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EXPERIMENTAL

The Effect of Liposuction Cannula Diameter on Fat Retention—Based on a Rheological Simulation

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Background: Autologous fat is considered as an ideal material for soft-tissue augmentation in plastic and reconstructive surgery. The primary drawback of autologous fat grafting is the high absorption rate, thus fat retention is considered as an essential indicator. There are several researches about the factors that can influence fat retention, including centrifugation and cannula size. However, rheological models of cannula during liposuction are limited. This research focuses on the effects of cannulas with diameters of 2 mm and 2.5 mm on fat retention, which is based on a rheological simulation of inlet pressure and maximum velocity. Experiments on mice were also conducted to confirm the result from the simulation.
Methods: A simulation was conducted with the physical parameters of the adipose tissue. Human lipoaspirate samples were obtained from patients by liposuction through cannulas of different diameters and were transferred into subcutaneous tissue of nude mice, a part of which were used in viscosity and density measurement. Graft retention was measured and fat quality was assessed through histologic analysis after 6 months.
Results: Viscosity and density of the fat tissue had significant effects on fat retention. The 2.5 mm diameter cannula had significantly lower inlet pressure and maximum velocity and thus led to higher graft retention, but oil cystic nodules appeared meanwhile.
Conclusions: Cannulas with larger diameters have lower inlet pressure and maximum velocity during the liposuction process, which further influences the viability of adipocytes and adipose stem cells and thus has larger fat graft retention. This research built a mathematical model with less bias than in vivo experiments and provides a general way for analyzing the outcome of a liposuction precisely, which adds to the data for cannula optimization. *(Plast Reconstr Surg Glob Open 2018;6:e2021; doi: 10.1097/GOX.0000000000002021; Published online 19 November 2018.)*

BACKGROUND

Due to the abundance and natural properties of fat, fat grafting remains a popular procedure for augmentation and reconstruction in plastic and reconstructive surgery, which can be applied in correcting volume body defects and soft-tissue augmentation, such as natural breast augmentation, gluteal augmentation, hand rejuvenation, and lower extremity rejuvenation.[1]

Autologous fat transplantation has long been reported since van der Meulen first attempted adipose grafting to treat facial defects,[1] whose efficiency highly depends on the number of vital adipocytes present during transplantation.[2] Coleman[3] then built a set of standardized procedure of fat grafting, which is still being performed today. With further study and technology, researchers have discovered the crucial role of adipose stem cells in lipotransfer and revealed a more complex and detailed map of this whole procedure.[4] Graft-to-recipient interaction is currently considered the rate-limiting effect during autologous fat

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grafting and techniques based on this principle have been developed, which stabilizes the percentage augmentation within 30% to 50%.[5] A breast augmentation device called BRAVA further increases the percentage augmentation to 80% and even 90%.[6] Cannula size is one of the major factors that have a significant impact on the viability of harvested adipose tissue.[7,8] Erdim et al.[9] and Kirkham et al.[7] found that the use of larger liposuction cannulas led to improved fat graft retention and quality,[2,10] which further facilitated clinical outcomes.

Literature focusing on the mechanism illustrated that pressure and velocity were the main elements influencing adipocytes viability during liposuction and injection.[11–13] Lee et al.[11] concluded that lower pressure led to obviously greater fat quality and retention.[14] Luan et al.[14] performed rheological tests on adipose tissue grafted through different cannulas and found that cannula geometry affected fat intactness, volume retention, and histologic properties of fat tissues. They also attempted to use mathematical calculation to explain their results theoretically, but did not reveal the distribution of pressure and velocity within the cannulas. Therefore, this research focuses on building a more accurate model with exploration of the exact distribution of static pressure and flowing velocity along the cannula and tries to explain the mechanism behind different fat retention when using cannulas of different diameters in an operation.

We built rheological models of 2 sets of liposuction cannulas to simulate the real process of lipoaspirates flowing in liposuction cannulas. Billings et al.[1] reported that higher pressure and velocity would cause damage to adipocytes and adipose-derived stem cells, correlating with fat grafting efficacy,[14] thus the inlet pressure and maximum flowing velocity were considered as 2 important evaluators of fat retention reflecting the viability of adipocytes reserved in fat tissue, while the viscosity and density of extracted adipose tissue were utilized as 2 parameters measuring fat conditions under different circumstances.

Considering that no similar simulation had been done before, experiments on mice were conducted to check if our simulation really worked. Histologic analyses were also performed to verify the quality of grafted fat tissue, presenting a comprehensive reference for liposuction process instead of only concerning about fat retention, which could be misleading.

MATERIALS AND METHODS

Materials Preparation

The liposuction cannulas with diameters of 2.5 mm and 2 mm were manufactured by Dino Medi-Tech Co., Ltd located in Hangzhou, Zhejiang Province, and provided by Plastic Surgery Hospital (Institute) of Chinese Academy of Medical Sciences & Peking Union Medical College. Figure 1 displays the schema image of the 2 liposuction cannulas with detailed scales.

