A method for performing cataract surgery by slicing or shearing thin layers of cataractous tissue with a surgical probe incorporating a very small diameter tip which performs as a rotary cutter. In one embodiment of the invention, this tip includes a pair of concentric tubes, the outer of which is stationary relative to the inner tube. The inner tube is driven by a miniature motor housed within the probe body. A saline solution conduit and an aspirating vacuum conduit are connected to the robe to supply an irrigating saline solution between the two cutter tips during surgery and an aspirating outlet for cataractous tissue through the bore of the rotating inner tube. The force of the aspirating vacuum is automatically controlled by a plunger which is actuated to close off the vacuum supply to limit any excessive aspiration surge forces which may be created by the reopening of a momentarily plugged tip. This automatic control is necessary to prevent anterior chamber collapse with undesired posterior corneal surface and vitreous face approximation to the probe tip. Several tip-cutter embodiments are shown which are adapted for use in surgical procedures requiring different degrees of cutting safety.
METHOD AND APPARATUS FOR CATARACT SURGERY

CROSS REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of U.S. Pat. application Ser. No. 643, filed Jan. 5, 1970, now abandoned, by the same inventors and entitled "Method and Apparatus for Cataract Surgery," and the entire disclosure of the parent application is incorporated herein either explicitly or by reference.

BACKGROUND OF THE INVENTION

Almost invariably, cataract surgery as performed in the prior art, has involved a large incision of the sclera. This incision is required to remove adequately the cataractous tissue. As a result of this incision, post operative recovery has been unnecessarily painful and prolonged. In many instances, the patient manually massages the eye in order to temporarily relieve the discomfort. In some instances, the large sutured incision is thus ruptured or the eye is functionally harmed.

The large incision has also enhanced the probability of post surgery infections which can result in the permanent loss of vision in severe cases.

Additionally, with the cost of hospital care increasing steadily, the long post operative recovery period has placed a high total cost on cataract surgery which could be reduced if a shorter hospital convalescence were made medically possible.

Accordingly, the present invention has as its major objectives minimizing the trauma and recovery time associated with cataract surgery to the extent that the patient benefits not only medically but also economically.

DESCRIPTION OF THE PRIOR ART

Aspiration of a cataract through a needle (hollow tube) in an effort to minimize the size of surgical incision probably dates back to antiquity. Compound needles have recently been proposed which provide both the irrigating and aspiration functions usually required to remove cataractous tissue. However, this technique has several disadvantages. For example, the surgeon does not have complete control of the operation, as an assistant must control the flow of the irrigating solution. Moreover, manipulation of the compound needle in the anterior chamber is more limited, and overfilling of the chamber by excessive irrigating pressure may rupture the posterior capsule. Current aspiration-irrigation techniques can only be used in soft cataractous lens surgery existing in patients under the approximate age of 30. After the age of 30, the lens nucleus becomes sclerotic and does not permit removal by aspiration-irrigation technique alone.

A more promising technique and apparatus has been recently introduced which has been generally termed an ultrasonic cataract emulsifier. In this arrangement, a small incision is made and a flow of artificial aqueous at a predetermined height to give a pressure of 20 mm mercury in the eye is allowed to flow between a silicon sleeve and a titanium needle. The titanium needle vibrations (reciprocates) at a frequency of about 40,000 cycles per second. The ultrasonic waves perform no function in the eye, as the cutting is strictly a contact phenomenon.

The ultrasonic vibrating tip contacts the cataractous lens, and the tissue, which has been irrigated, is aspirated through the bore of the vibrating tip which is connected to a vacuum pump.

When and if the tip becomes plugged by a piece of lens, the pump continues pumping, and the vacuum in the line builds up to help aspirate that piece of lens into the system. The longer the piece of lens remains on the tip, the higher the vacuum creates in the line.

This is a potentially dangerous system at the precise moment when the tip becomes unplugged, because the cornea can collapse onto the tip and the vitreous face can also be pulled forward. This dangerous potential is alleviated by the use of a flow meter, and a sensor in the flow meter which senses when the flow has dropped to zero (in other words when the tip is occluded). As soon as flow begins, a solenoid valve vents the suction line to the atmosphere briefly to thus prevent corneal collapse.

SUMMARY OF THE INVENTION

The present invention has been used for the removal of soft congenital cataracts as well as hard dense calcified congenital cataracts, development cataracts, traumatic cataracts including those associated with dense fibrous after-cataract membranes. In many of these cases, vitreous involvement and complications are a foregone conclusion. In these situations, the current aspiration-irrigation technique or the ultrasonic method would not be effective in the management of dense fibrous after-cataracts, traumatic cataracts, or calcified posterior polar congenital cataracts. Successful management of these cases also requires that a vitrectomy be performed. This is readily accomplished with the present invention and cannot be accomplished by the above-mentioned pre-existing techniques. The rotary cutter of this invention generates greater torque and permits the use of various novel tip configurations, thereby providing increased surgical safety and versatility.

Additionally, corneal collapse is prevented automatically in one embodiment of the invention by the use of an integral plunger which closes the vacuum or aspirating passages from the vacuum pump when the vacuum exceeds permissible limits. The line also reopen automatically when safe conditions are restored.

An important novel aspect of the invention resides in the provision of a "three-tube" cutting tip construction. This three-tube tip construction is particularly advantageous in that it is impossible for vitreous material to wind on the cutting tip rotor and positive infusion of irrigating fluid onto the surgical area is always assured. According to a further aspect of the invention axial loading on the cutting tip rotor is eliminated and this provides reduced tear and tear on the tip as well as improved cutting efficiency of the tip cutting edges. Novel tip configurations for cutting via shearing action and impacting action are also disclosed. The invention also permits the use of simplified irrigation and aspiration circuits.

The apparatus is greatly simplified over that of the prior art and, therefore, is less costly to produce and maintain.

DETAILED DESCRIPTION OF THE DRAWINGS

In order that all of the structural features for attaining the objects of this invention may be readily understood, reference is herein made to the following drawings wherein:
FIG. 1 shows an overall perspective view of the apparatus with the probe at the left and the operating console at the right;

FIG. 2 is a diagrammatic layout of the apparatus;

FIG. 3 is a front-end view of the probe;

FIG. 4 is a partial sectional view of the probe taken along the line 4—4 of FIG. 3;

FIG. 5 is a perspective view of a first embodiment of the probe tip;

FIG. 6 is a perspective view of a second embodiment of the probe tip;

FIG. 7 is a perspective view of a third embodiment of the probe tip;

FIG. 8 is a sectional view of the third embodiment of the probe tip taken along the line 8—8 of FIG. 7;

FIG. 9 is a sectional view taken along the line 9—9 of FIG. 4;

FIG. 10 is a perspective view of the surge-control plunger;

FIG. 11 is an enlarged sectional view of the tip and associated components of the probe;

FIG. 12 is a view of the human eye with the probe tip in the lens;

FIG. 13 is an enlarged view of that portion of the human eye adjacent the probe tip;

FIG. 14 is a perspective end view of one form of fragmenting type of cutting tip;

