COMBINATIONS OF VISCOELASTICS FOR USE DURING SURGERY

FIELD OF THE INVENTION

The invention described herein relates to the field of viscosurgery and involves a novel combination of viscoelastic agents that exhibit an improved rheological profile for certain types of surgery, especially ophthalmic surgery.

BACKGROUND OF THE INVENTION

There are a number of known viscous or viscoelastic agents for ophthalmic surgical use (hereinafter "agents" or "viscoelastic agents"), for example, VISCOAT® (Alcon Laboratories, Inc.), which contains sodium hyaluronate and chondroitin sulfate; Provisc® (Alcon), Healon®, Healon® GV and Healon® 5 (Pharmacia & Upjohn), Amvisc® and Amvisc Plus® (Bausch & Lomb), and Vitrax® (Allergan), all of which contain essentially pure sodium hyaluronate (HA); and finally the hydroxypropylmethylcellulose (HPMC) products such as Cellugel® (Alcon). All of these highly purified products are useful in certain ocular surgical procedures, such as cataract surgery. They are used by the skilled ophthalmic surgeon for several surgical purposes, including maintenance of intraocular spaces, protection of ophthalmic tissues, particularly corneal endothelial cells, and as an aid in manipulating ophthalmic tissues. These agents are generally viscous enough to permit the skilled surgeon to use them for their intended surgical purposes, but not so viscous that expression of the agent through a cannula of acceptable bore size might be made difficult.

As suggested by the number of commercially available products, however, no one viscoelastic agent best fulfills all of the surgical purposes. Due to their particular physical characteristics, certain viscoelastic agents will be better suited for particular aspects of the surgical procedure. For example, in cataract surgery, the combination of relatively low molecular weight sodium hyaluronate and chondroitin sulfate found in the VISCOAT® product works well in maintaining the anterior chamber during

capsulotomy, or anytime during the cataract procedure, and in adhering to and protecting tissues, particularly the corneal endothelium. However, due to its adhering and coating characteristics, the VISCOAT® product is more difficult to remove from the anterior chamber of the eye than some other agents. In addition, although it can be used to manipulate tissue for insertion of an intraocular lens (IOL) into the eye, certain other agents are better suited to perform this function.

Viscoelastic solutions of relatively high molecular weight sodium hyaluronate having functionally desirable viscosity, such as Healon® or the PROVISC® product (Alcon Laboratories, Inc.), are highly cohesive, but relatively non-adherent with respect to the tissues they may contact during surgery. These characteristics make such solutions well suited for use as a soft tool for the gentle manipulation of delicate tissues during surgery. For example, these viscoelastic agents can be used to inflate the capsular bag and facilitate the insertion of an IOL. Their cohesiveness and lack of adhering quality also make them easier to remove from the eye at the end of surgery. However, sodium hyaluronate is not as effective as some agents in protecting ophthalmic tissues, especially during phacoemulsification procedures.

HPMC adheres well to ophthalmic tissues and therefore protects them, but does not perform as well as, for example, the VISCOAT® product, in maintaining the anterior chamber, or as well as sodium hyaluronate in manipulating tissues. However, it can be easily diluted with irrigation fluid for removal following IOL implantation. The removal of the viscous or viscoelastic agent at the close of surgery is generally effected to prevent or reduce the severity of intraocular pressure spikes following surgery.

In general, viscous solutions containing relatively higher molecular weight agents, including high molecular weight sodium hyaluronate, are more effective in maintaining the intraocular space than less viscous solutions containing relatively lower molecular weight agents; however, the high molecular weight agents tend to be highly cohesive and may be prematurely aspirated from a surgical site. This may occur, for instance, if they come into contact with aspiration port of the phacoemulsification tip during a phacoemulsification procedure. The relatively lower molecular weight

products, which due to their tenacious characteristics adhere to and protect tissues, are more difficult to remove from the surgical site.

In recognition of the fact that each of the foregoing agents has certain advantages and disadvantages for a given surgical procedure, the use of multiple viscoelastic agents in a single surgical procedure has been suggested. See, U.S. Patent No. 5,273,056. The multiple viscoelastic approach has enjoyed some commercial success. Consider for example Pharmacia's Healon® series – each product containing a different molecular weight fraction of sodium hyaluronate – or Alcon's DuoVisc® product, which contains both Provisc® and Viscoat®. The need remains, therefore, for a single viscoelastic agent that can adequately perform each of the functions associated with a given surgical procedure. The compositions of the present invention are believed to meet that need.