Fresh lipoaspirate samples for transplantation experiments on mice were collected from 2 healthy human patients by liposuction with 2 mm cannulas and 2.5 mm cannulas used on each side from thighs, waists, and stomachs, respectively. A 500 ml negative pressure drainage bottle was utilized to extract fat tissue under 6×10^4 Pascal in fan shapes through 3-holed blunt cannula (2 mm and 2.5 mm in the inner diameter). Extracted fat was transferred into a sterile container, washed once with normal saline, filtered, and concentrated with sterile cotton and gauze. Processed fat was transferred into 1 ml syringes for later injection. The adipose samples used for the measurement of physical parameters were obtained from another 2 healthy human patients through suction-assisted lipectomy, which could protect the adipocytes from unexpected damage.

Measurement of the Physical Parameters of the Adipose Tissue

We first measured the viscosity and density of the adipose tissues. A total of 4 samples were collected from 2 patients and marked with A_1, A_2, B_1 and B_2.

NDJ-79 rotational viscometer was employed for viscosity measuring and temperature inside was kept at 37°C during the measurement. ME54E electronic balance was used to conduct mass metering, and a standard syringe was used to measure the volume. All the experiments in this part were conducted in the General Physics Laboratory of Tsinghua University.

Simulation

A model was created on computer to simulate the distribution of static pressure and flowing velocity along the liposuction cannulas with different diameters. The outlet pressure was set as a constant of -6×10^4 Pascal, which is consistent with the liposuction process in this study. For a more general situation, we built 5 models of cannulas with different diameters: 2.0, 2.5, 3.0, 3.5, and 4 mm. However, the result only shows the 2.0 and 2.5 mm cannula, due to the fact that the overwhelming majority of liposuction surgeries in China are carried by these 2 types of cannulas. Complete simulation data can be found in the supplementary materials.

The ANSYS 17.0 software used in finite element analysis in general was employed to conduct the rheological simulation. ICEM CFD 17.0 was applied to create the geometry model and prepare the mesh for calculation. Fluent 17.0 was applied to conduct numerical evaluation and display the final results. The settings of detailed parameters can be found in the supplementary materials.

We analyzed the distribution of static pressure and flowing velocity of the 4 samples and presented the result by cloud charts. A suppositional range of viscosity and density was also set to explore the relationship between the distribution and the physical parameters of the adipose tissue. To explore the relationship, a 3-dimensional surface with contour line was fitted and plotted with MATLAB R2017b.

Fat Grafting and Retention Measurement

This study was carried out strictly following the recommendations of the Guide for the Care and Health of Laboratory Animals of the Chinese National Health and Medical Research Council.

