Enhancing Lipoaspirate Efficiency by Altering Liposuction Cannula Design

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Background: Interplay between the components of a lipoplasty system (suction pump, suction tubing, collection canister, and cannula) determines liposuction efficiency. However, in clinical practice, none of the components are more important than the cannula. Cannula design including port design, port placement, and shaft characteristics is the single most influential contributor to flow resistance and dramatically effects speed of aspiration and final contour. Many variations on port design and placement are available, yet functional enhancements to the cannula shaft have largely been ignored. We have engineered a set of novel cannulas addressing vital elements of cannula design in the effort to enhance aspiration efficiency and efficacy.

Methods: Two novel cannula designs (dual- and multiport, in-line configuration), created using a unique proprietary manufacturing process, were evaluated against a popular industry standard design (tri-port, Mercedes configuration) to assess aspiration efficiency. Cannulas with shaft diameters of 3, 4, and 5 mm were attached to a standardized lipoplasty system and evaluated in real time for their ability to aspirate a viscous applesauce medium over a 5-minute time course. For each cannula, we calculated (1) the cross-sectional area of the cannula shaft, (2) single and total port area, (3) port-to-shaft ratio, and (4) theoretical resistance.

Results: The relationship between the cannula shaft and cannula port(s) directly influenced flow dynamics. Comparing medium uptake time, aspiration efficiency and the aspiration curves demonstrated a significant improvement of the 2 novel cannulas over the standard cannula in the 5- and 4-mm designations. In the 3-mm group, a difference in uptake time remained. However, a significant difference in aspiration efficiency was only seen between the dual-port novel cannula and tri-port Mercedes standard cannula. Further, differences in the aspiration curves between all 3-mm cannulas approached but did not reach significance.

Conclusions: We have developed 2 novel cannulas that maximize port features and seek to minimize the internal shaft resistance. Both designs demonstrate enhanced aspiration and uptake compared with an industry standard design. (Plast Reconstr Surg Glob Open 2014;2:e222; doi: 10.1097/GOX.0000000000000101; Published online 3 October 2014.)

With over 200,000 procedures performed in 2012, liposuction continues to be one of the most common elective cosmetic procedures performed as both a stand-alone intervention or as a contouring modality in combination with other procedures. When proceeding with fully elective procedures, patient safety and minimizing risk are of utmost importance. To this end, principals for ef-
effective liposuction technique and clinical end points have been well established to increase operative efficiency. Furthermore, achieving outstanding initial results and obviating the need for secondary revision surgeries are the major components of patient safety and satisfaction.

The components of a lipoplasty system for suction-assisted liposuction include the suction pump, suction tubing, a collection canister, and the suction cannula. Although all components contribute to the overall efficiency of the system, the magnitude of each individual piece is not equal. Small variances in vacuum (<2 in Hg) and tubing length (<2 feet) do not appreciably change overall efficacy during clinical liposuction. Proper selection of suction tubing and canister size based on planned lipoaspirate volume (larger volume = larger tubing internal diameter [ID] and canister) along with fine adjustments to maintain the manufacturer recommended pump settings provides consistently similar liposuction efficiency.

The most vital and variable component of the lipoplasty system is the liposuction cannula. Cannula selection serves a dual role. First, addition of the cannula has demonstrated to be the single most influential contributor to flow resistance in the lipoaspirate system. Second, through direct contact with the layers of adipose tissue to be addressed, the chosen cannula has a prominent influence on speed of resection, final contour, and quality of aspirate for potential adjunct grafting. Despite this importance, no universal standard has been established in the design and manufacturing of liposuction cannulas. A multitude of options with varying port and cannula shaft characteristics are offered, with little more than anecdotal evidence as to their clinical advantage. Often, the use of a specific cannula is based on surgeon familiarity and facility availability. We have designed 2 novel cannulas based on a proprietary manufacturing process aimed at decreasing flow resistance and increasing lipoaspirate efficacy. In this study, we compare the performance of our cannulas to a popular industry standard as part of a uniform lipoaspirate system.

MATERIALS AND METHODS
A series of experiments were designed to determine the aspiration rate of 2 unique cannula designs and an industry standard. Results were extended to include a comparison of cannulas with similar shaft diameter (3, 4, and 5 mm). For all experiments, aspiration medium consisted of 1 L of store purchased natural applesauce (Kroger, Cincinnati, Ohio). The weight (g) of applesauce aspirated at selected intervals over a 5-minute period was used to determine aspiration rate and efficiency of a given cannula. Weights were established using real-time readings on a Valor 1000 digital scale (Ohaus, Parsippany, N.J.). Trials were digitally recorded for reference.