Commonly assigned U.S. Patent Application Serial No. 09/857,543 discloses viscoelastic materials designed for use in otic surgery. Among the compositions disclosed therein is a formulation comprising 1.6% high molecular weight sodium hyaluronate and 4% chondroitin sulfate. The particular molecular weight ranges of the present invention, however, are neither disclosed nor suggested in that application, the contents of which are by this reference incorporated herein. Nor does that application suggest the unexpectedly improved performance realized by the present invention in ophthalmic surgery.

U.S. Patent No. 6,051,560 discloses combinations of HA and chondroitin sulfate for use in ophthalmic surgery. The commercial embodiment of that patent is found in the Viscoat® product, which, according to the package insert, contains 4 % by weight chondroitin sulfate having a molecular weight of approximately 22,500 daltons and 3 % by weight sodium hyaluronate having a molecular weight of over 500,000 daltons. As described above, the commercial product offers less than optimum performance in certain phases of the typical cataract surgical procedure. Quite unexpectedly, we have discovered that by modifying the molecular weight and concentrations of the polymeric components in the Viscoat® formulation, it is possible to create a viscoelastic agent that offers significantly improved overall performance compared to any of the products available on the market.

SUMMARY OF THE INVENTION

The present invention is directed to particular combinations of sodium hyaluronate and chondroitin sulfate, which exhibit a markedly improved rheology for performing all functions of a viscoelastic agent in an ophthalmic surgical procedure, especially a cataract procedure. During such a procedure, the unique blend of components in the viscoelastic agents of the present invention achieve satisfactory intraocular space maintenance and ocular tissue protection, and at the same time permit manipulation of ocular tissues and ease of removal at the end of the procedure. An object of the invention is to provide a single viscoelastic agent that affords the physician the functional benefits of a multiple agent system without the attendant cost and inconvenience of using multiple products/syringes during a single surgical procedure.

DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a graphic depiction of the rheological profiles of embodiments of the present invention, together with those of other viscoelastic formulations.

FIGURE 2 is a diagram depicting a preferred method of cohesion-dispersion determination.

DETAILED DESCRIPTION OF THE INVENTION

Viscoat® (Alcon) as discussed above, has been commercially marketed for years. The Viscoat® formulation, and methods of its manufacture are generally described in U.S. Patent No. 6,051,560, the entire contents of which are by this reference incorporated herein. Like all other stand-alone viscoelastic products currently on the market, the rheological properties of the Viscoat® material are not ideally suited for all steps of various surgical procedures, e.g. cataract surgery. The present invention is directed to new viscoelastic formulations having significantly altered rheological profiles, which

permit superior performance in ophthalmic surgery, and in particular in the conventional steps or phases in the surgical removal of cataracts.

The compositions of the present invention comprise a medium molecular weight hyaluronic acid salt, preferably sodium hyaluronate, in a concentration range from about 1.0 to about 2.0% w/v in combination with chondroitin sulfate at a concentration of about 3 to about 5% w/v in an aqueous solution suitable for ophthalmic surgery. For the hyaluronic acid/hyaluronate (HA) component, the preferred molecular weight range is about 1.5 to about 1.9 million daltons, and preferably approximately 1.7 million daltons. The preferred concentration range is from about 1.5 to about 1.8% w/v, and preferably about 1.6% w/v. For the chondroitin sulfate (CS) component, the preferred molecular weight is from about 20,000 or 25,000 to about 100,000 daltons, more preferably, from about 50,000 to about 90,000, and most preferably, about 80,000 daltons. The chondroitin sulfate component of the compositions of the present invention may be obtained in the desired molecular weight range from Seikagaku (Tokyo, Japan). The sodium hyaluronate component may be acquired from commercial sources such as Genzyme Corp. (Cambridge, MA), or prepared by means known to those skilled in the art. Molecular weight determinations of the HA component of the compositions of the present invention are weight average molecular weights as determined by gel permeation-HPLC. The compositions of the present invention may be prepared in the manner described in U.S. Patent No. 6,051,560 previously incorporated by reference, and in the manner described in Example 1 below.

Various viscoelastic formulations comprising HA and CS were prepared in accordance with Example 1 below. These formulations were then subjected to both subjective evaluation by skilled surgeons and rheological assessment as described below.

EXAMPLE 1

Viscoelastic Preparation

A. HA raw material (sodium hyaluronate) was obtained sterile.

B. CS raw material (sodium chondroitin sulfate) was obtained non-sterile. CS was fully hydrated in buffer and sterile filtered through a 0.2μ filter.

C. Sterile HA raw material was hydrated in the sterile CS/buffer solution following an aseptic process while mixing in two syringes connected via a Luer-Lok connector.

D. After proper mixing and over-night hydration, a sterile clear viscous solution was obtained which was stored in refrigerator for complete de-aeration.

E. The viscous solution was then filtered through a 4.5μ filter under 50 psi pressure to yield essentially particulate-free, clear solution.

EXAMPLE 2

TABLE 2
FORMULATONS EVALUATED

SOVD	Composition	Label
HMW HA (2.2 md)	1.6% HMWHA + 1% CS	A
	1.6% HMWHA + 2% CS	B
	1.6% HMWHA + 4% CS	C
MMW HA (1.6-1.7 md)	1.8% MMWHA + 1% CS	D
	1.8% MMWHA+ 4% CS	F
Viscoat	3% HA + 4% CS	G
Healon-GV	1.4% HMWHA	H

HMW = high molecular weight
MMW = medium molecular weight
md = million daltons

Rheological profiles of one preferred embodiment (Formula F) and other formulations tested, including marketed viscoelastic products are shown in Figure 1. From Figure 1 it is apparent that viscosity of Formula F falls uniquely between that of

Provisc and of Healon GV at low shear rates, but surprisingly falls between that of Viscoat and of Provisc at high shear rates.

EXAMPLE 3

Table 3 presents zero shear viscosity data for the formulation F and other formulations compared to those of the marketed viscoelastic products.

TABLE 3
ZERO SHEAR VISCOSITY

Formulation Label	Zero Shear Viscosity (Pa.s.)
A	2300
B	2600
C	2900
D	170
F	280
Viscoat	60
Provisc	150
Healon-GV	1500

Consistent with the data presented in Figure 1, the zero shear viscosities of the medium molecular weight HA formulations of the present invention (D and F) are greater than the zero shear viscosities of Viscoat and Provisc, but significantly less than that of Healon-GV.

EXAMPLE 4

Several physical parameters of viscoelastic materials have been measured and are well-documented including viscosity, pseudoplasticity (shear-thinning), and molecular weight. A method to measure their cohesion is described by Poyer et al., *Quantitative method to determine the cohesion of viscoelastic agents, by dynamic aspiration*, J. Cataract Refract. Surg., 24:1130-1135 (1998), the contents of which are by this reference

incorporated herein. Poyer et al. describe a cohesion-dispersion index (CDI) for viscoelastics which is determined in a manner generally depicted in FIGURE 2 and using the following materials and methods.

MATERIALS AND METHODS

Materials and Equipment

Polypropylene test tubes (found bottom, 14 mL) were obtained from Becton Dickinson Labware and polypropylene pipette tips (model RT-20), from Rainin Instrument Co. Cell culture clusters (24 well) were purchased from Costar. A Sartorius model 1612 balance was used for the gravimetric determinations and a positive displacement pipette (Rainin model M1000), for viscoelastic sample transfer. Vacuum was applied with a Gast vacuum pump.

Aspiration of Viscoelastic Sample

Polypropylene well inserts were cut from the bottom of 14 mL test tubes, weighted (W_0), and inserted into the well of a 24-well cell culture cluster for secure holding (FIGURE 2). Polypropylene provides a non-adsorptive surface to minimize interference with aspiration by potential adsorptive forces from the container. The viscoelastic sample (0.5 mL) was dispensed into the insert with a positive displacement pipette and the insert (containing sample) reweighed (W_1).

A regulated vacuum was connected via flexible polyvinylchloride tubing to a polypropylene pipette tip (internal diameter 0.5 mm). Vacuum was applied at various levels indicated by a gauge (5, 10, 15, 20, 24, and 28 inches Hg, equivalent to 127, 254, 381, 508, 610, and 711 mm Hg) to the viscoelastic samples, using a new sample (in duplicate) for each vacuum level. Vacuum was applied with the pipette tip held in the clamp of a dovetail slide. The tip was lowered into the sample for a contact time of 2 seconds. The tip's position was fixed at an angle of 80 degrees from the horizontal

surface of the sample, preventing obstruction of the tip by the bottom of the insert. After aspiration was performed for each sample, all inserts were re-weighed (W_2).