FIG. 15 is a perspective end view of another form of fragmenting type cutting tip;

FIG. 16 is a perspective end view of yet another form of fragmenting type cutting tip;

FIG. 17 is a longitudinal sectional view through another embodiment of the rotary cutter of the present invention;

FIG. 18 is an enlarged sectional view taken along line 18—18 in FIG. 17;

FIG. 19 is an enlarged longitudinal section view of the cutting tip of FIG. 17;

FIG. 20 is a perspective end view of the rotor of the cutting tip of FIG. 19;

FIG. 21 is a perspective end view of another form of rotor somewhat similar to that of FIG. 20;

FIG. 22 is a perspective end view of another cutting tip for use in the cutter of FIG. 17;

FIG. 23 is a perspective end view of yet another cutting tip for use in the cutter of FIG. 17;

FIG. 24 is a perspective end view of the rotor of the cutting tip of FIG. 23;

FIG. 25 is a perspective end view of another form of rotor similar to the rotor of FIG. 24, and

FIG. 26 is a schematic diagram of irrigation and aspiration circuits which may be used with the cutter of FIG. 17.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGS. 1 and 2, saline solution of conventional formulation for cataract surgery is stored in the inverted and elevated flask 10 and is supplied to probe 11 through a flexible conduit 12 which is connected to an inlet port 13 of probe 11 through a rigid plastic connector 9 fixed to the probe body by clamp 8. The flask 10 is held at a desired elevated position hereafter explained by an adjustable stand 30. The flow of saline solution may be stopped or restricted by manually manipulating valve 14 located in the saline solution conduit 12. Flow of saline solution can also be initiated by electrically energizing the clamp-type solenoid valve 29 with foot switch 28 to thereby release the clamp and open the saline conduit 12.

Port 16 of probe 11 is coupled to rigid plastic connector 7 and then to flexible vacuum conduit 15 which is routed through a coiled length of capillary tubing 18 (FIG. 2) and then through a three-way electrically operated solenoid valve 17 (FIG. 2). Solenoid valve 17 selectively connects conduit 15 to atmosphere, or to receiver flask 20 when solenoid 17a is energized to actuate plunger 17b to the left to enable spool 17c to connect conduit 15 to the flask. The receiver flask 20 is connected through a vacuum pressure regulator 19 equipped with a pressure gauge 23 to an electrically operated vacuum pump 21 (FIG. 2). Three-way solenoid valve 17 (FIG. 2) is electrically operated by a foot switch 22.

Probe 11 houses a rotating stepping motor 31 (the details of which are shown in FIG. 4). Electrical power is supplied to this motor through switch 33, a DC power supply 34, a fixed oscillator 35, a motor logic circuit 36 and a plurality of electrical conductors 32. The operating panel of console control 37 (FIG. 1) contains a master off-on power switch 38, a master saline off-on switch 39, a vacuum pump off-on switch 39, a vacuum pump off-on switch 40, a master vacuum off-on switch 41, and a master off-onutter switch 42. The schematic circuit connection of these components is shown in FIG. 2, with energizing potential being applied to power input terminal 25.

As is shown in the end view of FIG. 3, the body of probe 11 is generally cylindrical about the intersection of the horizontal and vertical center lines with a protrusion 24 providing a boss for the saline inlet port 13.

In FIG. 4, the rotating stepping motor 31 has a hollow shaft 43 projecting beyond both ends of the motor housing. A coupling 44 is permanently fixed to the left end of shaft 43. An adapter 45 is threaded into coupling 44. An inner and rotating tube 46 is received by and permanently fixed to adapter 45. Shaft 43 of the rotating stepping motor 31 is generally of a tubular configuration with passageway 47 extending axially throughout its entire length.

The left end of shaft 43 is rotatably sealed in the motor housing, and the right end of shaft 43 engages an O-ring 48 thus providing a seal on the outside diameter of shaft 43. This same O-ring 48 effects a seal between motor end bell 49 and the end face of valve body 50. The outside diameter of motor 31 is sealed against the inside diameter of probe 11 by O-ring 67. Valve body 50 is generally cylindrical in shape with a concentrically located bore 51. A plunger 52 (FIG. 10) is housed near the left end of bore 51. This plunger is closely and slidably fitted into bore 51. Plunger 52 is urged leftwardly by a helical spring 53 which is held in place by an adjusting screw 54 threadably engaged into the right end of valve body 50.

Two U-shaped crossports 55 intersect bore 51 radially just to the rear of plunger 52. These passageways 55 then connect to the rear counter bore 56 of valve body 50.

A slot 57 extends the entire length of valve body 50 to provide a passageway for the motor energizing conductors 52 and also a ground wire. Plunger body 52 (FIG. 10) has a passageway 59 extending from one end to the other parallel to but offset from the centerline of the plunger. Plunger 52 is prevented from fully contact-
ing the end of the motor shaft 43 by a small projection 59 which is an integral part of the end face of plunger 52.

An adapter body 60 is also positioned within probe 11. This adapter is generally cylindrical body with a passageway 61 running axially and concentrically through its entire length. The right end of passageway 61 terminates in port 16, and the left end of passageway 61 connects to counter bore 56, with an O-ring 62 effecting a seal between the end face of adapter body 60 and valve body 50. A slot 63 similar to slot 57 extends the full length of adapter body 60 to provide a passageway for motor conductors 32. A rubber grommet 64 envelops the motor conductors 32 within probe 11 to effect a strain relief for the motor conductors.

The entire motor assembly 31, the valve body 50, and the adapter body 60 are keyed together to maintain radial alignment and are compressibly are rigidly held within probe 11 by being trapped between the shoulder 66 of housing sleeve 26 and end 68 of the threaded adapter 65.

An outer tube 70 of probe tip 68 is permanently and concentrically received by the central bore of adapter 71. The right end of adapter 71 is threadably engaged concentrically into adapter 65. The amount of engagement of the threads of adapter 71 into adapter 65 is controlled by three set screws 72a, 72b and 72c (FIG. 3). Once the proper engagement is determined, these three set screws 72a, 72b and 72c can be tightened equally, thus locking the adapter 71 into adapter 65. An annular passageway 73 exists between the inside diameter of the outer tube 70 and the outside diameter of the rotatable tube 46 (FIG. 11). Saline solution entering at port 13 is forced to flow through passageway 74, chamber 97 and then through this annular passageway 73.

FIG. 4 shows that inside passageway 75 of rotatable tube 46 communicates through passageway 76 of adapter 45, passageway 47 of motor shaft 43, passageway 58 of plunger 52, double crossports 55, counter bore 56, passageway 61, to the vacuum inlet port 16.