Equipment
Liposuction Cannulas
The dual-port and multiport novel cannulas (Figs. 1, 2) were designed and manufactured according to a proprietary process with shaft diameters of 3, 4, and 5 mm in cooperation with Micrins (Eriem Surgical, Lake Forest, Ill.). The tri-port (Mercedes style) cannulas (Fig. 3) were manufactured by Grams Medical Inc. (Costa Mesa, Calif.) and acquired through institutional order. Tri-port cannulas used had standard shaft diameters of 3, 3.9, and 5 mm.

Lipoplasty System
To isolate the chosen cannula as the lone factor on run variability, a standard lipoplasty system was assembled, calibrated, and used for each run. The lipoplasty system was constructed from the following (1) self-contained suction pump: Hercules Aspirator by Wells Johnson Co. (Tucson, Ariz.), (2) disposable medium strength polyvinyl chloride suction tubing; 3/8˝ ID × 9/16 outer diameter × 10´ length: Medco Manufacturing (Spring, Tex.), and (3) 3000 mL Medi-Vac Guardian Collection Canister: Cardinal Health (Dublin, Ohio). All runs were performed at 28 in mm Hg with the vacuum control set to high.

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Fig. 1. Dual-port novel cannulas.
Initiation and termination of each run was controlled by a foot pedal allowing single investigator control.

**Aspiration Rate Determination**

The cannula to be tested was securely attached to the collection tubing. An empty collection canister was recorded as the starting weight. The lipoplasty system was turned on, and appropriate pressure and clearance of the vacuum were confirmed. The cannula was then vertically introduced into the applesauce medium allowing the cannula tip to remain 1 cm above the vessel bottom. No manipulation of the cannula was performed for the entire duration of the run. Weight of applesauce aspirated into the collection canister was recorded in real time at 15, 30, 45, 60, 90, 120, 150, 210, 240, 270, 300, 330, and 360 seconds. At 360 seconds, the cannula was removed from the medium and aspirate was allowed to clear from the tubing to the canister. This time of clearance and final aspirate weight were recorded. Conversion of weight (g) to volume (mL) was based on a standardized medium collection curve indicating an average density of 1.0281 g/mL. Triplicate runs were performed for each cannula design and diameter.

**Statistical Analysis**

Statistical analysis of the collection runs using the 2 novel cannulas and the standard cannula were completed using an unpaired t test (final collection) or Tukey’s multiple comparisons test with 95% confidence interval (dynamic run). All analyses were based on the collection weight of the aspiration medium. Analysis included head-to-head comparison based on cannula diameter. Differences were considered significant at $P < 0.05$.

**RESULTS**

**Cannula Port and Shaft Relationship**

Flow dynamics and vacuum force on avulsed fat particles are influenced by the relationship of the cannula port(s) to the cannula lumen. The true cross-sectional area of each cannula lumen was determined by measurement of the shaft ID (Table 1). In addition, each design was examined for the following relationships: (1) single and total port cross-sectional area (Table 2) and (2) the ratio of individual and total port-to-cannula cross-sectional area (Table 3).

**Cannula Resistance**

Resistance of the 2 novel cannula designs and the Mercedes cannula was calculated by the formula $R = \frac{L}{ID}$. Of note, the coefficient of friction was ignored. The difference in theoretical resistance between all cannulas is calculated to be less than 1% in the 5- and 3-mm groupings, with a marginal increase to 4% in the 4-mm grouping.

**Table 1. Cross-sectional Area of Cannula Shaft (cm²)**

| Cannula Shaft Diameter | Multiport Novel | Dual-port Novel | Tri-port Mercedes |
|------------------------|-----------------|-----------------|-------------------|
| 5 mm                   | 0.196           | 0.196           | 0.190             |
| 4 mm                   | 0.126           | 0.126           | 0.119             |
| 3 mm                   | 0.071           | 0.071           | 0.071             |

**Table 2. Cross-sectional Area of Cannula Port(s) (cm²)**

| Cannula Port | Multiport Novel | Dual-port Novel | Tri-port Mercedes |
|--------------|-----------------|-----------------|-------------------|
| 5-mm single port | 0.110           | 0.180           | 0.099             |
| 5-mm total port   | 1.320           | 0.360           | 0.297             |
| 4-mm single port   | 0.070           | 0.113           | 0.064             |
| 4-mm total port    | 0.840           | 0.226           | 0.18              |
| 3-mm single port   | 0.042           | 0.064           | 0.039             |
| 3-mm total port    | 0.505           | 0.128           | 0.117             |
Aspiration Rate

Size matched cannulas were compared based on the total amount of medium collected over a 5-minute time course. Results for the 5×30-mm cannula group are shown in Figure 4A. The multiport cannula demonstrated the largest per run collection with an average of 154.2 mL/min followed by the dual-port cannula with an average of 119.1 mL/min. Last, the standard Mercedes cannula averaged a collection of 90.0 mL/min. When comparing efficacy, a significant collection difference is noted between all cannula pairings in the group. The multiport cannula is 71% more effective in collection than the standard Mercedes style cannula (\(P = 0.0004\)). The dual-port cannula is 32% more effective in collection than the standard Mercedes style cannula (\(P = 0.0041\)). Comparing the 2 novel cannulas, the multiport is 29% more effective in collection than the dual-port cannula (\(P = 0.0036\)).

