (left and right) were used to form an initial assessment of a change in vacuum. The low vacuum setting was 22 in Hg and the high vacuum setting was 27 in Hg. Identical canisters, tubing (1/4-in), cannula (3.0 mm, 26-cm length), and anatomic sites (L and R) were used in each instance. The average drop in aspiration rate was 28% for the low vacuum setting compared to the high vacuum.
Suction-Assisted Lipoplasty: Physics, Optimization, and Clinical Verification

SCIENTIFIC FORUM

setting. Figure 1 shows that a drop from 27 in Hg to 22 in Hg results in a drop of 25% in aspiration rate for the same cannula and tubing in the bench study. Thus, while the actual removal rate cannot be predicted using Figure 1 and the number of clinical data points was small, the clinical and bench data correlated reasonably well with regard to percentage change and general trend.

Small-holed and large-holed cannulas

Suction cannulas work by avulsion of fatty tissue. The amount of avulsion or tearing is a function of the cannula design, specifically the cannula diameter, the port area, and sharpness of the port edges. These design features also impact the ability to sculpt, the degree of trauma to tissues, and influence postoperative pain, swelling, and bruising. These factors are the trade-offs in cannula design.

The following experiment was designed to evaluate the impact of small-holed versus large-holed cannulas in a clinical setting. Data from 4 patients and 8 anatomic sites (left vs. right) were used to form an initial assessment of a small-holed cannula aspiration rate compared with a large-holed cannula aspiration rate. Two 3.7-mm-diameter cannulas with a length of 26 cm were used. The small-holed 3.7-mm cannula had 6 ports, with a single port area of 0.0086 in² and a total port area of 0.0517 in². The large-holed 3.7-mm cannula had 2 ports, with a single port area of 0.0277 in² and a total port area of 0.0554 in². The tips of these cannulas are shown in Figure 6. Our intent was to get the total port area of each cannula design to be as close as possible so that the impact of the small versus large port areas could be examined. In this case, the total port area difference in the 2 designs was 6%. Identical canisters, tubing (1/4-in), vacuum level (27 in Hg), and anatomic sites (L and R side of the same patient) were used in each instance. The small-port design was found to be faster than the large-port design in each site studied by an average of 24%. We believe that the increase in aspiration rate for the small-holed cannula is due to 2 effects. First, the size (area) of the avulsed particles of fatty tissue was smaller than the area of the cannula lumen, which resulted in faster and more efficient flow in the cannula shaft. Second, the small-port cannula had 6 ports, which provided 3 times the number of “active sites” present in the 2-port cannula design. Based on these findings we believe that extraction using a cannula with a greater number of smaller ports is faster than extraction using a cannula with a smaller number of larger ports. This is a significant finding, applicable to optimal-suction cannula design. In addition, one would intuitively assume that aspirate consisting of smaller fat globules is less traumatic and also more suitable for autologous fat transfer.

Conclusion

Laboratory (bench) and clinical data were obtained to quantify the performance of each element of a suction-assisted lipoplasty system. The 4 most significant results of this experimentation were: (1) clear identification and quantification of the performance of each lipoplasty system component; (2) development of a simple method that can be used to estimate the “resistance” of any suction cannula or suction tube, which can then be used to estimate its impact on aspiration speed; (3) the unexpected finding that small-port cannula designs actually extract fat faster than cannulas of the same diameter and length with fewer, larger ports; and (4) sufficient correlation of bench data and clinical data to suggest that properly obtained bench data, in certain situations, can be used to estimate the impact of design changes in a clinical environment.

Annotated Bibliography

The author designed a double lumen shaft for a cannula. The second, smaller lumen could allow air to aspirate into the cavity, thereby eliminating the need to withdraw the cannula after each movement. This cannula never became popular, however, and is no longer made.


The author described 2 new suction cannula tips that he designed. One was a flat-tip dissecting cannula for subdermal resection. The other was a round dissection cannula with holes on 3 sides for liposuction. He claimed that these cannula tips make the dermis contract when the undersurface of the dermis is suctioned.


The author described a new type of cannula with what we now call a “Mercedes” type of pattern for the holes. This could be used with a syringe or with an aspirating machine.


This is an early article describing the harvest of fat by lipoplasty for autologous fat grafting. The authors specifically suggested using a fine-tip cannula with machine-generated suction. They advocated overcorrection by 50% and estimated that 30% to 60% of the fat is resorbed.


This article is significant in that it is the first published article describing a stainless steel, flattened-tip cannula. The authors claimed that the flattened tip is less traumatic and penetrates more easily. The article also discusses the design of straight and curved cannulas and the design of ergonomic cannula handles to reduce surgeon muscle fatigue.