In FIG. 5, a first embodiment of a probe tip 68 with its rotatable cutter is shown. In this version, a generally square or rectangular cutter bar 80 is recessed and permanently fixed radially across the end of the rotatable tube 46. This bar 80 is small enough to provide four segmented aspiration openings 82 which connect to passageway 75 (FIGS. 1 and 11). Likewise, a generally square or rectangular bar section 81 is recessed and permanently fixed radially across the end of tube 70 providing two segmented passageways 83 through which the saline solution can flow from the annular openings 73. The objective of this configuration is to provide a shearing or scissors action between the stationary cutter bar 81 and the rotatable cutter bar 80. To effect a good shearing action between these two bars, it is necessary to establish a very small end clearance which can be adjusted by controlling the amount of engagement of the thread on adapter 71. Untreading adapter 71 provides greater clearance, while threading it into adapter 65 (FIG. 4) reduces the clearance. Once a close clearance is established between the two cutter bars 80 and 81, adapter 71 can be secured in this position by the three set screws 72a, b, c. Accordingly, tip 68 acts as shearing cutter which removes cataractous tissue in thin layers by aspiration and removal through openings 82. In a preferred embodiment outer tube 70 has a diameter of the order of two millimeters.

In FIG. 6, a probe tip construction similar to that of FIG. 5 is shown, except the outer tube 70 is curled inwardly at its far end with a generally square bar 84 being recessed and permanently affixed radially across the end opening. With end 70c of tube 70 being curled inwardly, the annular passageway 73 is highly restricted at this point and, therefore, a plurality of radial holes 85 are provided in the outer tube 70 near its end. These radial holes 85 connect with the annular passageway 73 through which saline solution will flow. The clearance between the bars 80 and 84 can be adjusted in the same manner as described with the probe tip of FIG. 5. The curling of tube 70 at 70c minimizes the chances of injuring non-cataract tissue during surgery, such as the posterior lens capsule. Additionally, the injection of saline solution by radial holes 85, which are removed from the cutters bars 80, 84 tends to minimize the tendency for the saline solution to force the cataractous tissue away from the cutters.

FIGS. 7 and 8 show a third embodiment of a rotatable cutting probe tip. In this version, the end 70b of the outer tube 70 is closed completely and an end portion 70c of the inside diameter of the tube 70 is reduced so that it fits closely with the outside diameter of the rotatable tube 46. Saline solution under pressure from the elevated flask 10 flows from the annular passageway 73 through two holes 91 located angularly and radially through the wall section of tube 70 just prior to the area 70c where the inside diameter of tube 70 is reduced. Two radial holes 90 are located near the end portion 70c. A sharp edge 93 exists where these two holes intersect the reduced bore 94 of the outer tube 70. The end 46a of rotatable tube is notched so that only approximately a 180° wall segment of the rotatable tube 46 extends to almost the closed end of tube 70 adjacent holes 90. This end configuration of tube 46 provides a straight line cutting edge 92 as is more clearly shown in FIG. 8. Under this arrangement, as tube 46 rotates, tissue drawn through the holes 90 is sheared off as cutting edge 92 contacts successively the inside edges 93 of the holes 90. The vacuum then draws this cut tissue and other fluids into passageway 75 by aspiration.

As previously stated, saline solution is supplied to the inlet port 13 under the pressure established by the elevation of the flask 10 (FIG. 1). This head pressure causes saline solution to flow through passageway 74 into the chamber 97 and thence into the annular passageway 73 (FIG. 4). From the foregoing description, it is apparent that with the outer tube 70 inserted into the anterior chamber of the eye, saline solution will flow through passageway 73 and out the appropriate opening in the end of tube 70 into the anterior chamber, whence it will be drawn out of the anterior chamber by means of a partial vacuum existing in the passageway 75. This fluid, along with fragmented cataractous tissue, will be drawn into the passageway 75 (FIG. 2) and through passageways 76, 47, 58, 55, 56, 61 and into the vacuum line 15 through the coiled capillary restrictor 18, the three-way solenoid valve 17 (when energized) and into the evacuated collector bottle 20. The suction created in passageway 75 will also assist in pulling the cataractous material into engagement with the appropriate cutters at the end of the tubes 70 and 46.
To prevent excessive pressure from developing in the anterior chamber, the flask of saline solution is ele-
vated only to a point which will provide a pressure which can be withstood by the lens. This pressure is of
the order of 0.4 psig (20mm water column) which can be obtained by elevating the effective head of the flask
approximately 10 in. above the probe. The saline so-
lution conduit and passageways are adequately sized so
that with this head pressure an adequate volume (ap-
proximately 7 cc's per minute) of saline solution will
flow from the ports connected to the annular passage-
way 73. The flow of saline solution can be started or
stopped by the actuation of the foot switch 28, which
in turn controls a solenoid-operated clamp valve 29
(assuming power switch 38 and saline switch 39 are
closed). Energization of solenoid 29a releases the flow
restricting clamp. The flow rate of saline solution can
also be throttled by manually adjusting the screw type
clamp valve 14.

In order to provide the maximum force to push or as-
pirate cataractous tissue into the cutters, it is desirable
to have available a high vacuum pressure when the end
opening of tube 70 contacts the cataract. In other
words, the greater this vacuum pressure, the greater
will be the force pushing the cataract material into the
end opening of the tube 70 and thus into engagement
with the cutters. However, when using a high vacuum
such as 25 inch mercury column which is approxi-
mately 12¾ psi absolute, it becomes apparent that this
vacuum pressure could extract from the anterior cham-
ber a far greater volume of saline solution than can be
supplied to the anterior chamber with a head pressure of
only one-third psig in the saline solution system. If
the vacuum system extracts fluid from the anterior
chamber faster than the saline solution can be supplied
to the anterior chamber, a collapse of the anterior
chamber of the eye will result.

In order to provide safely the high vacuum pressure
and thus the desired intense force to remove the cata-
ratous tissue, it is necessary to restrict the vacuum sys-
tem when the end of tube 70 is not contacting the cata-
ract so that it cannot aspirate more saline solution from
the anterior chamber than can be supplied by the saline
solution system. If this precaution is not observed, it
is possible to collapse the anterior chamber thus undesir-
ably cutting healthy tissue.

There are two methods of achieving this safety re-
striction in the vacuum system — (1) provide a small
input orifice in the vacuum system at the probe tip, or
(2) increase the length of the vacuum system conduit
so that under free flow conditions the total restriction of
the system will not permit more saline solution to be
drawn from the lens capsule than can be supplied by
the saline solution system. It has been found through
calculation and experiment that the orifice ap-
proach requires an orifice of such a small diameter that
it can be easily clogged by cataractous tissue. There-
fore, a sufficient length of capillary tubing 18 having a
relatively large ID is used to create this desired restric-
tion by increasing the length of the vacuum system's
conduit. With this coiled length of capillary tubing 18
in the vacuum system, the quantity of saline solution
that can be pulled out of the anterior chamber is lim-
ited to an amount less than that supplied by the saline
solution system.

If, however, the outlet saline ports at the end of the
tube 70 are blocked — such as by pressing them against
a brunesce n cataractous tissue — the vacuum pressure
in the entire system will rise to the maximum permitted
by the regulator 19. If this blockage at the end of tube
70 is then removed after the vacuum pressure has
reached it maximum, there would exist a high inrush or
surge of fluid from the anterior chamber into the vac-
uum system due to the accumulator or capacitor effect
created by the volume of vacuum existing in the con-
duit and passageways of the vacuum system. Such a
surge could quickly extract the small volume of fluid
existing in the anterior chamber and cause a collapse of
the anterior chamber. An automatic surge eliminat-
ing means is, therefore, provided in this device which
consists of plunger 52 and its passageway 58, the bore
51, the crossports 55, and spring 53.