Data and Statistical Analysis

The percentage of the viscoelastic sample aspirated was calculated as follows:

$$\% \text{ Aspirated} = \frac{(W_1 - W_2)}{(W_1 - W_0)} \times 100\%$$

Data were plotted as percentage aspirated versus vacuum. the slopes of the steepest portion of the curve for each viscoelastic (based on the 2 steepest points of the curve) were compared for statistical significance using covariance analysis (SAS Institute, Inc.). The value of each slope represents the CDI of a particular viscoelastic agent (percentage aspirated/100 mm Hg vacuum).

The break point of a viscoelastic agent represents the vacuum level at which bolus removal of the agent begins. Bolus removal (for the purpose of break point) is defined as having more than 25% of the sample removed by a single vacuum level. Break point was determined using the percentage aspirated versus vacuum curves. Dispersive viscoelastic agents tend to have a low break point and cohesive compounds, a relatively high break point (indicative of sudden bolus removal).

The foregoing methodologies were used to determine the viscosity and CDI of the viscoelastic compositions.

TABLE 4

Cohesion-Dispersion Index (CDI)

Product	CDI
SOVD-F Optimum	12.3
SOVD[1] (pre-eto)	11.3, 9.0, 11.3
SOVD[1] (post-eto)	14,.3, 13.2, 15.0
SOVD[2]	11.4
SOVD[2] 1.65%HA	13.2
SOVD[2] 1.7%HA	12.8
Viscoat	3.4
Provisc	46
Healon	40
Healon-GV	72

[1]Heat degraded HA (sodium hyaluronate) raw material (1.6%HA).
[2]Homogenized HA (sodium hyaluronate) raw material.
The terms "pre-eto" and "post-eto" refer to before and after ethylene oxide sterilization treatment, respectively. Unless otherwise indicated, HA concentration in the SOVD formulations is approximately 1.6 %. All concentrations are w/v.

The medium molecular weight HA formulations of the present invention (denoted SOVD in Table 4) have CDIs ranging from 9 to 15. The molecular weights of the sodium hyaluronate in these SOVD formulations range from 1.6 to 1.7 million daltons. The SOVD CDI values are significantly greater than the CDI of Viscoat, and significantly lower than the CDIs of Provisc, Healon and Healon-GV.

EXAMPLE 5

TABLE 5

EVALUATION OF PREFERRED EMBODIMENT

Sodium hyaluronate (medium MW: 1.5-1.9 md, preferably 1.6-1.7 md)	1.0-2.0% w/v, preferably 1.5-1.8% w/v, most preferably 1.6%
Sodium chondroitin sulfate (MW:20,000 – 100,000 daltons, preferably 50,000-90,000, and most preferably 80,000 daltons	3-5% w/v, preferably 4%
Monobasic sodium phosphate	0.045%w/v
Dibasic sodium phosphate	0.2%w/v
NaCl	0.31%w/v
HCl/NaOH	To adjust pH
Water for Injection USP	QS 100% w/v

The preferred composition of the present invention is viscoelastic polymer solution intended for intraocular use as a surgical aid in anterior segment surgeries. It is comprised of a medium molecular weight fraction of sodium hyaluronate (HA) at a concentration of 1.6% and sodium chondroitin sulfate (CS) at a concentration of 4% dissolved in a physiological buffer. It has an osmolality and pH similar to aqueous humor. The HA has an average molecular weight of 1.6 to1.7 million daltons and was obtained from Genzyme (Cambridge, MA). The preferred formulation has a viscosity at rest of 250-350 Pa.s. (250,000-350,000 times higher than aqueous humor). No signs of immunogenicity were reported in previous studies on HA and CS performed in humans. In a pre-clinical study in a rabbit model, this preferred embodiment was found to maintain the anterior chamber dome during phacoemulsification by remaining in the eye during phacoemulsification surgery. Proper dome maintenance is essential for effective protection of the corneal endothelium. In comparison to marketed viscoelastic products (Healon-GV and Healon-5), the composition of the present invention created and maintained a deeper anterior chamber during the phaco procedure, and thereby it allowed safe and controlled manipulation in the eye, with minimized trauma to the corneal endothelium and other tissues. In comparison to Viscoat, the composition of the present invention was easier to remove after phaco during the irrigation/aspiration (I/A)

procedure, and it created and maintained a clear field of vision during surgery. The composition of the present invention is easy to inject, as the viscosity decreases considerably when expelled through the cannula, but then immediately returns to its high viscosity state after injection. Preliminary results of pre-clinical safety indicate that the inventive composition was non-inflammatory to intraocular tissues and had an acceptable IOP profile in comparison to Healon.

Skilled practitioners will recognize that the preferred compositions of the present invention will also be particularly useful in the treatment of chondromalacia and osteoarthitis , especially grade I and grade II osteoarthritis, through intraarticular injection as described in commonly assigned U.S. Patent Application Serial No. 10/082,743 relating to the use of sodium hyaluronate and chondroitin sulfate mixtures in such therapy. The contents of said application are by this reference incorporated herein.

Those skilled in the art will similarly appreciate that the compositions and methods of the present invention will have utility in a variety of therapies and especially in drug delivery, cosmetic surgery and reconstructive surgery. The present invention is particularly well suited for delivery of anti-fibrotics, antibiotics, steroidal and non-steroidal antiinflammatories, anesthetics, analgesics and other medicaments or gene therapies to diseased or traumatized tissues in need thereof. Cosmetically, these compositions may be injected to reduce wrinkles or to treat varicose veins. For treatment of dermal lines or wrinkles, these compositions may be combined with a muscle relaxing agent such as botulinum toxin type A, commercially available as BOTOX® (Allergan, Inc., Irvine CA, USA), and injected subdermally in the conventional manner. The presently disclosed compositions and methods may also be used in any environment where there is a need for tissue separation or stabilization and the potential exists for complications, typically post-surgical, arising from tissue fibrosis and/or adhesions. They will be particularly useful in nasal, spinal cord, cardiovascular, orthopoedic and orthodontic surgical procedures that would otherwise be prone to such complications. Skilled practitioners will recognize that the preferred retention characteristics of the viscoelastic agent will depend upon the type of procedure for which it is being employed.

As used herein, the term "ophthalmically acceptable," when used to describe salts or vehicles, means any salt or vehicle that would be suitable for administration to the eye of a patient by any conventional means,and particularly during surgery, without significant risk of deleterious health consequences. Sodium salts of hyaluronic acid and chondroitin sulfate, and aqueous vehicles are most preferred.

The invention has been described by reference to certain preferred embodiments; however, it should be understood that it may be embodied in other specific forms or variations thereof without departing from its spirit or central characteristics. The embodiments described above are therefore considered to be illustrative in all respects and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description.

WHAT IS CLAIMED IS:

1. A sterile, aqueous viscoelastic composition for use in ophthalmic surgical procedures, comprising a combination of hyaluronic acid and chondroitin sulfate, or ophthalmically acceptable salts thereof, in an ophthalmically acceptable vehicle, wherein the hyaluronic acid or ophthalmically acceptable salt thereof has a molecular weight of 1,500,000 to 1,900,000 daltons and is present at a concentration of 1.0% to 2.0% w/v; and wherein the chondroitin sulfate or ophthalmically acceptable salt thereof has a molecular weight of 20,000 to 100,000 daltons and is present at a concentration of 3 to 5% w/v.

2. The composition of claim 1, wherein the composition comprises sodium hyaluronate at a concentration of 1.5 to 1.8%w/v.

3. The composition of claim 2, wherein the sodium hyaluronate has a molecular weight of 1,600,000 to 1,700,000 daltons.

4. The composition of claim 3, wherein the sodium hyaluronate is present at a concentration of 1.6% w/v, and wherein the chondroitin sulfate or ophthalmically acceptable salt thereof has a molecular weight of 50,000 to 90,000 daltons and is present at a concentration of 4% w/v.

5. The composition of claim 4, wherein the composition further comprises:

monobasic sodium phosphate at	0.045%w/v;
dibasic sodium phosphate at	0.2%w/v; and
NaCl at	0.31%w/v.

6. A method of performing cataract surgery on an eye, comprising administering to the eye a tissue stabilizing effective amount of the composition of any of claims 1-5.