This is one of the best historical reviews written from the personal viewpoint of the author. The author covers significant events from the 1970s through the 1990s, including his personal preferences. The author discusses how the radius of the cannula affects the amount of fat that can be removed. According to Poiseuille’s law, as the radius increases, the amount of fat that can be removed increases to the fourth power. The author describes and gives credit to Dr. Fred Grazer for developing the “Mercedes” tip cannula, which has 3 holes at 120-degree angles from each other along the same point on the shaft. He briefly mentions cannula design factors as well.


This article is a questionnaire review of liposuction results with a 3- to 9-year follow up in 1340 patients. The authors concluded that long-term results are mostly satisfactory.


The authors recommended using cannulas with 1 or more holes about 1 cm from the tip for better control when treating the calves and ankles with suction-assisted lipectomy. The authors also recommended using 4 to 5-mm diameter cannulas for small- to medium-size calves (occasionally, 6-mm size cannulas for larger calves), and specially designed extra-long cannulas (45 m long) for the calves and ankles.


The author discussed “guided cannulas” with 1, 2, or 3 openings. He recommended that “beginning surgeons” use a 1-hole cannula and that “experienced surgeons” use a 3-hole cannula. The idea of the “guided cannula” is to avoid touching the most superficial 1 cm of fat. This is an idea that has largely been “debunked.”


The authors described a suction curette system for trochanteric fat using a “planotome,” a device that resects a uniform layer of fat under the skin. This machine consisted of a rotating blade inside a cannula. This technique often produced unsightly results.


The author recommends using a small-caliber, blunt-ended cannula design with a single opening near the tip.


This is a prospective, contralateral case-controlled study comparing 2 different SAL techniques. The patients were “blinded” in the study, making this an excellent study design. The conclusion was that the 2 techniques were equally safe, and they compared very favorably in patient satisfaction, aesthetic result, speed of recovery, and side effects. The PAL technique was easier for the surgeon and may be faster.


This report was an early report using a procedure almost identical to Dr. Illouz’s technique, except without wetting solution was used. Large metal cannulas with diameters of 6 to 10 mm were used.


This is probably the first report using the syringe technique in aesthetic surgery. In this technique, adding saline to the syringe and cannula will help to create a seal that makes it easier to suction.


The authors described a technique to increase skin contraction by perforating lipoplasty on the undersurface of the skin. They described a cannula tip design that is a Grazer-Grans “Mercedes” tip with 3 holes oriented at 120 degrees from each other. They recommended using 1.8 to 3-mm cannulas for this type of superficial lipoplasty. This article suggested that subdermal liposuction can be done safely, using straight-shaft liposuction catheters with 2 different tip designs.


This article advocated the benefits of the “Redon cannula,” a lightweight plexiglass cannula with a dull, rounded tip. The authors advocated this cannula design to reduce bleeding. The plexiglass cannula also allows the surgeon to closely monitor the liposaprate in the clear plexiglass cannula.


This article reviewed a study in 15 patients that showed hematocrit (measured in aspirate) of 5% to 54%, using the “dry technique” for lipoplasty. The cannulas used were 8-mm cannulas for buttocks and thighs. For smaller fat deposits, 3.7- to 6-mm cannulas were used. This article mentions the “1750 cc rule” that was advocated quite often in the 1980s.


The author discussed cannula design for superficial liposculpture of the face and neck in detail. He used small-caliber cannulas (3 to 4 mm in diameter) on 75 patients but also seemed to advocate Toledo’s approach using even smaller diameter cannulas (1.5 to 3 mm diameter) with a flattened distal cannula tip with 1 hole proximal to the tapered tip. He advocated superficial liposculpture of the neck as a procedure by itself or combined with open face lift or neck lift procedures. He claimed that significant skin contraction occurs with this procedure.


Although this book is now more than 10 years old, it still has an excellent description of the physics of vacuum, vacuum measurements, the physics of cannulas, and how the equipment for suction-assisted lipocontoury works (eg, vacuum pump design).


This is a very technical, mathematically-based description of fluid dynamics in conditions of turbulent flow. It discusses the Navier-Stokes equation in detail.

This is a very good article clearing up the meanings of various terminologies used to describe liposuction procedures.


This is a very good study that cleared up the myths and misunderstanding about the optimal vacuum pressure needed for liposuction. The author concluded that with blunt suction cannulas, a vacuum pressure higher than 0.5 atm was necessary for reasonably efficient fat aspiration to occur.


This is the updated version of Dr. Hetter’s 1984 first edition. It includes some information that was not in the original chapter on physics. There is a good discussion about the ideal vacuum pressure for liposuction. He also mentioned 2 very important principles of cannula design: (1) the smaller the diameter of the cannula that can reasonably be used, the more even the surface; and (2) the shorter the shaft of the cannula, the better the surgeon’s control of the instrument.