This surge eliminating means functions as follows:
Under low or normal flow, the pressure drop or differen-
tial pressure acting upon the end face area 99 (FIG.
10) of the plunger 52 does not create sufficient force
to move the plunger 52 back against the force of spring
53. However, when a surge or high flow is encountered,
there exists a high pressure drop or differential pressure
acting on end face area 99. This differential pressure is
created by the restriction caused by passageway 58
through which the flow must pass to continue through
the vacuum system. This high differential pressure ex-
erts a sufficient force across end face area 99 of slid-
able plunger 52 to overcome the spring force exerted
by spring 53, and thus moves plunger 52 to a position
where it closes ports 55 or in some instances modulates
the degree of closure. With ports 55 closed, the surge
is stopped and the pressure on each end of plunger 52
equalizes and the spring force can then return the
plunger 52 to its normal or forward position. In addi-
tion to the differential pressure moving plunger 52
back to close the ports 55, there exists an impinging
force to assist in this movement. This impinging force
is caused by the velocity and mass of the fluid striking
end face surface 99 of the plunger 52 as the fluid
emerges from the nozzle-like passage 47. Passageway
58 is positioned off center in plunger 52 to provide a
suitable surface 99 to maximize the force of this im-
ingement.

A non-automatic vacuum surge safeguard is also pro-
vided. In particular, when foot switch 22 is opened by
mometary foot operation, the electric solenoid valve 17
shuts off the vacuum supply to the probe. That is, sole-
noid 17a is deenergized enabling anchored spring 17c
to pull plunger 17b and its connected spool 17d to
the right. This action vents conduit 15 to atmospheric vent
17e. This foot switch controlled venting is done to re-
duce a vacuum surge when the vacuum supply to the
probe is excessive and not adequately controlled by the
automatic action of plunger 52.

DETAILED DESCRIPTION OF THE PREFERRED
SURGICAL PROCEDURE

The cataract surgical procedure may be performed
under conventional local or general anesthesia.

An eyelid speculum (not shown) is inserted for eyelid
separation. A "4"~"0" black silk bridal suture is placed
beneath the superior rectus muscle for traction and fixa-
tion of globe position. Referring to FIGS. 12 and 13,
a 3 to 4 mm. conjunctival limbus based flap 77 is dis-
sected at 12 o'clock. The flap is widened to a 6 to 8
mm. width. The flap is dissected well forward with scis-
sors so as to expose the surgical limbus 78. Hemostasis
is maintained through the conventional use of a light cautery.

The globe is fixed near the 6 o'clock limbus with a forceps and a small 4 mm. keratome incision is made through the surgical limbus 78 at 12 o'clock into the anterior chamber 79. The probe tip of FIGS. 5, 6, 7, 14, 15, or 16 is introduced into the anterior chamber 79 through the limbal incision 78 and placed through the anterior lens capsule 86 and into the lens cortex 88. Balanced saline solution is irrigated into the lens 89 (by manually closing switches 38, 39 and closing foot switch 28) and anterior chamber 79 from the saline openings in the probe tip 68. This completes the energizing circuit for solenoid 29a to release solenoid clamp 29.

Simultaneous aspiration through the center of the probe tip 68 is accomplished by vacuum pump 21 by manually closing vacuum pump switch 40 and also manually closing master vacuum switch 41 and closing foot switch 22 to connect conduit 15 to flask 20.

Preliminary lens fragmentation is accomplished by coring and honey-combing the hard lens nucleus with the various end-cutter tips enumerated above. Final aspiration of tenacious cataractous lens cortical tissue 88 and hard lens nucleus 95 is rendered possible through the use of rotary side cutters FIG. 7, FIG. 22, FIG. 19, FIG. 23. The rotary cutting blades in the side-cutting probe tip are activated by the operating surgeon by manually closing cutter switch 42 and closing cutter foot switch 33. Whenever it is necessary to work close to the iris 96, the rotary cutter is stopped by opening foot switch 33. The tissue to be extracted is pulled forward and away from the iris or corneal tissue by means of vacuum traction only. Once the tissue and probe tip are free of iris and other tissue to be avoided, the rotary cutter is activated by closing the foot switch 33 in order to shred the tissue into particles capable of aspiration.

Throughout the procedure, collapse of anterior chamber 79 is prevented by the hemostatic volume-pressure relationship between the irrigating fluid and vacuum aspiration flow. The surge control plunger 52 incorporated into the probe handle prevents a surge of aspiration once a plugged probe tip is cleared. Otherwise, an unchecked vacuum aspirating surge due to vacuum pressure buildup while the probe tip is temporarily plugged by a large mass of cataractous material that is being shredded by the rotary cutter, would lead to anterior chamber collapse with undesired posterior corneal surface and vitreous face approximation to the probe tip. If necessary due to ineffectiveness of the automatic vacuum control dependent upon plunger 52, an undesirable vacuum surge can be eliminated by venting the system by operation of master vacuum switch 41 and/or foot switch 22 to deenergize solenoid 17a to vent conduit 15 to vent 17e. This operation drives solenoid valve 17 into a venting position as previously described.

The side position of the irrigating openings on the probe tip shown in FIGS. 6 and 7 serves to direct the irrigating stream away from the probe tip so as to avoid flushing the lens material away from the aspirating cutting tip. The side position also avoids obstruction by an engaged cataractous mass.

The particular tip embodiment shown in FIG. 7 offers an additional safeguard when cutting near posterior lens capsule 98 is involved.

All lens contents involving the central pupillary area down to the posterior lens capsule which may or may not be removed are shredded and aspirated and deposited into collector bottle 20. In many cases of dense posterior capsular opacities, it is necessary to remove the posterior capsule. This is combined with the performance of a shallow anterior vitrectomy in order to prevent the forward migration of vitreous into the anterior chamber, where it could give rise to pupillary block and secondary glaucoma. The presence of vitreous in the anterior chamber could also lead to other complications resulting from vitreous adhesions to surgical wound and subsequent traction to the iris and/or retina. Vitrectomy in the course of the removal of traumatic cataracts wherein vitreous already occupies the anterior chamber, is readily accomplished with the present invention.

If preoperative pupillary dilation is inadequate, a sector iridectomy may be incorporated into the technique using a fine No. 30 gauge wire canula bent into an iris hook and iris scissors.

With adequate pupillary dilation, a normal pupil can be retained with a small peripheral iridectomy performed at the completion of the cataract extraction. Small peripheral cortical lens remnants left behind under the iris root do not interfere with the visual result.

The corneoscleral incision is closed with one uninterrupted fine cataract suture and the conjunctival Tenon's flap is closed with either interrupted or running "3-0" catgut suture. The "4-0" bridginal fixation suture is removed. A cataract dressing is applied and the patient is returned to his room.

