

INJECTOR FOR VISCOUS MATERIALS

Related Application

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The priority of provisional U.S. application Ser. No. 60/536,080, filed January 12, 2004, is claimed pursuant to 35 USC 119(e) and 363.. The disclosure of that application is incorporated by reference herein in its entirety.

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Background of Invention

In ophthalmic surgery, a high viscosity material often called a surgical viscoelastic is injected into the eye as a surgical aid. Viscoelastic materials used in ophthalmic surgery include compositions containing hyaluronic acid, chondroitin sulfate or chemically modified cellulose. Due to the unusual shear thinning or thixotropic properties of such materials, viscoelastics are injectable through a small bore needle or cannula, then recoil to a material providing stiff gel-like properties after injection. A viscoelastic is often injected into the anterior chamber of the eye during cataract surgery to maintain the intraocular space and protect the corneal endothelium from mechanical damage. The injection of viscoelastic is used to dilate tissue spaces such as Schlemm's canal during glaucoma surgery. Injection of viscoelastic is also used to dissect tissues such as the lens capsule or retinal membranes.

Viscoelastics are typically delivered to tissues with a syringe under manual control by the surgeon. A hand operated syringe is used to inject the viscoelastic through a needle or cannula attached onto a distal luer connector of the syringe. Due to the high viscosity of the material, it is often difficult to manually produce sufficient force with a syringe, especially with small bore cannulas or needles. In addition, the dynamic flow nature of viscoelastic materials makes it difficult to deliver small amounts in a precise, controlled manner.

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The present invention is related to a means for improved delivery of high viscosity materials through a cannula or needle into tissues.

Summary of the Invention

The present invention provides an injector for viscous materials comprising a syringe body having distal and proximal ends and a hollow bore connecting these ends, the distal end having a fluid outlet. A plunger is
5 disposed within the hollow bore and is coupled to a positive displacement mechanism capable of progressively advancing the plunger toward the distal end to eject fluid material contained within the hollow bore through the fluid outlet.

10 The positive displacement mechanism may comprise a threaded rod attached to the plunger or a linear translation device having a series of mechanical stops.

The positive displacement mechanism may be coupled to a powered
15 source of motion to provide an even and constant force to drive the plunger.

Brief Description of the Drawings

Fig. 1 is a schematic cross-sectional view of a first embodiment of an injector according to the invention.

20 Fig. 2 is a schematic cross-sectional view of a second embodiment of an injector according to the invention.

Fig. 3 is a schematic cross-sectional view of a third embodiment of an injector according to the invention.

Fig. 4 is a schematic cross-sectional view of a fourth embodiment of an
25 injector according to the invention that accommodates a pressure gauge to measure and regulate pressure at the injector outlet.

Fig. 5 is a graph of pressure v. flow rate of delivery of viscoelastic material from an injector as described in Example 5.

30 Description of Invention

The injector of the present invention comprises a syringe body with a proximal end and an opposing distal end, with a hollow bore between the two ends. A plunger is disposed within the hollow bore and is coupled to a mechanism that provides positive displacement of the plunger upon actuation.

The positive displacement mechanism allows high precision in delivery of viscous and in particular, viscoelastic materials from the syringe body from the distal end. By "positive displacement" it is meant that force is applied to the plunger and/or the linear translation of the plunger is incrementally restricted in such a way as to provide a constant or incrementally precise, controllable delivery of the materials from the distal end of the syringe body. The positive displacement mechanism may be configured to allow progressive linear translation of the plunger in discrete increments to control delivery. The syringe body has a fluid outlet at the distal end that may terminate in a connector such as a luer fitting for attachment of a needle or cannula.

Referring to Fig. 1, in one embodiment of the injector **3**, a threaded rod **1** is attached at its distal end to a plunger **6**. The plunger **6** is located within a syringe body **4** having a proximal flange **8**. A cap **5** is connected to the flange **8**. At the proximal end of the rod **1** is a handle **2** which can serve as a thumbwheel to turn the rod to advance the plunger **6**. A stopper **7** is located within the syringe body **4** to form an air tight seal when force of the advancing plunger is applied against the viscous material within the syringe body. The viscous material is ejected through the distal end of the syringe body into an appropriate receiving device.

In another embodiment of an injector **10**, referring to Fig. 2, a cartridge **12** prefilled with viscoelastic material and comprising a rubber septum **22** at the distal end can be loaded into the syringe body **11** and then injected in a controlled manner using a screw mechanism comprising a threaded rod **18** attached to a distal plunger assembly **16** comprising a plunger **19**, thrust bushing **20** and rubber stopper **23** that move slidably within the syringe body **11**. The injector **10** comprises a cap assembly **15** and the syringe body **11**. The plunger **19** may have a seal such as an O ring or rubber flange (not shown) to assist in forming a fluid tight seal between the plunger **19** and the syringe body **11**. The threaded rod **18** extends out through a mating threaded orifice in the cap assembly **15** at the proximal end of the syringe body **11**. Turning the end of the rod **18** advances the plunger **19** to eject the viscous material loaded within a cartridge **12**. The cap **15** may be removed to insert

the prefilled cartridge **12** into the bore of the syringe body **11**. The syringe body incorporates an internal needle **13**, at the distal end of the injector to penetrate into the cartridge. The needle provides a flow path from the cartridge to a male luer fitting **14** on the distal end of the injector. The rubber septum **22** provides fluid tight sealing of the cartridge to the internal needle. The internal thrust bushing **20** and rubber stopper **23** at the end of the plunger assembly **16** interface to the proximal end of the cartridge **12**. When the injector handle **21** is turned, the threaded rod **18** acts upon the plunger assembly **16** to provide a positive displacement action to the cartridge to deliver the cartridge contents through the distal luer fitting **14**.

The use of a positive displacement mechanism insures the precise and repeatable delivery characteristics due to the lack of a compressible component. Injectors according to the invention precisely deliver small increments (microquantities) of a viscous fluid, typically in the range of 5 to 25 microliters. The invention is advantageous particularly because the delivery of small amounts of viscous fluids is difficult when attempting to deliver through a small bore needle, microcannula or microcatheter. The precise delivery of small amounts of a viscous fluid is especially critical in microsurgery where the fluid is used to dilate or dissect delicate tissue structures.

Referring to Fig. 3, in another embodiment, the positive displacement mechanism comprises a threaded rod **40** that attaches syringe body plate **41** to a plunger plate **44** parallel thereto. Turning of the rod **40** moves the plates **41** and **44** toward or away from each other. Attachment of the plate **41** to the syringe body **42** of the plate **44** to the plunger shaft **43**, the plunger is moved to allow precision control of the delivery of material from the syringe body.

In another embodiment, the positive displacement mechanism comprises a plunger with a series of spaced mechanical stops having predetermined spacing arranged to allow linear advancement of the plunger from one mechanical stop to the next. A release mechanism or additional advancement force may be utilized to continue to advance the plunger to the

next stop. The amount of plunger translation allowed by each stop may be tailored to set the precision of injector delivery.

In another embodiment, the positive displacement mechanism is
5 attached to a conventional syringe body, allowing it to be used with a variety of prepackaged viscoelastic syringe kits. For example, the mechanism may be attached to the syringe flange and act on or replace the provided plunger.

It is thus also a feature that the injector may be provided in kits
including an injector, one or more microcannulae for delivery of materials from
10 the injector to a surgical site, and/or prepackaged cartridges containing viscoelastic material useful in surgical or medical applications

The injector may be fabricated from any suitable high strength material such as metals and polymers. Preferred are materials with may be sterilized
15 by conventional means such as by autoclaving, ethylene oxide gas treatment or exposure to ionizing radiation. Suitable materials include metals such as steel and titanium, polymers such as polysulfone, polyethylene, nylon, polymethylmethacrylate, polyethylene terephthalate, polypropylene and polycarbonate.

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The injector may also be used for rate-controlled delivery to precisely deliver viscous fluids at a slow and predetermined flow rate by maintaining a predetermined varied or constant injection pressure. When injecting through a small bore device such as a microcannula or a microcatheter with controlled
25 injection pressure, a constant or predetermined profiled flow rate of viscous fluid results. Regulation of injection pressure measured at the injector output or within the injector allows control of the flow rate. Referring to Fig. 4, pressure regulation may be accomplished by attaching a pressure gauge 36 or transducer to an injector 35. A constant injection pressure may be
30 maintained by manual control of the positive displacement mechanism while monitoring injection pressure or alternatively by electrical feedback to a powered actuator driving the injection mechanism. In an alternate embodiment, pressure regulation may also be accomplished by mechanical means by limiting applied force by the positive displacement mechanism. For

example, a clutch mechanism may be integrated into a screw drive mechanism to limit the maximum force applied to delivery the viscous material.

- 5 The injector may also incorporate a pressure relief valve into the injector to prevent over pressurization or pressure spike during viscous fluid delivery. The pressure relief valve may consist of a ball and spring assembly, where the ball is pressed across an orifice by spring force until the injection pressure overcomes the spring force to allow fluid flow and pressure release.
- 10 The relief valve may be designed to allow user adjustment of the maximum injection pressure.

The following examples are provided for the purpose of illustration and are not intended to limit the scope of the invention in any way.

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Example 1:

- An injector was fabricated from a syringe body machined from polycarbonate, designed to receive a prefilled cartridge of viscoelastic material. At its distal end, a sharpened 22 gauge needle was bonded into a
- 20 small axial through-hole in the syringe body. Concentric with the needle was a counterbore to accept a male luer fitting. The sharpened proximal end of the needle projected into the bore of the syringe in order to puncture the rubber septum of the cartridge when it was loaded into the syringe body. At its proximal end, the syringe body was externally threaded to mate to a cap and
- 25 plunger assembly. The cap assembly consisted of an internally threaded (1/2-13 UNC) machined polycarbonate cap with a small threaded (5-40 UNC) hole through its center in which a threaded stainless steel rod was located. Attached to the distal end of the threaded rod was a polycarbonate plunger that had a low friction acetyl thrust bushing fastened to its face. A knurled
- 30 thumbwheel was attached to the proximal end of the threaded rod. The cartridge of viscoelastic material as supplied by the manufacturer (Advanced Medical Optics Inc.) was sealed with a rubber septum at the distal end and rubber stopper within the bore. Following loading of the cartridge into the bore of the syringe, thereby puncturing the septum, the cap assembly was

screwed onto the syringe with the plunger end of the screw inserted into the cartridge bore. The screw was advanced until the thrust bushing contacted the rubber stopper. Continuing to advance the screw resulted in viscoelastic material being ejected from the syringe body through the needle and luer fitting. The acetyl thrust bushing prevented the rotating screw from applying a torque to the stopper and helped maintain the seal of the stopper in the cartridge bore. Based on the pitch of the thread (40 threads per inch) and the bore of the cartridge (6.72mm), a precise amount of viscoelastic material could be ejected from the syringe.

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Screw: 1 revolution = $1/40$ in = 0.025 in = 0.635mm

Cartridge bore area: $\pi * (6.72)^2/4 = 35.4\text{mm}^2$

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Volume/turn: $0.635 * 35.4 = 22.5 \text{ mm}^3$

Example 2:

An injector was fabricated with a screw driven syringe plunger designed to receive a conventional syringe body. The device consisted of a cap portion which had a slot for insertion of the syringe flange, a feed screw for advancement of the plunger, and a thumbwheel for turning the feed screw. In preparation for use, the screw feed was retracted into its proximal most position. The flange on the syringe was then inserted into the slot in the cap, and the syringe bore was aligned with the axis of the cap. The screw was then advanced into the syringe bore until the plunger contacted the stopper in the syringe. Continuing to advance the screw resulted in viscoelastic material being ejected from the syringe body through the needle and luer fitting.

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Example 3.

The injector of Example 1 was tested for delivery of three surgical viscoelastic materials, Healon, Healon GV, and Healon 5 (Advanced Medical Optics Inc.) with corresponding viscosities at zero shear of 300,000 mPas, 3,000,000 mPas and 7,000,000 mPas. Each viscoelastic material was delivered at $1/4$, $1/2$, and 1 turn of the screw mechanism of the injector. The

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resulting material delivered was placed in a tared weigh boat and weighed on an analytical balance (Mettler AG285). The results are shown below in Table 1. The resulting delivery of viscoelastic material from the injector demonstrated linear delivery characteristics in response to the turning of the screw mechanism. Since the viscoelastic materials all had a density close to 1 mg/mm³, the weight of material delivered also demonstrated good correspondence to the calculated volumetric delivery.

Table 1

<u>Injectate</u>	<u>1/4 Turn</u>	<u>1/2 Turn</u>	<u>1 Turn</u>	
Healon	5.11	10.74	22.53	milligram
Healon GV	5.63	10.87	20.60	milligram
Healon 5	5.82	11.32	23.03	milligram
Average	5.52	10.97	22.05	milligram
Calculated Volumetric Delivery	5.625	11.25	22.5	mm ³
Avg Std Error of Delivery for All Three Injectates	13.5%	5.9%	5.5%	

Example 4.

To demonstrate constant flow delivery of surgical viscoelastic material through an ophthalmic microcannula with a 90 micron diameter lumen (iScience Surgical Corporation, Redwood City CA), the injector of Example 1 was attached to the microcannula in series with a pressure gauge. The viscoelastic material (Healon GV, Advanced Medical Optics Inc.) was delivered to fill the system. The injector screw was tightened to achieve a delivery pressure of 300 psi, +-5%, and held in that range for 60 seconds. All of the fluid expressed from the tip of the microcannula during that period was captured in a dish and weighed. The data from five tests was then averaged and the standard deviation calculated. The results are shown in Table 2.

Table 2

Test Number	Mass of Expressed Viscoelastic (grams)
1	0.0048
2	0.0060
3	0.0056
4	0.0049
5	0.0055
Average	0.00536
Std Dev	0.00050

- 5 The injector delivered a constant flow of viscoelastic material of approximately 5.4 milligrams per minute, corresponding to approximately 5.4 microliters per minute.

Example 5

- 10 To demonstrate the ability to control constant flow delivery, the rate of fluid flow of surgical viscoelastic material (Healon GV, Advanced Medical Optics, Inc.) through an ophthalmic microcannula with a 90 micron diameter lumen (iScience Surgical Corporation) at a series of fixed pressures between 100 and 400 psi was measured. A minimum of three samples were tested
- 15 three times at each pressure, and a total of nine pressure levels were tested (100, 150, 175, 200, 225, 250, 300, 350, and 400 psi). Each sample was tested by connecting the positive displacement injector of Example 1 in series with a calibrated pressure gauge and then to the microcannula. The screw feed on the injector was advanced until viscoelastic material filled the
- 20 microcannula and was expressed from the distal tip. The rate of screw advancement was then manually adjusted to keep the infusion pressure at the target level. The target pressure level was maintained for a minimum of three minutes and viscoelastic fluid was captured in a small cup. At the conclusion of the three minutes the expressed viscoelastic fluid was weighed and the
- 25 flow rate calculated. Referring to Fig. 5, the data on the graph represents the average values at each pressure.

Claims:

1. An injector for viscous materials comprising a syringe body with a proximal end, a distal end with an outlet and a hollow bore between the ends;
5 and a plunger disposed within the hollow bore coupled to a positive displacement mechanism that progressively advances the plunger toward the distal end of the syringe body to eject the material within the hollow bore through said outlet.
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2. The injector according to claim 1 wherein said positive displacement mechanism comprises a threaded rod attached to said plunger.
3. The injector according to claim 2 wherein said threaded rod has
15 a thread pitch greater than or equal to 40 threads per inch.
4. The injector according to claim 1 wherein said positive displacement mechanism comprises a series of spaced mechanical stops for controlling the linear displacement of said plunger.
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5. The injector according to claim 1 wherein said positive displacement mechanism is coupled to a powered source of motion.
6. The injector according to claim 1 wherein said positive
25 displacement mechanism provides a repeatable increment of delivered volume of material of less than about 25 microliters.
7. The injector according to claim 1 additionally comprising means for regulation of the injection pressure.
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8. The injector according to claim 1 additionally comprising an injector pressure monitor.

9. The injector according to claim 8 wherein said monitor provides feedback information on pressure to an actuator, wherein said actuator provides power to drive said positive displacement mechanism.

5 10. The injector according to claim 7 wherein said means for regulation of the injection pressure comprises an attenuator to limit the force applied to eject said material.

10 11. The injector according to claim 10 wherein said attenuator comprises a clutch engageable to said positive displacement mechanism.

12. The injector according to claim 1 additionally comprising a pressure relief valve to relieve pressure within said hollow bore.

15 13. A device for delivering microquantities of viscous materials comprising
an injector for viscous materials comprising a syringe body with a proximal end, a distal end with an outlet and a hollow bore between the ends; and a plunger disposed within the hollow bore coupled to a positive
20 displacement mechanism that progressively advances the plunger toward the distal end of the syringe body to eject the material within the hollow bore through said outlet;
and
a microcannula.

25 14. A device according to claim 13 wherein said microquantities are in the range of about 5 to 25 microliters.

30 15. The device according to claim 13 wherein in said injector said positive displacement mechanism comprises a threaded rod attached to said plunger.

16. The device according to claim 15 wherein said threaded rod has a thread pitch greater than or equal to 40 threads per inch.

17. The device according to claim 13 wherein in said injector said positive displacement mechanism comprises a linear translation mechanism with a series of spaced mechanical stops.

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18. The device according to claim 13 wherein in said injector said positive displacement mechanism is coupled to a powered source of motion.

19. The device according to claim 13 wherein in said injector said positive displacement mechanism provides a repeatable increment of delivered volume of material of less than about 25 microliters.

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20. The device according to claim 13 wherein said injector additionally comprising means for regulation of the injection pressure.

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21. The device according to claim 13 wherein said injector additionally comprising an injector pressure monitor.

22. The device according to claim 21 wherein said monitor provides feedback information on pressure to an actuator, wherein said actuator provides power to drive said positive displacement mechanism.

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23. The device according to claim 20 wherein said means for regulation of the injection pressure comprises an attenuator to limit the force applied to eject said material.

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24. The device according to claim 23 wherein said attenuator comprises a clutch engageable to said positive displacement mechanism.

25. The device according to claim 13 wherein said injector additionally comprises a pressure relief valve to relieve pressure within said hollow bore.

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26. A kit for delivering microquantities of viscous materials comprising

an injector for viscous materials comprising a syringe body with a proximal end, a distal end with an outlet and a hollow bore between the ends;
5 and a plunger disposed within the hollow bore coupled to a positive displacement mechanism that progressively advances the plunger toward the distal end of the syringe body to eject the material within the hollow bore through said outlet;

and

10 a microcannula.

27. A kit according to claim 26 further comprising a prepackaged cartridge adapted to be accommodated within said injector, said cartridge containing said viscous materials.

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28. A kit for delivering microquantities of viscous materials comprising

an injector for viscous materials comprising a syringe body with a proximal end, a distal end with an outlet and a hollow bore between the ends;
20 and a plunger disposed within the hollow bore coupled to a positive displacement mechanism that progressively advances the plunger toward the distal end of the syringe body to eject the material within the hollow bore through said outlet;

and

25 a prepackaged cartridge adapted to be accommodated within said injector, said cartridge containing said viscous materials.

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