A similar trend was observed when comparing the 4×30-mm cannula group (Fig. 4B). Again, the multiport cannula demonstrated the largest per run collection with an average of 126.1 mL/min. Next, the dual-port cannula per run average was 90.8 mL/min followed by the standard Mercedes cannula, which averaged 45.8 mL/min per run. A significant collection difference is noted between all cannula pairings in the group. The multiport cannula is 175% more effective in collection than the standard Mercedes style cannula (\(P = 0.0021\)). The dual-port cannula is approximately 98% more effective in collection than the standard Mercedes style cannula (\(P = 0.0003\)). Comparing the 2 novel cannulas, the multiport is 39% more effective in collection than the dual-port cannula (\(P = 0.0021\)).

The previous collection trends continue for the 3×30-mm cannula group (Fig. 4C). The multiport cannula was the most efficient with a per run average of 47.4 mL/min followed by the 2-port cannula with an average of 43.9 mL/min. Once more, the standard Mercedes style cannula averaged the lowest collection of the group at 38.6 mL/min per run. The lone significant collection difference for this group is noted when comparing the 2-port cannula and the standard Mercedes style cannula demonstrating a 14% increase in efficiency by the novel cannula (\(P = 0.0133\)).

Aspiration Curve and Time to Uptake

The aspiration/time curves for all cannula groupings are shown in Figure 5. None of the cannulas in the 5-, 4-, or 3-mm grouping plateau off or deviate from a linear rate of pull throughout the full 5-minute time course. Uptake, as calculated by the slope of the aspiration curve, was significantly increased for the multiport and dual-port

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**Table 3. Ratio of Cannula Port-to-shaft Cross-sectional Area**

|                | Multiport Novel | Dual-port Novel | Tri-port Mercedes |
|----------------|-----------------|-----------------|-------------------|
| 5-mm single port | 0.5:1           | 0.9:1           | 0.5:1             |
| 5-mm total port  | 6.6:1           | 1.8:1           | 1.6:1             |
| 4-mm single port | 0.5:1           | 0.9:1           | 0.5:1             |
| 4-mm total port  | 6.6:1           | 1.8:1           | 1.6:1             |
| 3-mm single port | 0.5:1           | 0.9:1           | 0.5:1             |
| 3-mm total port  | 6.6:1           | 1.8:1           | 1.6:1             |

**Table 4. Theoretical Cannula Resistance (R = L/ID)**

|        | Multiport Novel | Dual-port Novel | Tri-port Mercedes |
|--------|-----------------|-----------------|-------------------|
| 5 mm   | 60.6            | 60.6            | 61.2              |
| 4 mm   | 75.9            | 75.9            | 78.9              |
| 3 mm   | 101.6           | 101.6           | 102.4             |

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Fig. 4. Aspiration rate of novel vs standard cannulas. Total aspirated medium over a 5-minute time course is shown for 5-mm (A), 4-mm (B), and 3-mm (C) cannulas. *Significance (\(P \leq 0.05\)).
novel cannulas versus the standard Mercedes style cannula within the 5- and 4-mm group. In contrast to the larger cannulas, comparison within the 3-mm grouping approached but did not reach significance.

The time for aspirated medium to hit the collection canister for each run was compared (data not shown). In the 5 × 30-mm cannula set, the average uptake time of the dual-port (22.7 seconds) and multiport (22.3 seconds) cannulas were significantly quicker than the standard Mercedes style cannula (43.3 seconds). The novel cannulas represent a 92% reduction in initial uptake time over the standard design. Again, in the 4 × 30-mm cannula set, the dual-port (27 seconds) and multiport (25 seconds) cannulas average uptake was significantly faster than the Mercedes style cannula (69.7 seconds). Here, the novel cannulas represent a 168% reduction in initial uptake time over the standard design. For the 3 × 30-mm cannula set, the uptake times of the dual-port (71.3 seconds) and multiport (67.7 seconds) cannulas were not significantly different than the Mercedes style cannula (84.7 seconds). Nevertheless, this still represents a 21% reduction in uptake time.

**DISCUSSION**

The literature focusing on liposuction cannula physics is sparse; however, it is clear that the liposuction cannula is an important contributor to the overall resistance of a lipoaspirate system. Many variations on port and shaft characteristics have influenced modern cannula design in an attempt to optimize results. These interchangeable properties contribute to the flow characteristics of a cannula and form the basis for surgeon selection and preference.

In the most comprehensive study to date, Fodor et al. established the following design parameters for optimal aspiration rate: (1) When the cross-sectional area of a single port is less than one-half the cross-sectional area of the cannula lumen, a significant reduction in aspiration speed is noted. (2) There is no additional benefit to aspiration speed when the cross-sectional area of the cannula port exceeds a 1:1 ratio with the cannula lumen. (3) In multiport cannulas, a total port cross-sectional area greater than 1.5 times the cross-sectional area of the cannula lumen affords no additional benefit to aspiration speed. (4) For cannulas with identical dimensions and total port cross-sectional area, multiple smaller ports showed a greater aspiration speed than fewer large ports.

We have introduced 2 novel cannulas that challenge these design limits. Based on the above parameters, the standard Mercedes cannula chosen for this study, with a single and total port-to-lumen ratio of 0.5:1 and 1.6:1, respectively, should represent a maximally efficient cannula. Any further increase to these ratios should demonstrate no further benefit to aspiration speed. Yet, in the 4- and 5-mm groupings, the 2 novel cannulas significantly outperformed the standard for aspiration efficacy and uptake. This is best exemplified when comparing the multiport cannula with the standard Mercedes cannula. More than quadrupling the total port-to-shaft ratio to 6.6:1 in the novel cannula demonstrated a 72% (5 mm) and 175% (4 mm) increase in aspiration efficiency. To control for any unidentified factors that may alter efficiency with such a large increase in total port-to-shaft ratio, the novel dual-port cannula was designed to have similar port ratios to the standard Mercedes. Even with only a slight increase in the ratios, the novel dual-port cannula had 33% (5 mm) and 99% (4 mm) greater aspiration efficiency than the standard. Calculation of the theoretical resistance between the novel dual-port and tri-port standard cannula showed no major discrepancy that would...
account for the level of difference noted in these experiments. Despite divergence from purported design limits, superior results were displayed by the novel cannulas.

In a comparison study of multiple stock cannulas, Young and Brandon found that for a given cannula diameter, tip geometry has minimal effect on the rate of aspiration as long as all ports are at least 4 mm in diameter. Both our dual-port and multiport novel cannulas fit this criterion, so no major difference in aspiration between the 2 should be noted. Yet, in comparison, the multiport cannula is significantly more efficient by 30% (5 mm) and 39% (4 mm) indicating an influence from tip geometry does exist. The authors recognize the existence of frictional forces associated with losses in ideal flow dynamics and suggest improvements may be realized through a reduction in systemic friction. We agree that the coefficient of friction cannot be discounted and steps to reduce friction losses within the internal cannula shaft are part of the proprietary manufacturing process of the novel cannulas. Further study is needed to delineate the relative contribution of port design and internal shaft properties in our cannula design.

Although the performance trends seen in the larger diameter cannulas continued in the 3-mm grouping, these values often came short of statistical significance. Several possibilities may explain this phenomenon. In the clinical setting, clogging of the cannula has been reported to significantly decrease the rate of aspiration when cannula diameter is less than 4 mm.8 For a fixed length cannula, moving from 4 to 3 mm may be the point at which the ID becomes the chief determinant in limiting overall aspirate flow masking the benefits of our manufacturing process. Alternatively, given the prolonged time to uptake of all cannulas in this grouping, it may be necessary to carry out a longer time course to reach significance in overall aspiration efficacy. Finally, the tighter aspiration curves suggest a greater number of trials may be needed to properly power the study and determine significance.

Although promising, the results obtained were from a controlled, well-regulated system using a nonbiologic medium. The amount of homogenous lipoaspirate needed to complete prolonged runs of all cannulas would be a logistical challenge. Use of applesauce as a medium provided a viable substitute for measuring uptake over multiple runs. Changes in consistency of the medium following lipoaspiration were negated by the ability to provide a fresh lot for each run. To build on this study, additional investigation is ongoing using ex vivo and in vivo lipoaspiration of adipose tissue. Additionally, any improvement in efficiency must be tempered by the heightened potential for contour irregularities. In vivo studies will provide insight into this fundamental component of successful liposuction.

CONCLUSIONS

Port design and the coefficient of friction inherent to a cannula are significant variables affecting lipoaspirate efficiency and efficacy. We have developed a set of novel cannulas using a proprietary manufacturing process aimed at reducing internal friction and optimizing lipoaspirate uptake. The results of this study demonstrate a dramatic improvement of our 2 novel cannulas over a common industry standard. Furthermore, this is the first study showing that previously outlined limits on flow dynamics in the liposuction cannula can be redefined. Together, this suggests our unique manufacturing process is of significant benefit to cannula design.

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