In FIGS. 14, 15 and 16 there are disclosed fragmentary perspective views of the end construction of three embodiments of an "end-core" type cutting tip which may be used with probe 11. These tips are especially useful in coring and fragmenting tissue from underlying attachments either with or without simultaneous aspiration and irrigation. Therefore, looking first at FIG. 14, the first end-core cutting tip 110 comprises an outer tube 112 and an inner tube 114 arranged to rotate within outer tube 112. The forward end of outer tube 112 has a snug fit around inner tube 114 to seal the forward end of a fluid passage which is provided between the two tubes. An opening 116 in the side wall of outer tube 112 provides a discharge outlet to the surgical area for irrigating solution which flows through the fluid passage from probe 11. The forward end of inner tube 114 is honed around the outside to a generally conical shape which tapers radially inwardly in the forward direction as at 118 so that tube 114 has a razor sharp cutting edge 120 lying substantially on a circle in a plane perpendicular to the axis of tip 110. Aspiration is effected through the bore of inner tube 114 back to probe 11.

A second end-core cutting tip 122 in FIG. 15 is of generally similar construction having outer and inner tubes 124 and 126 respectively and a discharge opening 128 for the irrigating fluid passage between the tubes. Aspiration is via the bore of inner tube 126. The forward end of inner tube 126 is also conically honed as at 130, but a plurality of circumferentially spaced axial serrations 132 are provided around the forward end of the tube. Thus, the cutting edge of tube 126 is not circumferentially continuous as was edge 120 of tip.
110, but rather inner tube 126 has a plurality of individual arcuate razor sharp cutting edges 134 lying substantially on a circle perpendicular to the tip axis. A third end-core cutting tip 136 in FIG. 16 is of generally similar construction having an outer tube 138, inner tube 140 and a discharge outlet 142 for the fluid passage between the tubes. The forward end of inner tube 126 is also conically honed as at 144. A pair of diametrically opposed rectangular slots 146, extend axially rearwardly from the forward end of tube 140. In this way tube 140 has a pair of diametrically opposed, arcuately extending, razor sharp cutting edges 148 lying substantially on a circle perpendicular to the tip axis. Aspiration is via the bore of inner tube 140.

As mentioned before, the particular advantage of the end-core type cutting tip resides in its coring and fragmenting capability. With the end-core tip of the present invention such coring and fragmenting is greatly facilitated and represents a notable improvement in surgical procedures. Thus by virtue of the present invention, calcified or fibrous plaques of lens opacity can be fragmented, and aspirated as can dense, rigid, congenital posterior polar cataract, membranous traumatic aftercataract and senile brunescent nuclear cataract. The cutting tips of FIGS. 14, 15 and 16 do not possess the shearing type cutting action of the earlier described tips in the earlier drawing figures; rather tips 110, 122 and 136 exhibit cutting action, which results in fragmenta-

tion and coring of tissue, when the rotating rotor is pressed slightly into the tissue. Cutting can be done with or without simultaneous aspiration and irrigation according to the desire of the surgeon performing the procedure. By initially using any of the end-core tips in a surgical procedure, large masses of tissue can be effi-
ciently broken apart and sucked up by the cutting in-

strument. As a result the invention can provide improved efficiency by reducing overall surgical time, while simultaneously, because of its improved cutting action, minimizing or eliminating the risk of injury to adjacent tissue which is not intended to be removed.

The invention further provides a second embodiment of cutting instrument, or probe, disclosed in FIG. 17, and identified by the numeral 150. Cutting instrument 150 comprises a generally tubular motor housing 152 and a generally tubular spindle body 154 threaded onto the forward end of housing 152 as at 156. A 12 volt DC permanent magnet motor 158 is contained within hous-
ing 152, and a gear head 160 is mounted onto the axi-

ally forward end of motor 158. The forward end of motor 158 is telescopically inserted into the open rear end of the gear head housing. A tubular shell 164 is telescopically inserted over the rear end of motor 158 to enclose the terminal conductor construction via which electricity is conducted to motor 158. A pair of spring-loaded electrical terminals 166, 168 extend through the rear of shell 164 and are biased into engagement with suitable electrical connections in an end plug 170 which is threaded into the open rear end of housing 152 as at 172. A cable 174 containing positive, negative and ground wires leads from plug 170 to a three terminal connector 176 which is adapted to be connected to a source of 12 volt DC power for energiz-
ing motor 158. The diametrically reduced forward end of gear head 160 fits within a correspondingly diametri-
cally-reduced forward portion of the bore of housing 152. An annular anti-slip disk 178 between gear head 160 and shoulder 179 prevents motor 158 from angularly slipping within the bore of housing 152 when motor torque is developed. A drive shaft 180 having an open diametrical slot 182 at the forward end thereof protrudes from the diametrically reduced forward portion of gear head 160. When elec-
tric power is applied via connector 176 through termi-

nals 166, 168 to motor 158, shaft 180 rotates. The speed of shaft 180 is equal to the speed of motor 158 divided by the gear ratio of gear head 160. Gear reduc-
tion of 6.3 to 1 and 11.8 to 1 have been found to pro-

vide suitable ranges of cutting speeds when used in con-
junction with motor 158 having a maximum speed of 11,000 rpm. (Without a gear head up to 11,000 rpm can be obtained.) It will be appreciated that that optimu-

mum cutting speed will depend upon the cutter tip con-

struction and the nature of the surgery. The speed may be varied according to well-known techniques by varying the percentage of voltage applied to the motor.

A drive shaft 184 is journaled for rotation within spindle body 154 via a pair of axially spaced glass filled Teflon bearings 186 and 188. The rear end of shaft 184 is operatively coupled for rotation with shaft 180 via a novel axial lost motion coupling which will be ex-

plained later in greater detail. Bearings 186 and 188 are inserted into opposite ends of diametrically reduced bore segments 190, 192 which are separated by a fur-
ther diametrically reduced bore segment 194. A coil spring 196 is disposed around the portion of shaft 184 within bore portion 194. Spring 196 bears against washers 198 and 200 which are arranged within bore segments 190 and 192 respectively so that washer 198 compresses an annular seal 202 between itself and bearing 186 and washer 200 compresses an annular seal 204 between itself and bearing 188 to thereby seal the ends of bore segment 194. Bearings 186 and 188 are retained axially in the illustrated position with their respective lips bearing against shoulders at the ends of bore segments 190 and 192. Retention is effected by means of a tubular adapter body 212 which is inserted over and affixed to the end of shaft 184 which protrudes forwardly through bearing 186, and a tubular coupling 226 which is threaded onto the rear end of shaft 184 as at 234. Coupling 226 is threaded onto shaft 184 an amount sufficient to draw adapter 212 against bearing 186 and itself (i.e. coupling 226) against bearing 188 whereby adapter body 212 and coupling 226 retain bearings 186 and 188 in the illustrated position.