Although the book is almost 20 years old, this chapter has an excellent discussion about the cannula designs available in the early 1980s, including descriptions and photos of the abortion curette, Teimourian curette, Kesserling curette, Illoz cannula, Grazer-Grains modification, Hetter-Padget modification, and plastic disposable cannulas.


This chapter has an informative table (Table 2.1) listing the cannula types that have been developed for suction-assisted lipectomy. There is also a table outlining recommended cannula choices, based on the diameter of the cannula and the length of the shaft. This is a nice review of the history of liposuction that is easy for a lay person or surgeon to read.


This is the first large series of lipolysis cases reported in the literature, authored by the “father of suction-assisted lipoplasty.” The author used large, blunt-tipped cannulas with a single hole laterally, designed originally as a uterine curette. He used a small volume of saline (100 cc), distilled water (20 cc) and hyaluronidase to “rupture” adipocyte membranes, a claim that was never substantiated. He used curved and straight cannulas, ranging in diameter from 5 mm to 10 mm, including 10-mm diameter cannulas for the buttocks and hips, 8-mm cannulas for the knees, ankles, abdomen, and arms, and 5-mm cannulas for the face.


This is an early report describing cannulas designed by the author and called “Aspiradeps.” They are large-diameter straight and curved (bent) cannulas with 2 holes on one side that are hooked up to 0.4 and 0.6 atm of negative pressure. The cannulas were blunt-tipped but had a slightly recessed blade.


This is one of the earliest reports in the literature on using Kesselring’s sharp cannula technique. This cannula has only historical interest now.


This book chapter is old and mostly obsolete, but still it has a good description of the sharp cannulas invented by Dr. Kesselring and his argument in support of their superiority.


This article is very relevant in that Dr. Lewis modified his cannula size from 6 mm to 3.7 mm to decrease morbidity and undesirable results.


This is an early, well-written article on blunt suction lipoplasty using the “wet technique.” Dr. Lewis specifically advocated the use of “relatively small” cannulas for lipolysis of the abdomen. To my knowledge, this may be the earliest mention of the advantage/importance of using smaller-diameter cannulas.


Syringe liposculpture is compared to machine-aspirated liposculpture. The author suggested that the syringe technique was superior because it results in less blood loss, faster healing, less pain, and an earlier return to work.


In a letter to the editor, the author described using the number 10 Fraser tip nasal speculum as a simple method for performing lipoplasty.


This article discusses the technique of pointing the cannula hole upward to “etch” the abdominal wall with “selective” areas of superficial liposuction.


Dr. Mladick designed a set of curved shaft cannulas, with both concave shafts and convex shafts, to facilitate SAL of the ankles and calves.


The author described a new device for lipoplasty named the “Liposoft” machine. It consisted of stainless steel cannulas coated with Teflon that rotate from 25 rpm to 400 rpm. The author/inventors claimed that this system can reduce trauma. No evidence for this was given except for one case report.


Ozcan’s experimental data suggested a correlation between lipolysis complications, the amount of negative vacuum suction used, and the sharpness of the cannula.


This article suggested that large-lipoaspirate SAL can be safely performed (average volume of fat aspirated was 14,000 cc in 120 patients) without needing blood transfusions. The technique combined superficial and deep lipolysis, and tumescent and supertumescence techniques. The authors used 5- to 8-mm diameter cannulas to accomplish their goals.


This is a good review article that describes the design of a “Illoz” type cannula tip, a “cobra” cannula tip, and a “Mercedes” cannula tip. The author’s preference is the “Mercedes” tip, which has 3 holes at the same location on the shaft, oriented 120 degrees from each other.


This was a large questionnaire of 612 surgeons in the United States and Canada. No major complications were reported. The most common minor complications were persistent anesthesia, seroma, and persistent edema.


The author recommended a cannula design with a 2.4-mm diameter.


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The author recommended a cannula design with a 2.4-mm diameter.
This is an excellent research study on the systemic effects of liposuction. A syringe system was used with a 5-mm bullet-tipped cannula.


The author recommended using four 3-mm diameter cannulas to treat the upper arms.


This early report on lipoplasty technique has only historical interest now.


This is one of the earliest reports on lipoplasty. It has only historical interest now.


One of the earliest reports of lipoplasty. The described technique consisted of blind undermining of the skin with long scissors, followed by scraping with a sharp uterine curette. The author's published results were good, but other surgeons who performed the procedure reported a high incidence of complications, including lymphorrhea, hematoma, and skin necrosis. For this reason, the report has only historical value.


Like the author's other early reports on lipoplasty, this description has only historical value. (See previous entries.)


The author believed that the best material for cannula design is metal. However, plastic cannulas have an advantage in that they are disposable, lightweight, and semitransparent, which allows the surgeon to observe the liposaprate (fat) before it reaches the tubing. The author spent several pages discussing the pros and cons of cannula tip design, cannula length, openings (holes), tip shape, and diameter.


This is one of the early reports on lipoplasty technique.