Micro Screw Pump to Discharge Effusion from Human Middle Ear

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In this paper we report the development of a micro screw pump for discharging effusion from middle ear for treatment of otitis media. This tool extrudes effusion using a newly designed screw, which rotates at 90,000 rpm in a pipe penetrated through tympanic membrane. This tool satisfies the discharge performance especially for high viscosity effusion while it has smaller diameter such as about 0.5 mm. We also performed clinical application to prove its feasibility usage.

1. Introduction
For treatment of otitis media, suction of effusion is conventionally performed after puncture or myringotomy through tympanic membrane [1]. However cutting its radial fiber bundles causes unnecessary hypertrophy, scar and sclerosis [2]. Doctor needs to cut as small as possible, using a small penetrating pipe. But the small pipe cannot suck high viscosity effusion. Doctor also needs to discharge effusion within 20 seconds. Generally, effusion volume inside middle ear is about 50 mm³, so that discharge rate should be more than 2.5 mm³/s. Also sound pressure level in the operation should be not harmful for patient’s middle ear. Environmental Protection Agency suggests 75 dB as permissible sound pressure level.

To satisfy requirements above, we add a rotating screw inside the pipe. In this research we introduced the micro screw pump for discharging effusion from middle ear and verify its clinical application.

2. Design of micro screw pump
As the screw, we designed twisted wires as shown in Fig.1. To prevent their separation, we fixed them with acrylic resin cured by an ultra violet light. Next we inserted the twisted wire into a pipe as shown in Fig. 2. The pipe is an injection needle used in the hospital routinely. The twisted wires screw is flexible even in rotating; doctor can bent the pipe/screw at an angle in Fig. 2, operating it in a best posture while watching the tympanic membrane.

In the research, we designed three types of the micro screw pump appeared in Fig. 3. Type A using a DC motor has maximum rotation speed of 24,000 rpm. In results, this speed was not able to achieve enough discharge rate. Type B using an air turbine can increase rotation speed to 60,000 rpm, producing enough discharge rate. But in results, this is too noisy so that it needs a thick cover to reduce noise. Type C using a synchronous motor can increase to 90,000 rpm with a gearbox. The motor is designed for dentists to handle like a pencil; The tool satisfied doctors with its silence and its disinfection procedure. Each pump can sucked effusion using negative pressure made by a vacuum pump.

Consequently, we checked various design parameters: rotation speed (less than 90,000 rpm), inner
diameter of pipe (ID; 0.23, 0.3, 0.38, 0.45, 0.46, 0.56, 1.23 mm), outer diameter of twisted wires (OD; 0.16, 0.2, 0.24, 0.28, 0.32, 0.36, 1.1 mm), twisted angle (TA; 10, 15, 20, 25 degree), negative pressure (NP; less than 60 kPa). As standard viscosity fluid, we used 85, 450, 1800, 13000 mPa•s standard fluids.

3. Evaluation of micro screw pump

We evaluated the micro screw pumps as presented in Fig. 4 to Fig. 9. Especially we checked influence on its discharge rate under various design parameters mentioned above.

Fig. 4 shows discharge rate at various fluid viscosity under suction only, extrusion only and both. As sucking higher viscosity, discharge rate becomes lower drastically. But extrusion only performs constant discharge rate even at high viscosity. When using both suction and extrusion, we can get the summation of discharge rate each.

Fig. 5 indicates the same tendency with various screws/pipes. We calculated an ideal discharge rate assuming that the screw can extrude the volume inside its lead. Compared with the ideal rate, the experimental rate was by 1 – 3 % much smaller. The slip between screw and fluid should happen. For future plan to increase the rate much more, we are trying a square cross-section wire for another thick pump. The square one has higher rate by 3 – 7 times than the round one.

To increase the discharge rate, we increase negative pressure and rotation speed. Fig. 6 shows negative pressure is effective at lower viscosity. The rate increases twice at 100 mPa•s.

Fig. 7 shows, as rotation speed increases, the rate increases linearly. So faster type C is better than type A or B.
Fig. 4 Discharge rate at various fluid viscosity under extrusion and suction

Fig. 5 Discharge rate at various fluid viscosity under extrusion (e) and suction (s)

Fig. 6 Discharge rate at various fluid viscosity under suction of negative pressure

Fig. 7 Discharge rate at various screw rotation speed

Fig. 8 Discharge rate at various gap between pipe and screw

Fig. 9 Discharge rate at various lead screw

Fig. 10 Clinical application
Fig. 8 indicates that the gap between the screw and the pipe almost doesn’t affect the rate. We observed the flow inside the pipe using a 450 mPa·s fluid with aluminum powders; the fluid which was 10 µm away from the screw didn’t move; the large slip happened; the gap of more than 10 µm is not effective for the discharge rate, but it is necessary for easy insertion of the screw into the pipe. Fig. 9 shows the influence of lead angle of the screw on discharge rate; lower angle is twice better in 10-25 degrees range.

Now we clinically applied the micro screw pump as shown in Fig. 10. Its parameters were the following: type C, 90,000 rpm, ID 0.45 mm, OD 0.28 mm, NP 51 kPa, TA 20 degree. We successfully performed 27 cases (80 %) out of 34 cases. The failure cause of 7 cases was high viscosity of effusion which looked like a solid, or small volume of effusion which stayed on the inside wall of middle ear.

We need more cases, but now we conjecture from effusion viscosity distribution measured by us that conventional suction using the ID 0.6 mm pipe could discharge only about 25 percent of 12 cases, and the micro screw pump could also discharge the rest of cases.

Sound pressure level of type C was 72 dB. It was below tolerable level. It was measured at 15 mm distance from tip of the pipe, namely near ear of the patient.

4. Conclusions
To discharge effusion from middle ear under minimum invasion, we developed the micro screw pump using twisted rotating wire. This tool successfully treats the 80 % operations within 20 seconds under the 90,000 rpm rotating screw and the 0.45 mm inner diameter of pipe.

5. Acknowledgment
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6. Reference