A tubular conduit 206 is inserted into an inclined bore in the side wall of body 154 to intercept bore seg-

ment 194. A passage 208 extends rearwardly through shaft 184 from the forward end thereof and terminates at a hole 210 in the side wall of shaft 184. Hole 210 opens to the axially sealed annular space 207 around shaft 184 within bore segment 194. The adapter 246 of a cutting tip assembly 216 is threaded onto the forward end of adapter body 212 as at 214. Thus a passage is provided from tube 206 through space 207, hole 210, passage 208 and coupling 226 to adapter 212. As will
be seen in greater detail hereinafter, aspirating suction is applied to this passage and thence through tip 216 to the cutting area thereof.

An end cap 218 is threaded onto the forward end of spindle body 154 as at 219. Cap 218 and the forward end of body 154 are arranged relative to adapter body 212 such that an axially extending free space 221 is provided around adapter body 212 within the instrument. An inlet tube 220 is inserted into an inclined bore in body 154 to intercept space 221. As will be seen in greater detail hereinafter, irrigating fluid is introduced via tube 220, through space 221 and a passage in tip assembly 216 for dispersing irrigating fluid onto the surgical area. The portion of tip assembly 216 forward of adapter 246 extends through the bore of end cap 218 and is retained by means of a collet nut 222 which is inserted over the forward end of tip assembly 216 and threaded onto the forward end of end cap 218 as at 223. A gasket 224 seals the bore of end cap 218 around tip 216. A clip 239 for retaining flexible conduits to tubes 206 and 220 is provided around housing 152.

The coupling arrangement between shaft 180 and shaft 184 provides an axial lost motion connection whereby axial forces from shaft 180 are not transmitted through to the cutting tip 216, and the motor and gear head can be readily assembled and replaced if necessary. Details of this coupling can be seen in FIGS. 17 and 18. A pair of diametrically opposed axial slots 225 in coupling 226 extend forwardly from the rear end thereof. A key 229 extends diametrically across the rear end of coupling 226 with the ends of key 229 received in slots 228. The key is suitably shaped so that it cannot be substantially displaced radially of the coupling. An annular retaining ring 232 around coupling 226 axially retains key 229 in slots 228. A coupling spring 233 is disposed within coupling 226 and bears against the rear end of shaft 184 and the central portion of key 229 thereby biasing key 229 axially rearwardly against ring 232. When end plug 170 is being threaded onto spindle body 154, the motor and gear head are urged axially forwardly so that shaft 180 fits into the bore of coupling 226 and slot 182 engages the central portion of key 229. This provides an axial lost motion connection with key 229 being displaced axially forwardly of coupling 226 against the bias of spring 233 an amount sufficient to accommodate the motor and gear head. Furthermore in the assembled instrument any axial loading on shaft 184 by shaft 180 is cushioned by spring 233.

The details of cutting tip assembly 216 are illustrated in FIG. 19. Cutting tip assembly 216 represents one form of tip which may be used with either of the above instruments. The assembly 216 comprises an outer stator tube 240, an inner stator tube 242, a rotor tube 244 and adapter 246 which is affixed to the rear end of rotor tube 244 for connection to coupling body 212. Inner stator tube 242 extends completely through outer stator tube 240. The axial ends of outer stator tube 240 are shaped to fit snugly around the outside of inner stator tube 242. The rear end of tube 240 may be silver soldered to tube 242 as shown to preclude any relative rotation between the tubes. The relative sizes of tubes 240 and 242 such that an annular axially extending fluid passage 246 is provided between the two stator tubes. One or more inlet openings 248 are provided in outer stator tube 240 at the rear end thereof and one or more discharge opening 250 are provided in tube 240 at the forward end thereof. As illustrated the openings may be of circular shape and may face generally radially outwardly. Openings 248 are open to space 221 so that the irrigating fluid which enters instrument 150 via tube 220 can flow through space 221, openings 248, along passage 246 and out via openings 250 onto the surgical area. The forward end of inner stator tube 242 which projects forwardly from the forward end of outer stator tube 240 comprises a circular opening 252 in its side wall which opening defines a sharp cutting edge 254. The forward end of tube 242 is closed by an end wall 256 which may be in the form of a plug inserted into and affixed to the side wall of the tube. (Note: This construction is not illustrated in the drawing.) According to one of the important features of the invention the side wall of tube 242 is solid and thus rotor 244 is shielded at openings 250. Rotor 244 comprises a cut-away opening 258 at the forward end thereof which leaves an axially extending arcuate cross-sectioned finger 260 extending from the annular cross-sectioned tubular portion constituting the remainder of rotor 244. The shape of finger 260 is such that razor sharp straight axial cutting edges 262 are provided along the axial edges of finger parallel to the tip axis. When rotor 244 rotates within tube 242 the leading cutting edge 262 cooperates with cutting edge 254 of the inner stator tube to shear tissue. Note that the forward end of finger 260 is spaced slightly from end wall 256. Since axial loading on rotor 244 is substantially eliminated by the construction of instrument 150, there is no possibility of the axially forward end of rotor 244 grinding into end wall 256. The only interaction between rotor 244 and inner stator tube 242 is the rotational contact between the side walls thereof. Thus, because of this aspect of the invention, the cutting tips can last longer and the possibility of material (such as minute metal flakes) being ground away from end wall 256 and/or the forward end of finger 260 is eliminated. This is especially important for eye surgery when such minute metal particles could possibly escape into the eye of the patient. Rotor 244 extends through the rear end of tube 242 and a sealing coupling 266 seals the open rear end of inner tube 242 to rotor 244. Coupling 266 may be heat shrunk onto the tubes to provide a fluid seal which permits rotor 244 to rotate within tube 242. The rear end of rotor 244 fits within a bore in adapter 246. The bore 264 of rotor 244 is thereby open to passage 208. Aspirating suction which enters instrument 150 via tube 206 is transmitted through passage 208, and bore 264, to the forward end of the tip assembly. With suction applied to tube 206 excess irrigating fluid as well as cut tissue pieces can be sucked through opening 252 along bore 264 and passage 208 back for discharge via tube 206. When motor 158 is energized, the rotation of shaft 180 is transmitted via coupling 226, shaft 184 and adapter body 212 to turn adapter 246 and hence rotor 244. The stator structure of the tip is constrained by rotation by collet nut 222.

FIG. 22 illustrates a fragmentary perspective view of the forward end of another form of cutting tip construction wherein similar parts are identified by like numerals. The tip of FIG. 22 differs from the tip of FIG. 19 in that opening 252 in inner stator tube 242 of FIG. 22 is of generally rectangular shape. The opening 252 of FIG. 22 lies in a plane which extends axially of the tip intercepting both end wall 256
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and the side wall of the inner stator tube. Cutting edges 254 extend along the sides and front of the opening. The side edges are straight axial edges parallel to the tip axis. The rotor 244 of FIG. 22 has a pair of diametrically opposed fingers 260 instead of the single finger 260 in FIG. 19. The cutting tips of FIGS. 19 and 22 are termed "protected side cutters". It is necessary to apply aspirating suction to these tips to suck tissue into openings 252 for subsequent cutting.

FIG. 23 discloses yet another form of tip wherein like components of the preceding figures are identified by like numerals. The cutting tip of FIG. 23 has its opening 252 lying in a plane which is at an acute angle relative to the axis of the tip. The plane intercepts both the end wall and side wall of the inner stator tube and thus defines a generally elliptical contour in the side wall and a straight transverse segment in the front end wall. The cutting edge 254 also has corresponding elliptical and straight contoured sections. This cutting tip is termed on "exposed side cutter". It can perform some cutting without the necessity of accompanying aspirating suction.