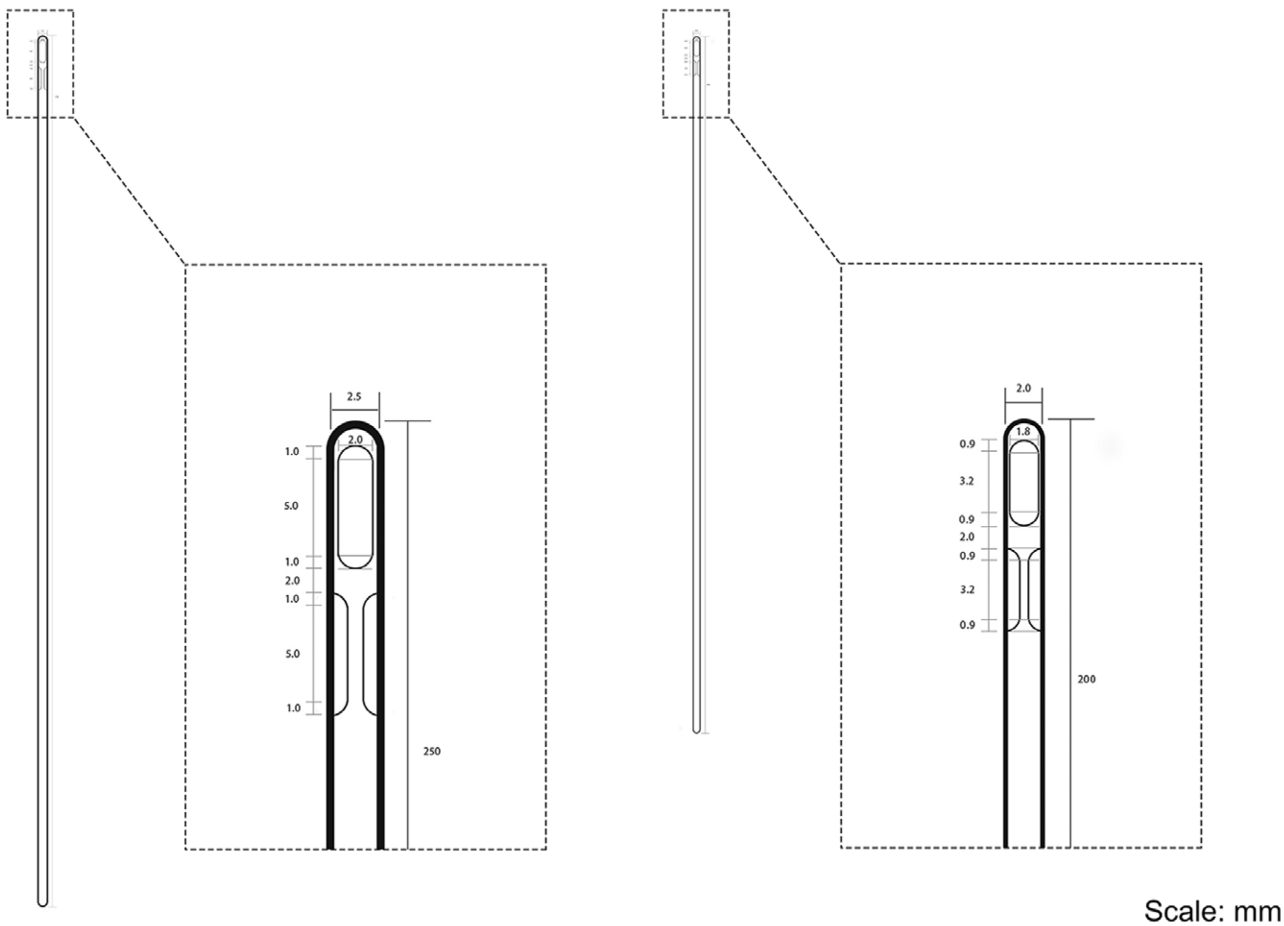

Fig. 1. Schema models of liposuction cannulas.

Six 5-week nude mice (BALB/c-nu, SPF) were used in the experiment. The fat samples collected by 2.5 mm, and 2 mm cannulas were first condensed with dry cotton pad to allow normal saline, oil, and blood cells to be absorbed. Then the samples were transferred into 1-ml normal syringes. A total of 0.2 ml fat was injected successively into the left and right side of each mouse's back through a 18-Gauge, 1-hole blunt cannula. We conducted the injection process manually to inject uniformly on several points on the nude mice due to the fat volume for injections is quite small. To minimize the instability caused by manual injection, one researcher conducted all the injection.

Mice were raised with routine laboratory diet and activity. After 6 month of fat grafting, the mice were anesthetized and incisions were made in the midline of the dorsal skin. The implanted regions were exposed and the grafted fat was gently and completely excised out of the dermis. Excised fat tissue was put in to a 1-ml syringe containing 0.5 ml normal saline; thus, we could read the retention volume. The ratio $\frac{\text{Retention volume}}{\text{Origin volume}\,(0.2\text{ml})}$ was considered as the fat retention rate. We will simply use the retention volume since the origin volume was a constant in this experiment.

HISTOLOGIC ANALYSIS

Grafted fat was removed for histologic analysis after 6 months to check the quality of the newborn fat tissue, which was fixed in 10% formalin, dehydrated, and then embedded in paraffin. Hematoxylin and eosin staining (HE staining) was conducted. Images were taken using a light microscope at 4×.

STATISTICAL ANALYSIS

All the statistical analyses were completed by R software 3.3.3, which can be downloaded freely at Comprehensive R Archive Network (CRAN). Data are presented as mean ± SD. Paired *t* test was conducted, and a value of $P \leq 0.05$ was considered statistically significant ($^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$).

RESULTS

Physical Parameters of Adipose Tissue

Viscosity of the samples in this experiment ranges from 3.0 cP to 7.0 cP (the viscosity of pure water is 1.0 cP) while the density ranges from 938.4 kg/m^3 to 1,027.9 kg/m^3. Table 1 displays the viscosity and density of 4 adipose tissue samples.

Static Pressure Distribution

The inlet of the cannula always has a much larger pressure than surroundings. We considered the inlet pressure

Table 1. Viscosity and Density of Adipose Tissue Samples

Sample Marks	Viscosity/cP	Density/(kg/m³)
A_1	6.5	1,027.9
A_2	7.0	938.4
B_1	5.0	1,025.2
B_2	3.0	1,000.7
Mean ± SD	5.4 ± 1.8	998.1 ± 41.6

as an evaluator because a higher inlet pressure would squeeze the adipocytes and cause damage. The 2.5 mm cannulas has a lower inlet static pressure distribution than the 2 mm cannulas for all the samples in this experiment, as shown in Figure 2 ($^*P = 0.04493$). We noticed that when it comes to a low viscosity (sample B_2), the inlet pressure of the 2 cannulas became close. When we set a lower viscosity ($\eta<2.5$cP), the 2 mm cannula has a lower inlet pressure instead (data not shown).

Adipose tissue with larger density and lower viscosity tends to suffer from a lower pressure during liposuction, while viscosity has a much stronger effect. Figure 3 fits the inlet pressure and the viscosity and density. The contour lines indicate the relationship. The general distributions of the static pressure are displayed in Figure 4.

Flowing Velocity Distribution

We mainly focus on the head of the cannula because the central part of the fluid always has the maximum viscosity when it reaches a stable state at the end part of the cannula, as normal Newtonian fluid performs. An isolated part with a maximum velocity can be observed at the central part in the head part of the cannula. The maximum velocity was simulated and set as another evaluator because a higher maximum velocity can cause sharper pounding between the adipocyte and other elements (eg, tissue fragment, cannula wall, flushing fluid) and cause severer damage to adipocyte.

The 2.5 mm cannula has a lower maximum velocity than 2 mm cannula for all the 4 samples, and the differences are significant ($^*P = 0.02672$), as shown in Figure 2. Lower viscosity of the adipose tissue tends to diminish the difference however.

Adipose tissue with larger density and viscosity has lower maximum velocity. Figure 5 fits the maximum velocity and the viscosity, and density and the contour lines show

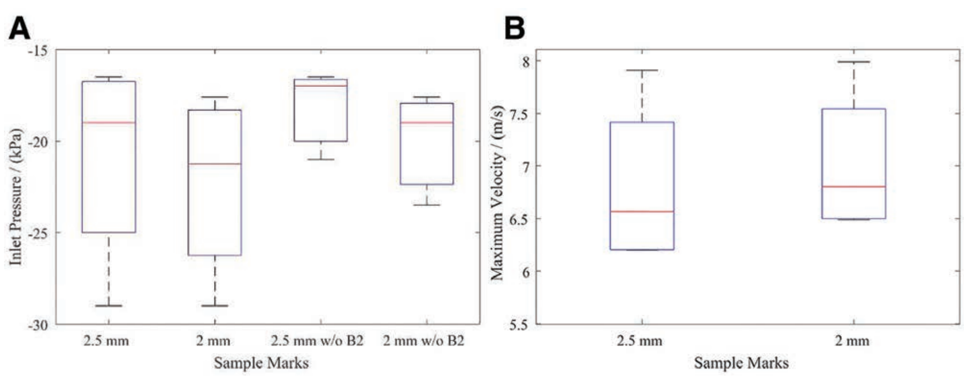

Fig. 2. A, Inlet pressure of the 2 cannulas. The 2.5 mm cannula has a significant lower absolute value of inlet pressure ($^*P = 0.04493$) than the 2 mm cannula when sample B_2 is excluded. B, Maximum velocity of the 2 cannulas. The 2.5 mm cannula has a significant lower maximum velocity ($^*P = 0.02672$) than the 2 mm cannula.

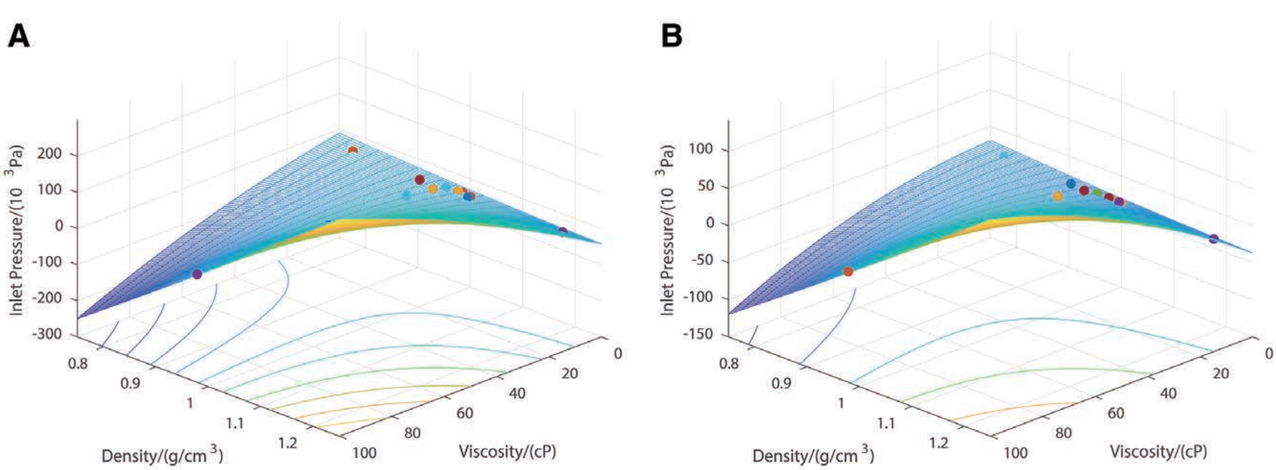

Fig. 3. The relationship among the inlet pressure, viscosity, and density. A, Liposuction cannula with diameter of 2.5 mm. B, Liposuction cannula with diameter of 2.0 mm.

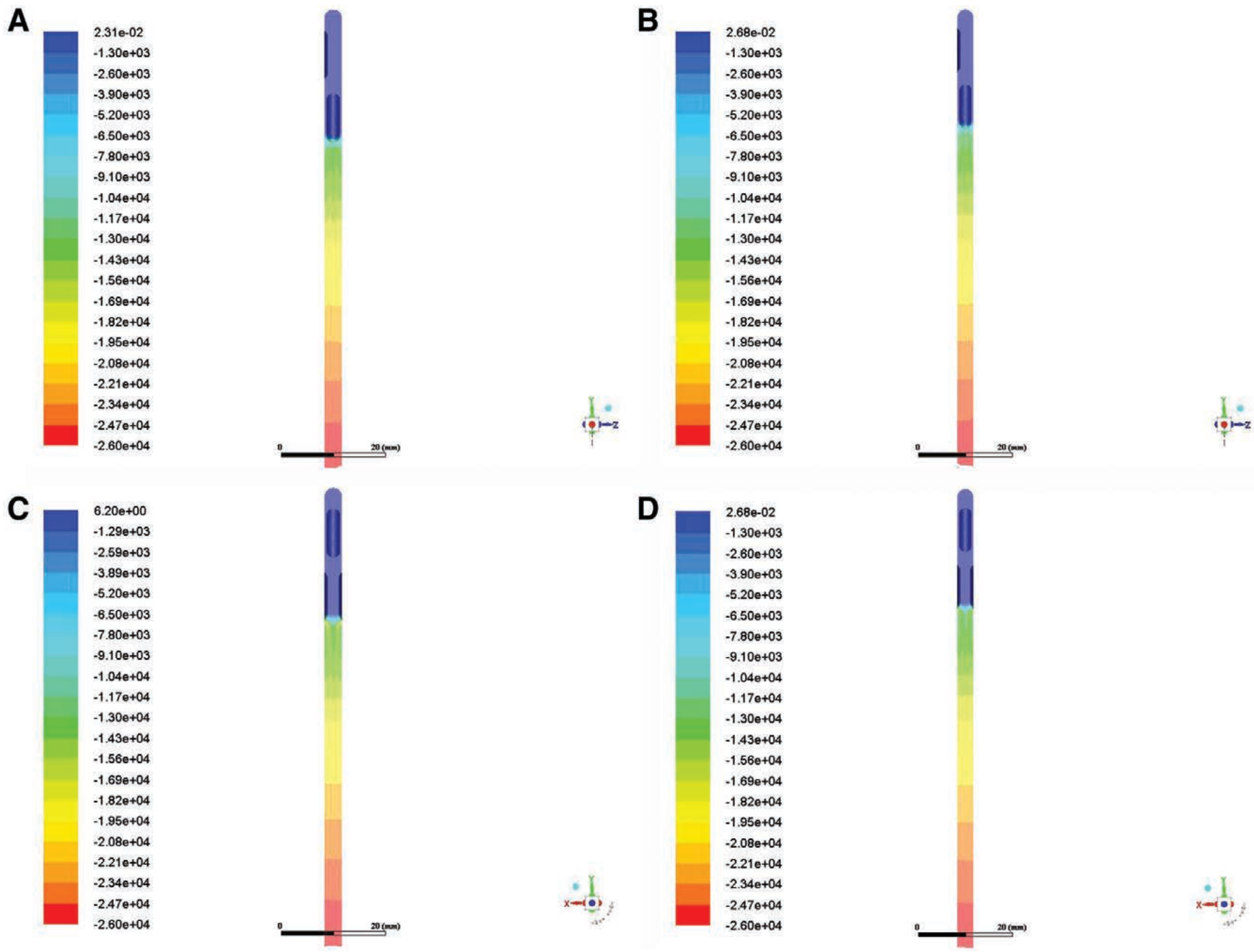

Fig. 4. The static pressure distribution pattern in liposuction cannulas. A and C, 2.5 mm liposuction cannula from lateral and front view, respectively. B and D, 2.0 mm liposuction cannula from lateral and front view, respectively.

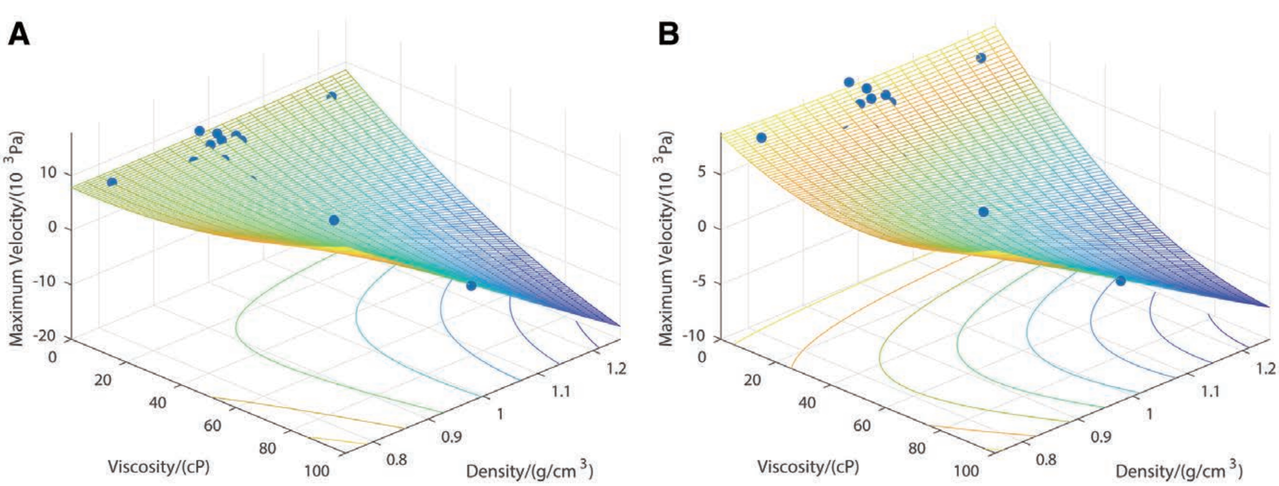

Fig. 5. The relationship among the maximum velocity, viscosity, and density. A, Liposuction cannula with diameter of 2.5 mm. B, Liposuction cannula with diameter of 2.0 mm.

the relationship. Figure 6 shows the general distribution of velocity among the cannula.

Fat Graft Retention

Both of the mass and volume retentions of 2.5mm cannula are significantly higher than the 2mm cannula (*P = 0.01007 and *P = 0.0105, successively), as shown in Figure 7. Figure 8 shows the grafted fat tissue in vivo. The raw data, for conciseness, are shown in **Supplemental Digital Contents 1–3** (**see table, Supplemental Digital Content 1**, which displays the basic parameters set in the simulation, ***http://links.lww.com/PRSGO/A925***; **see table, Supplemental Digital Content 2**, which displays the complete data of the simulation of 5 cannulas with different diameters, ***http://links.lww.com/PRSGO/A926***; **see table, Supplemental Digital Content 3**, which displays the complete data of the volume and mass retention rate of the adipose tissue, ***http://links.lww.com/PRSGO/A927***).

DISCUSSION

This research is for the first time applying a mathematical simulation with the information we know so far, which provides a systemic reference for liposuction.

We found that larger diameter of the liposuction cannula has significantly lower inlet pressure and maximum velocity along the cannula, which can further influence the viability of adipocytes during liposuction and finally result in larger fat retention volumes.

Viscosity and density are 2 important parameters that can influence the results. The C-shape contour lines in Figure 2 and Figure 5 suggest that the relationship between the evaluators and the parameters is not linear and even not monotonically changes in a wide range (eg, η>80.0cP). However, we have not observed a nonmonotonic change in the range set in this simulation, which should cover normal adipose tissue.

Relationship between viscosity and inlet pressure is one of the most important things to concern about in the simulation. Considering the fact that viscosity of normal adipose tissue should be larger in 5.0 cP as shown in Table 1, we drew the conclusion that the 2.5mm cannula should have a larger fat graft retention because the fat cell suffered less from the liposuction process and keep the integrated structure better. The experiment conducted on mice confirmed the hypothesis drawn from the simula-

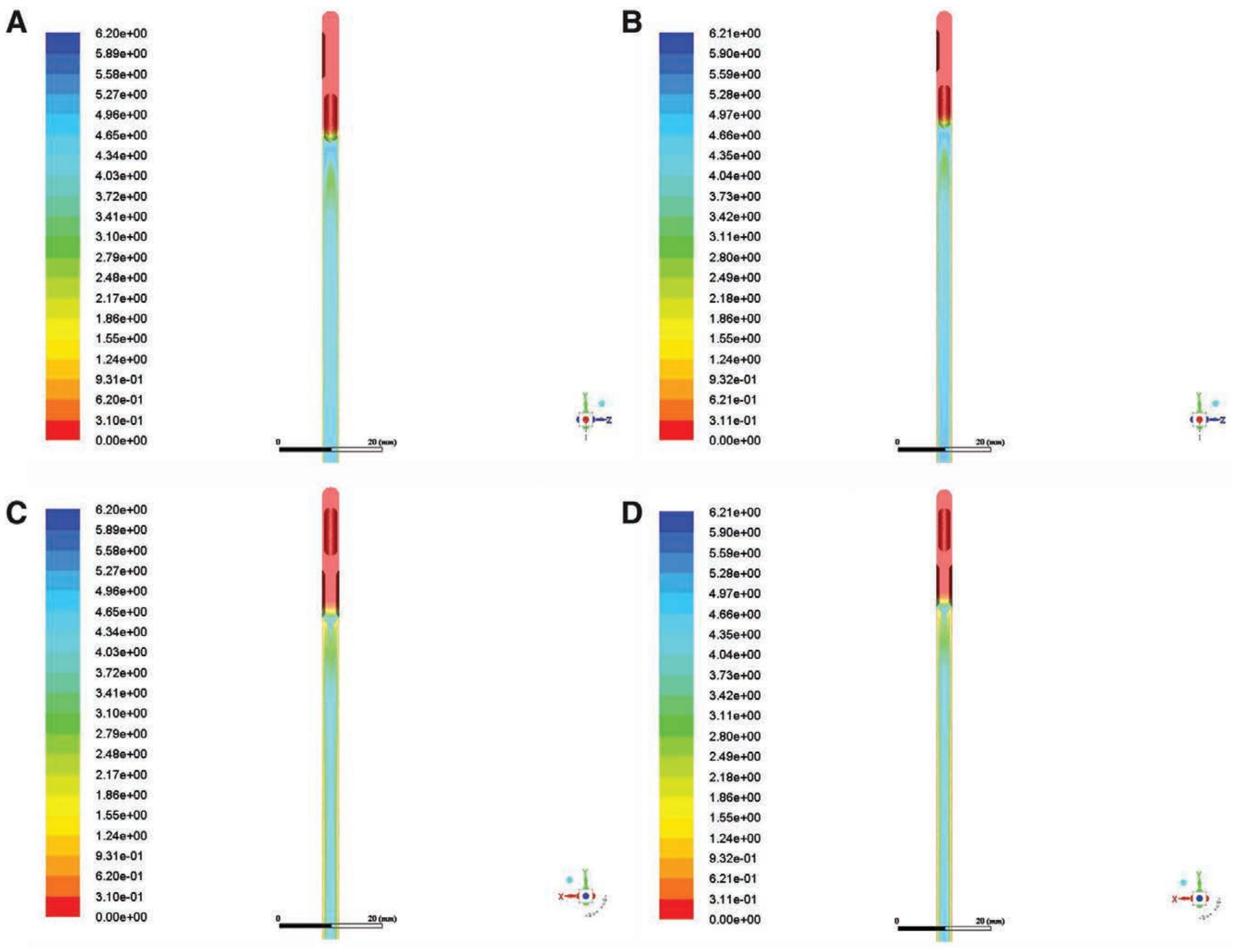

Fig. 6. The flowing velocity distribution pattern in liposuction cannulas. A and C, 2.5mm liposuction cannula from lateral and front view, respectively. B and D, 2.0mm liposuction cannula from lateral and front view, respectively. The dark blue part in the central is the isolated high-velocity part.

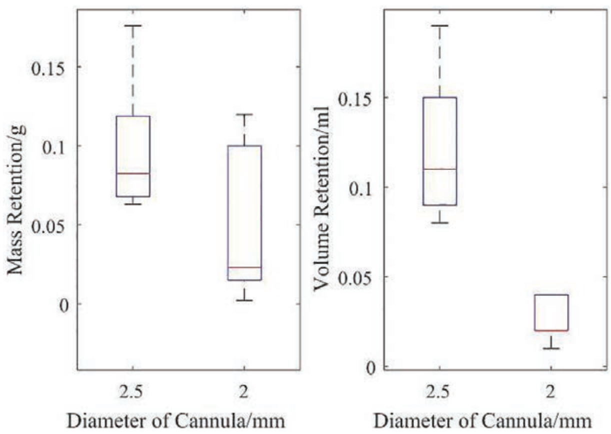

Fig. 7. Fat retention of the 2 cannulas. Orange, blue: Mass retention. The 2.5 mm cannula has a significant higher mass retention ($^{*}P$ = 0.01007). Green, red: Volume retention. The 2.5 mm cannula has a significant higher volume retention ($^{*}P$ = 0.0105).

tion, which indicated that the employment of the 2.5 mm liposuction cannula would increase the fat graft retention.

It should be noticed that when viscosity further decreases, the size relationship of the inlet pressure reverses as has been discussed above, which implies that 2 mm cannulas are more suitable for low-viscosity adipose tissue. The reason for this phenomenon is currently unclear, but may be attributed to the fact that the lipoaspirate behaves in a non-Newton manner. Histological analyses reveal that this phenomenon might have influence on the generation of oil cystic nodule, which will be described below.

The isolated part with a high maximum velocity exists in both 2.5 mm cannula and 2 mm cannula. The isolated high-velocity part became taller and slender while the viscosity increased and finally disappeared at η=50.0cP (data not shown). However, this condition was far beyond the normal circumstances of fat tissue thus meaningless in this research.

The simulation data and the contour lines in Figure 5 demonstrate that density has much slighter effects on inlet pressure and maximum velocity. This phenomenon may be due to the small range and variation of the density of the normal adipose tissue ($998.1 \pm 41.6\ \text{kg} / m^3$).

In addition, we noticed that the difference of maximum velocity between the 2.5 mm cannula and 2 mm cannula became smaller when viscosity decreased. This may suggest surgeons to use the 2 mm cannula at the end of a liposuction for the sake of a lower inlet pressure as described above.

Though most of the evidences point out that the employment of 2.5 mm liposuction cannula in an operation can result in a larger fat graft retention, histological analyses have revealed another problem. Several small oil cystic nodules existed in the grafted fat tissue extracted by the 2.5 mm liposuction cannula as Figure 9 shows, while no oil cystic nodules were observed in the grafted fat tissue taken by the 2 mm cannula.

This phenomenon may be due to the reversed relationship between inlet pressure and liposuction outcomes when the viscosity of the lipoaspirate is relatively low, as

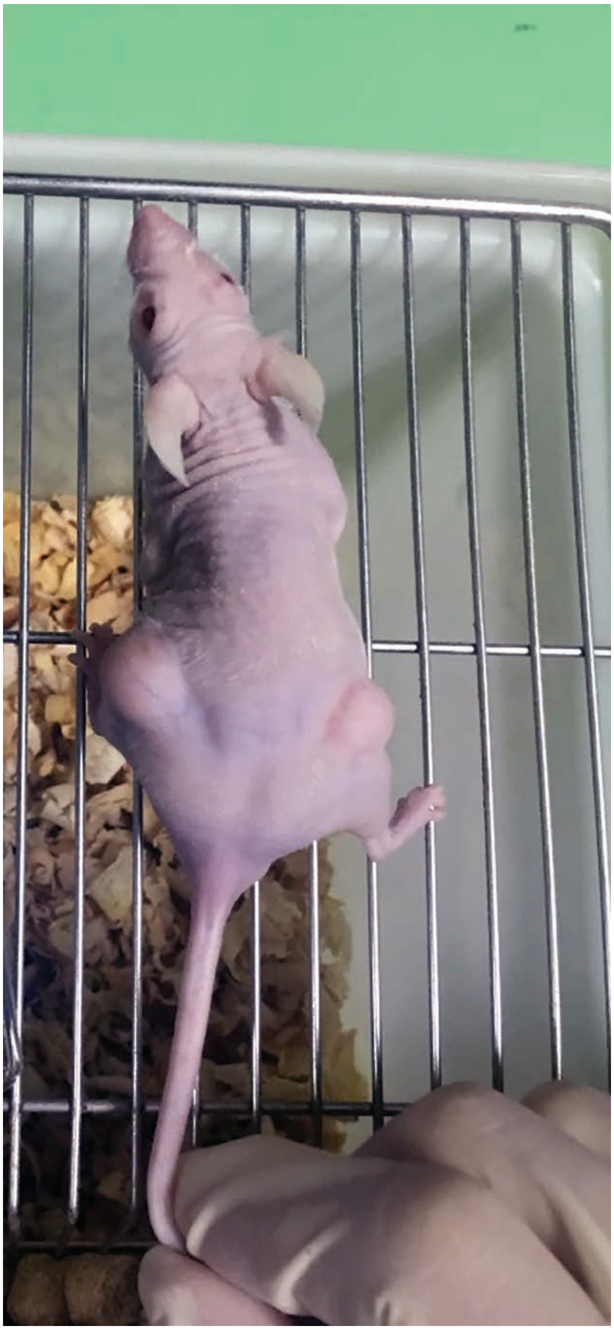

Fig. 8. Photograph of nude mouse injected with lipoaspirates that were extracted through 2.5 mm and 2.0 mm cannulas on either side of the body. Left: 2.5 mm; right: 2 mm.

described above. Many researches focus on the generation and metabolism of the oil cystic nodules, but a common agreement has not been reached so far. This research provides another view to this problem.

The generation of oil cystic nodules may contribute to the volume retention, but it is not considered as a major factor of larger fat graft retention in 2.5 mm cannulas, as the oil cystic nodules appears quite rare. In addition, the 2.5 mm cannula has a larger mass retention as well, which cannot be attributed to the generation of oil cystic nodules because oil

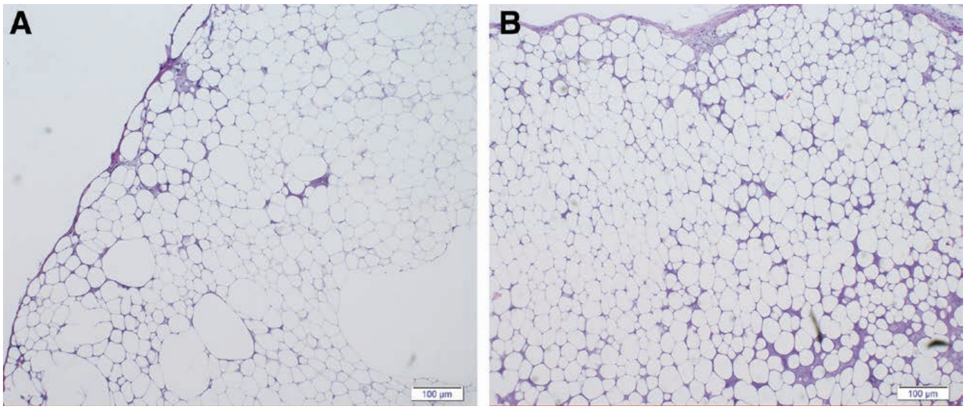

Fig. 9. Histologic images between fat grafts extracted through different cannulas. A, 2.5 mm. B, 2 mm. Oil cystic nodules could be only observed in the grafted fat tissue obtained by the 2.5 mm cannula.

has a lower density. Based on the reasons above, the major factors of the larger fat graft retention in 2.5 mm cannula should be inlet pressure and maximum velocity.

One limitation of this research is that the simulation were conducted with the assumption of a Newtonian fluid while the adipose tissue may behave as non-Newtonian fluids[14] and Fahraeus-Lindqvist effect may happen. Therefore, a more precise simulation should be conducted to further analyze this problem.

Meanwhile, only 2 types of liposuction cannulas were employed in this experiment. Further researches may focus on more types of liposuction cannulas or changing other variables, such as the pressure outlet. Anyhow, this research provides a general way for optimizing the outcome of a liposuction, and this model is flexible enough to be used in other situations.

Our research has significant clinical values. Based on our results, we suggest that a surgeon should use a 2.5 mm cannula when fat graft retention is the first concern, such as breast reconstruction with fat grafting. However, during a more elaborate operation, like facial rejuvenation, the 2 mm cannula should be employed to avoid the generation of oil cystic nodules. And this research is to provide a mathematical view and general reference of the choice of liposuction cannulas rather than focusing only on medical phenomenon.

Finally, we would like to emphasize the importance of applicability of mathematical or biomechanical simulation in surgical operation designing. So far only limited literature can be found in this theme,[14] though these techniques are surely effective for optimizing prediction of the outcomes of surgical operations.

CONCLUSIONS

Larger diameter cannulas have lower inlet pressure and maximum velocity during the liposuction process, which further influence the viability of adipocytes and thus have larger fat graft retention. Viscosity and density of fat tissue are 2 important parameters during liposuction. However, oil cystic nodules form in the grafted fat tissue obtained by the 2.5 mm cannula after 6 months. This research is clinically significant and provides a general way for optimizing the outcome of a liposuction.

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