As mentioned earlier one advantage of cutting tip 216 is that rotor 244 is shielded from exposure to the outside at openings 250 by the adjacent wall of the inner stator tube. Another advantage of this "three tube" tip construction is that sealing between the rotor and the stator structure is not nearly as critical as in the "two tube" tips. In the earlier two tube tips having a rotor tube and only a single stator tube, not only must the forward end of the stator tube have a sufficiently snug fit with the wall of the rotor tube to prevent fluid from "short circuiting" into the rotor aspiration bore without flushing the surgical area but also it must at the same time permit the rotor to turn without undue restriction. With the three tube construction, the possibility of a fluid short circuit is eliminated. This is because the inner and outer stator tubes which define the fluid passage for the irrigating fluid are not rotating with respect to each other. Therefore, the seal of the forward end of the outer tube around the inner tube can be made tight and leakproof. Thus when irrigating fluid is discharged via the outlet openings 250, flow of fluid onto the surgical area is always assured. Also because the inner stator tube shields rotor 244 at openings 250, tissue adjacent the immediate surgical area are being cut at opening 252 which might enter opening 250 cannot be caught by the rotor finger and wound around the rotating rotor. This is especially important in cataract removal where it is often desired to perform a shallow anterior vitrectomy without wrapping uncut vitreous on the rotor through the irrigation port.

FIGS. 20 and 21 illustrate two other forms of single finger rotor similar to that in FIG. 19. Like numerals from FIG. 19 are retained to identify like elements in FIGS. 20 and 21. Like the rotor of FIG. 19, the rotor finger 260 in FIG. 20 has a curved radially outer surface 260a matching the curvature of the inner wall of inner stator tube. However, the inner surface 260b of the rotor finger in FIG. 20 is flat while the corresponding surface of the rotor finger of FIG. 19 is curved. In FIG. 21 the rotor finger has a greater arcuate extent about the axis of the tube. The forward end of the rotor finger has an end wall 260c across the forward end of the finger. The cutting edge 262 does not extend the full length of the finger; rather the cutting edge is provided by beveling the forward edge portion of the finger inwardly so that the cutting edge extends axially rearwardly from the forward end of the finger only a fraction of the total length of the finger. The edge at the end wall is similarly inwardly beveled to provide a transverse cutting edge 262a connecting the two axial cutting edges 262. In order to optimize the cooperative shearing and cutting action of the rotor and stator cutting edges, the entire portion of finger 260 which is axially coextensive with opening 252 can be made to bear against the inner wall of inner stator tube 242, for example, in the following fashion. Each rotor finger is first bent and next the forward ends of the rotor cutting edges are flared outwardly such that the rotor cutting edges bear against the inner wall of inner stator tube 242 at least as far rearwardly as the rear end of the opening 252. In this way the rotor cutting edges have an extremely close approximation to the inner wall of tube 242 and optimum cutting action is attained when rotor 244 turns.

FIGS. 24 and 25 illustrate two forms of two finger rotors. Like numerals from the earlier figures are retained to identify like elements in FIGS. 24 and 25. The rotor of FIG. 24 is used in the cutting tips of FIG. 23 and FIG. 22. In their free states fingers 260 extend radially outwardly in the forward direction at a small acute angle to the axis of the rotor. With the rotor inserted into the inner stator tube, the fingers bear against the tube side wall, and this results in improved cutting action when the tip is used. In the tip of FIG. 25 the outer surface of the forward ends of the fingers are honed at 260d to a circular cross-section which matches that of the inner wall of the inner stator tube. In this way, the contact of the fingers with the inner stator tube wall is distributed along a portion of the axial lengths of the inner stator tube wall and of the fingers. This is in contrast to the rotor of FIG. 24 which at least theoretically would have only an arcuate edge contact of each finger with the inner stator tube wall; however, it is preferred to shape the fingers in FIG. 24 as described above in FIGS. 20 and 21 to provide optimum cutting and shearing action.

FIG. 26 illustrates simplified aspirating suction systems for use with probe 150. A syringe S connects to tube 206 while tube 220 connects through a valve V to a pair of fluid dispensing containers B1 and B2 disposed at different vertical levels. Containers B1 and B2 are arranged to provide gravity feed of irrigating fluid to probe 150. In one position valve V permits flow from only container B1, and this provides a limited flow of fluid onto the surgical area. When valve V is in another position, flow is from only container B2; this provides increased flow since container B2 is at a higher level. Possible flow to container B1 from container B2 is blocked by valve V. Valve may be controlled by the surgeon or his assisting personnel. Syringe S can be operated by assisting personnel at the command of the surgeon to provide aspirating suction for removing fluid and/or cut tissue. An important advantage of using syringes S is that in critical areas, for example close to the retina or iris, the amount of suction can be precisely controlled by the assisting personnel and if need be pressure can be applied via syringe S to discharge any material which may have been drawn into the tip via previous aspirating suction from syringe S.

The present invention makes an important and noteworthy contribution to the surgical art, and in particular to eye surgery where extremely close precision is required in relatively dimensionally limited areas. With
the instruments, the cutting tips and the method of the invention, the surgeon can perform difficult, intricate surgical procedures with increased safety to the patient and usually with a minimum of surgical time. It will also be appreciated that the apparatus of the invention provides the surgeon with a high degree of versatility in that various combinations of the disclosed rotor and stator structures are possible in a single cutting tip assembly. Furthermore, the various tip constructions may be used with either type of disclosed probe.

It is to be understood that the foregoing description is that of a preferred embodiment of the invention. Various changes and modifications may be made without departing from the spirit and scope of the invention as defined by the appended claims.

We claim:

1. An axially-extending cutting tip for a surgical instrument having a body and a rotatory shaft mounted on said body, said cutting tip comprising a stator tube, an opening in the side wall of said stator tube defining a generally axially extending sharp cutting edge, and a rotor within said stator tube comprising at least one axially extending finger at the forward end thereof, a generally axially extending sharp cutting edge on said finger cooperative with the cutting edge of said stator tube when said rotor rotates within said stator tube, said finger being constrained by said stator tube to bias said finger cutting edge against the side wall of said stator tube.

2. The cutting tip of claim 1 wherein said finger has an arcuate cross section.

3. The cutting tip of claim 2 wherein the cutting edge on said finger extends axially parallel to the tip axis.

4. The cutting tip of claim 3 wherein the cutting edge on said finger is fashioned at the outer edge of an inwardly directed bevel on said finger.

5. The cutting tip of claim 2 including an end wall at the forward end of said finger.

6. The cutting tip of claim 5 including a cutting edge on said end wall.

7. The cutting tip of claim 1 wherein said stator tube has an end wall at the forward end thereof and the forward end of said finger is spaced rearwardly of said end wall.

8. A cutting tip for a surgical instrument, said cutting tip comprising: a stator tube having a side wall the inside of which is of cylindrical shape; an opening in said stator tube intercepting at least said side wall and defining on said side wall a sharp cutting edge; a rotor element within said stator tube, said rotor element comprising a body having a cylindrical outer wall snugly journaling said rotor element within said stator tube and a finger extending forwardly of said body, said finger comprising a sharp cutting edge cooperating with said cutting edge on said stator tube side wall; said rotor element, when unconstrained by said stator tube, having a portion of said finger thereof disposed outside of an imaginary cylindrical surface defined by a forward continuation of the cylindrical outer wall of said stator body; said rotor element, when constrained within said stator tube, biasing said finger thereof against the inside of said stator tube side wall.

9. A cutting tip as claimed in claim 8 wherein said finger is inclined radially outwardly and axially forwardly of said rotor body when said rotor element is unconstrained and is substantially parallel to the cutting tip axis when said rotor element is constrained within said stator tube.

10. A cutting tip as claimed in claim 9 wherein said finger has a radially outer surface at least a portion of which bears against the inside of said stator tube side wall and has a curvature substantially matching the curvature of the inside of said stator tube side wall.

11. A cutting tip as claimed in claim 10 wherein said finger further includes an additional cutting edge fashion on the other of said finger sides.

12. A cutting tip as claimed in claim 11 wherein said finger further includes an additional cutting edge fashion on the other of said finger sides.

13. A cutting tip as claimed in claim 12 wherein said finger cutting edges are biased against the inside of said stator tube side wall.

14. A cutting tip as claimed in claim 13 wherein said finger cutting edges are substantially parallel to the axis of the cutting tip when said rotor element is constrained within said stator tube.

15. A cutting tip as claimed in claim 8 wherein said stator tube has a transverse end wall at the forward end thereof and the forward end of said finger is spaced rearwardly of said stator tube end wall.

16. A cutting tip as claimed in claim 8 wherein said finger cutting edge is biased against the inside of said stator tube side wall.

17. A cutting tip as claimed in claim 8 wherein said finger is of arcuate transverse cross section having circumferentially spaced finger side edges and said cutting edge on said finger is fashioned on one of said finger side edges.

18. A cutting tip as claimed in claim 17 wherein said finger, when unconstrained, has said one finger side edge flared outwardly biasing said finger cutting edge against the inside of said stator tube side wall.

19. A cutting tip as claimed in claim 18 wherein said finger has an additional cutting edge extending along the other of said finger side edges and biased against the inside of said stator tube side wall.

20. A cutting tip as claimed in claim 19 wherein said finger cutting edges are straight.

21. A cutting tip as claimed in claim 19 wherein said finger cutting edges are parallel to the cutting tip axis.

22. A cutting tip as claimed in claim 8 wherein said finger has a radially outer surface, the forward end of which is contoured to match the contour of the inside of the stator tube side wall and which contoured forward end is biased against the inside of said stator tube side wall.

23. A cutting tip as claimed in claim 22 wherein said finger cutting edge extends axially along a side edge of the radially outer surface of said finger.

24. A cutting tip for a surgical instrument, said cutting tip comprising: a stator tube having a side wall the inside of which is of cylindrical shape; an opening in said stator tube intercepting at least said side wall and defining on said side wall a sharp cutting edge; a rotor element within said stator tube, said rotor element comprising a body having a cylindrical outer wall snugly journaling said rotor element within said stator tube and a finger extending forwardly of said body, said finger comprising a sharp cutting edge cooperating with said cutting edge on said stator tube side wall; said rotor element, when unconstrained by said stator tube, having a portion of said finger thereof disposed outside of an imaginary cylindrical surface defined by a forward continuation of the cylindrical outer wall of said stator body; said rotor element, when constrained within said stator tube, biasing said finger thereof against the inside of said stator tube side wall.

25. A cutting tip as claimed in claim 24 wherein said finger is inclined radially outwardly and axially forwardly of said rotor body when said rotor element is unconstrained and is substantially parallel to the cutting tip axis when said rotor element is constrained within said stator tube.
ward continuation of the cylindrical outer wall of said rotor body; said rotor element, when constrained within said stator tube, biasing said finger cutting edge against the inside of said stator tube side wall.

25. A cutting tip as claimed in claim 24 wherein said finger is inclined radially outwardly and axially forwardly of said rotor body when said rotor element is unconstrained and is substantially parallel to the cutting tip axis when said rotor element is constrained within said stator tube.

26. A cutting tip as claimed in claim 25 wherein said finger has a radially outer surface at least a portion of which is biased against the inside of said stator tube side wall and has a curvature substantially matching the curvature of the inside of said stator tube side wall.

27. A cutting tip as claimed in claim 26 wherein said finger has axially extending sides and said cutting edge on said finger is fashioned on one of said finger sides.

28. A cutting tip as claimed in claim 27 wherein said finger further includes an additional cutting edge fashioned on the other of said finger sides and biased against the inside of said stator tube side wall.

29. A cutting tip as claimed in claim 24 wherein said finger is of arcuate transverse cross section having circumferentially spaced finger side edges and said cutting edge on said finger is fashioned on one of said finger side edges.

30. A cutting tip as claimed in claim 29 wherein said finger has one finger side edge flared outwardly to cause said finger cutting edge to be biased against the inside of said stator tube side wall.

31. A cutting tip as claimed in claim 30 including an additional cutting edge extending along the other of said finger side edges and biased against the inside of said stator tube side wall.

32. A cutting tip as claimed in claim 31 wherein said finger cutting edges are straight.

33. A cutting tip as claimed in claim 31 wherein said finger cutting edges are parallel to the cutting tip axis.

34. A cutting tip as claimed in claim 1 wherein said rotor includes a fluid passage therethrough.

35. A cutting tip as claimed in claim 8 wherein said rotor body includes a fluid passage therethrough.

36. A cutting tip as claimed in claim 24 wherein said rotor body includes a fluid passage therethrough.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,882,872
DATED : May 13, 1975
INVENTOR(S) : Nicholas G. Douvas and Henry T. Dinkelkamp

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:
Address Henry T. Dinkelkamp, "Ardard" should be --Orchard--.
Abstract, line 10, "robe" should be --probe--.
Column 1, line 25, "premanent" should be --permanent--.
Column 1, lines 33 and 34, "patent" should be --patient--.
Column 1, line 66, "phomenum" should be --phenomenon--.
Column 4, line 25, delete "a vacuum pump off-on switch 39,".
Column 5, line 18, "are" (second occurrence) should be --and--.
Column 5, line 60, "Untreading" should be --Unthreading--.
Column 11, line 21, "calfified" should be --calcified--.
Column 11, line 40, "ot" should be --to--.
Column 14, line 21, "annular" should be --annually--.
Column 15, line 20, "on" should be --an--.
Column 15, line 46, delete "are".
Claim 10, line 3, (Column 18, line 5), "rotor" should be --stator--.
Claim 12, line 3, "fashion" should be --fashioned--.
Claim 25, line 1, "claimemd" should be --claimed--.

Signed and Sealed this

seventh Day of October 1975

[SEAL]

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks