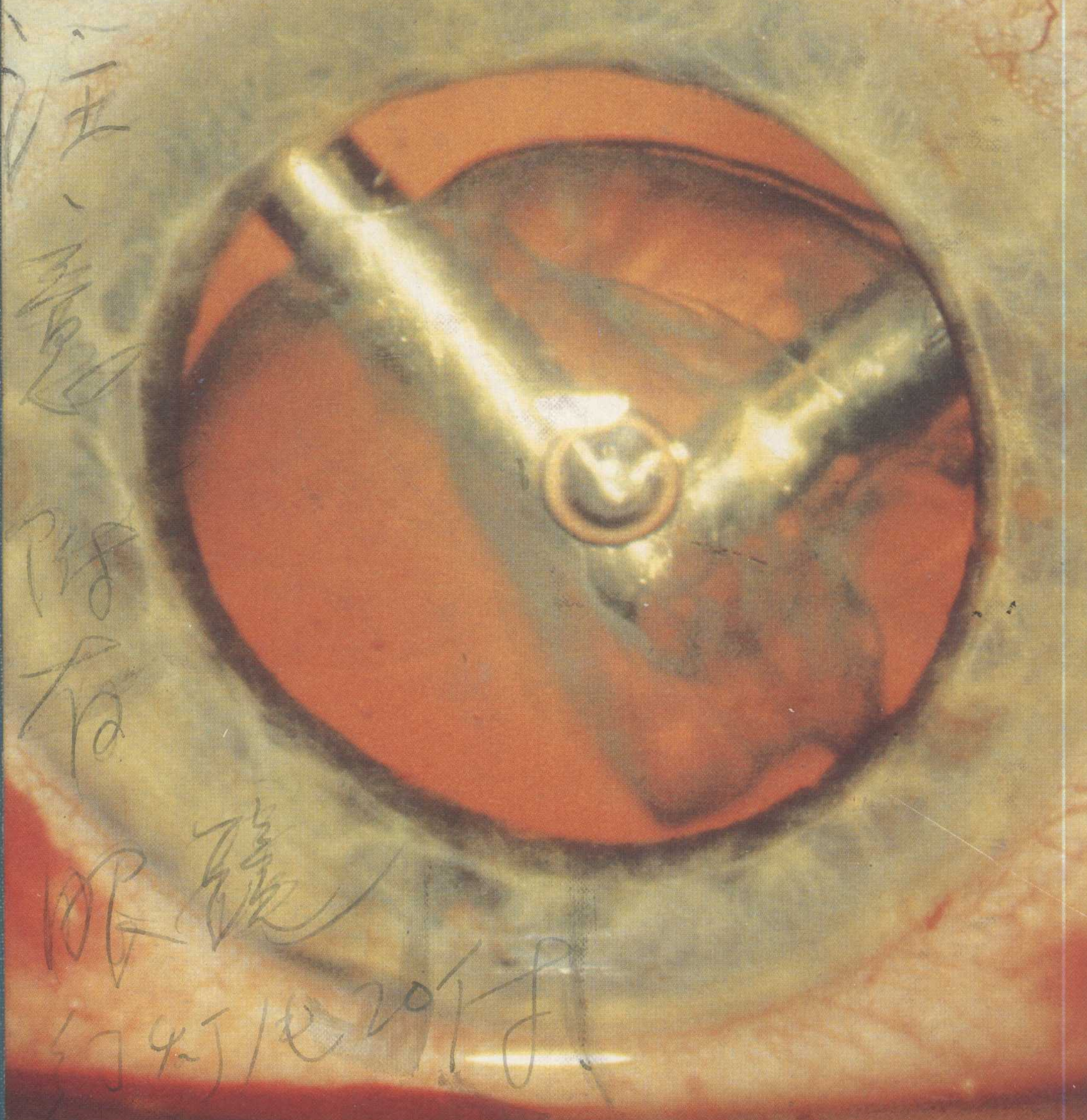
ULTRASONIC FRAGMENTATION FOR INTRAOCULAR SURGERY



Louis J. Girard

ADVANCED TECHNIQUES IN OPHTHALMIC MICROSURGERY

VOLUME I

ADVANCED TECHNIQUES
IN
OPHTHALMIC MICROSURGERY

VOLUME ONE

ULTRASONIC FRAGMENTATION FOR INTRAOCULAR SURGERY

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and 140 stereoscopic views in full color on 20 View-Master® reels

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FOREWORD

When Dr. Girard asked me to write the foreword to this book, I hestitated. First, Louis Girard and I have been not only close professional associates but also close personal friends for more than 30 years, and I thought that I might not be as objective as this responsibility demands. Second, although I have used Dr. Girard's instrument on several occasions, I have had more experience with the phacoemulsifier of Dr. Kelman. Therefore I do not consider myself competent to evaluate each of the surgical approaches that the author discusses in detail in this volume. I will have to leave the final judgment of these techniques to the reviewers of this book and to the readers who will be inspired by it to perform them.

Louis Girard can best be described as a "man for all seasons" in ophthalmology. His extensive bibliography includes more than 200 publications and films. There is probably not an ophthalmologist living who has not heard Dr. Girard speak on a variety of subjects at both national and international meetings. He is at home surgically in any part of the eye or adnexa. He began documenting his techniques and those of others on film as early as 1950. His more recent films are masterpieces of clarity that serve admirably to teach the techniques he advocates. It is fitting, therefore, that this book is illustrated in part by excerpts from these films, constituting yet another innovation by the author.

Early in his professional career, Dr. Girard was afflicted with unilateral cataract. His mentor, and then office associate, Dr. Conrad Berens, removed this cataract but with the unfortunate complication of vitreous loss, necessitating an iridectomy. Lou, as he has done with everything in his life, took this in his stride, fitted himself with a contact lens, reestablished his binocularity, and continued with his surgery and his active life. From this experience he developed an interest in contact lenses, which resulted eventually in a book on the subject that has become a classic in its time. Also, his interest in the prevention of vitreous loss and the management of vitreous loss probably has been an outgrowth of his own experience.

In addition to his interest in anterior segment surgery and in contact lenses, Dr. Girard has long been interested in surgical instrumentation. Shortly after Kelman introduced his ultrasound instrument, the phacoemulsifier, for cataract surgery, Dr. Girard, recognizing an even greater potential for this principle, designed a similar instrument utilizing a two-needle technique rather than the single multipurpose tip advocated by Kelman. Dr. Girard had initiated the two-needle technique for the aspiration of soft congenital cataracts. His contention is that the single, necessarily larger, tip requires too large an incision and therefore does not allow the safety and control possible with the two-needle approach. In corroboration of his views, we now find the advocates of phacoemulsification and machine vitrectomy espousing the two-needle technique.

In his book, Dr. Girard has presented his microsonic fragmentor as being applicable in a variety of surgical situations. This is possible because the frequency of the generator powering the fragmenting tip has an amplitude 10 to 32 microns greater than that powering the phacoemulsifier. Thus, in addition to emulsifying lenticular material, his instrument is capable of fragmenting iris, vitreous, and capsular material. This capability has led Dr. Girard deeper into the eye, where he has successfully fragmented blood and traction bands in the vitreous.

As it was necessary sometimes to remove a cataract in order to visualize better the pathologic vitreous, Dr. Girard began to use his instrument, already in place through the pars plana, to remove the lens. This lead to his newest technique, pars plana lensectomy, which undoubtedly will be one of the more controversial sections of this excellent book. For the master surgeon, such as Dr. Girard, the removal of lens fragments that "get away" appears to be easy when one watches him in the operating room. Nevertheless, the deliberate removal of the anterior vitreous combined with an incomplete removal of the lens in routine cataract surgery will, I am sure, excite some comment.

Though this volume is a compilation of some of the more recent thinking in ophthalmology, the surgical techniques presented are primarily those of Dr. Girard. His machine is now in constant use throughout the United States as well as in many countries abroad. Because of its versatility, it is considered by many to have some advantages over Kelman's pioneering phacoemulsifier. Certainly, it appears to be applicable to many more surgical situations and gives the promise of new techniques heretofore considered hazardous or impossible.

Dr. Girard is to be congratulated on his ingenuity, his innovative surgical approaches, his excellent text, and his unique method of illustration. I am proud to be his contemporary and his friend.

Richard C. Troutman, M.D., F.A.C.S.

New York, February 12, 1979

PREFACE

For years ophthalmic and other surgeons have been inventing machines of various types to aid in surgery, such as sewing machines, skin clips, and motor-driven trephines. Until recently, however, ophthalmic surgeons have relied on their hands and simple instruments to do a majority of their surgery. In the past few years a number of machines have been introduced and placed on the market for extracapsular cataract extraction, vitrectomy, and associated procedures. All of these instruments require the use of the operating microscope for ophthalmic surgery. At the time of this writing, I am sure that we are only on the threshold of tremendous innovation in instrumentation.

Ultrasonic fragmentation (USF) is a term I have given to a technique of fragmentation of various ocular structures, such as the lens, iris, ciliary body, and vitreous, which enables these structures to be aspirated through a small (23 or 20 gauge) needle. The technique is an outgrowth of a closed system of aspiration and irrigation for extracapsular cataract extraction.[24]

In 1966 I described a closed-system, bimanual, two-needle technique for the aspiration and irrigation of congenital and soft cataracts. The technique essentially involved the introduction into the anterior chamber of two 23 gauge needles, each being connected by a plastic tube to a 60 cc syringe. One syringe, filled with balanced salt solution, is used by an assistant to keep the anterior chamber formed while the second syringe is used for aspiration (Fig. 1). This technique has been employed successfully for 12 years without serious complications and has been adopted by many ophthalmic surgeons.

The advantages of this technique are: (1) the procedure can be performed entirely at one sitting; (2) the anterior chamber remains formed during the entire procedure, thus reducing the dangers of damage to the endothelium and to the posterior capsule of the lens; (3) should the pupil contract during the procedure, it can be redilated by adding epinephrine to the irrigating solution; (4) the incisions are so small that no sutures are required in most cases; and (5) the post-operative convalescence is short, enabling the patient to use a contact lens within a week or two following surgery.

The technique is applicable in any case of soft cataract—congenital, traumatic, or senile—and has been utilized successfully in patients up to 72 years of age. When the nucleus is hard, however, it is not possible to aspirate the nuclear material through a 23 gauge needle. The technique of Kelman[64-66,77] of using ultrasonic vibration to break up (emulsify) the nucleus so that it may be aspirated was the inspiration for extending the age range to which the aspiration-irrigation technique can be applied. By applying ultrasonic vibration to the irrigating needle it is possible to fragment the nucleus in hard, senile cataracts so that the material may be aspirated through a 23 or 20 gauge cannula.

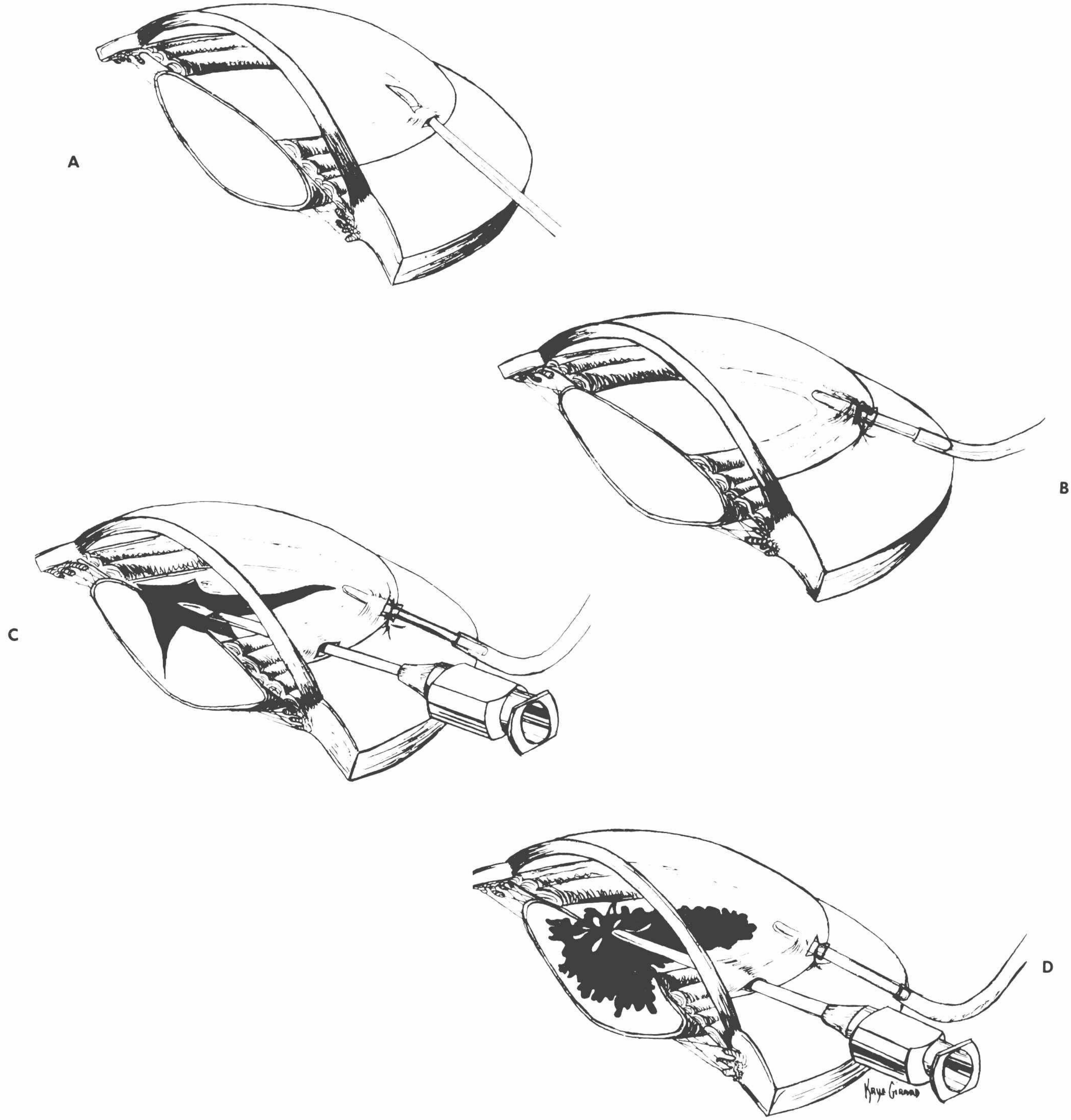


Fig. 1. Girard closed bimanual system of aspiration and irrigation for soft cataracts: congenital, traumatic, and senile. **A,** Beveled incision is made with Girard knife in superior quadrant, temporal or nasal, 1 mm inside limbus. **B,** A 23 gauge needle connected by plastic tubing to a 60 ml syringe containing balanced salt solution is used to keep the anterior chamber formed. **C,** Large capsulotomy is made. **D,** Lens material is aspirated in posterior chamber with second 23 gauge needle while anterior chamber is kept formed by irrigation. (From Girard, L. J.: Aspiration-irrigation of congenital and traumatic cataracts, Arch. Ophthalmol. **77:**387, March, 1967. Copyright 1967, American Medical Association.)

To accomplish ultrasonic vibration of the needle, a simple solid-state ultrasonic unit was used to design a prototype instrument. It was discovered that the instrument could fragment not only hard cataract[36,42] nuclei but also other ocular tissues such as vitreous, iris, and ciliary body so that they could be aspirated through a 23 or 20 gauge cannula. The instrument and the idea were presented to Mr. Gil Weatherly, former president of Sparta Corporation, who agreed to develop a commercial model. He employed Mr. Edward Murry of Fibrasonics, Inc., who designed the present model. Murry patented the instrument under his name.

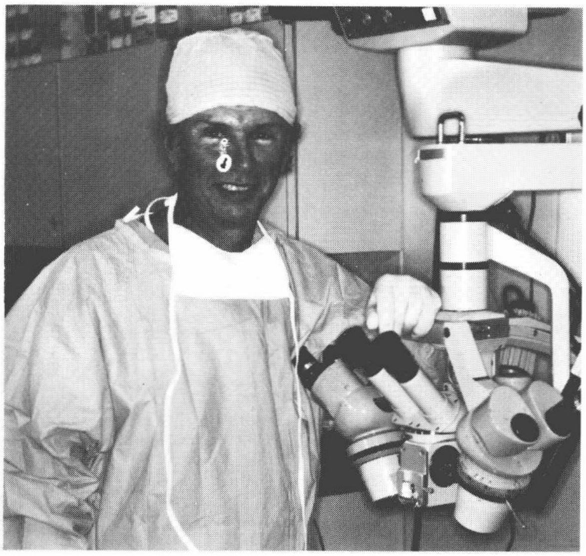
The Ultrasonic Fragmentor consists of an electrically powered oscillator that activates a piezoelectric crystal, causing it to vibrate at approximately 35,000 to 40,000 cycles per second (35 to 40 kilohertz). These vibrations are transmitted by resonance to the tip of the aspirating needle, which has been shown to vibrate longitudinally 0.09 mm when the fragmentor is activated. It is the physical movement of the tip of the needle that produces the fragmentation of the lens and other ocular materials.

The purpose of this text is to describe the mechanism of ultrasonic fragmentation (USF), the instrument (the Ultrasonic Fragmentor [USF]), the ophthalmic surgical techniques with which the fragmentor has been used, and the results in certain conditions. All of the techniques described are original. As the usefulness and versatility of this instrument become known, improvements in the instrument and techniques no doubt will be forthcoming. Illustrations consist of art work, external and slit-lamp photographs (both monocular and stereoscopic), and stereoscopic color transparencies taken through the operating microscope.

I am indebted to Allen Mewbourne and Victor Alexander for their help in preparing the photographic illustrations, to Jan Reddin and Gay Girard in preparing the art work, and to Linda Hughes and Corneille Smith in the preparation of the manuscript.

I wish to thank the Phillips Foundation for its support and encouragement in the development of the stereoscopic photographic illustrations.

Louis Girard



INSTRUCTIONS TO THE READER

This book is illustrated with black and white monocular photographs, drawings, black and white stereoscopic photographs, and stereoscopic transparencies.

To view the stereoscopic black and white photographs, the reader should use a pair of +7.00 diopter trial lenses and relax his accommodation. Stereopsis can be improved with practice. A lorgnette with plastic lenses of +7.00 diopter and 4 prism BO accompanies this book. Additional lorgnettes can be purchased from Southwest Optical Co., 4126 Southwest Freeway, Suite 510, Houston, Texas 77027.

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BRIEF SCIENTIFIC BACKGROUND

Acoustic waves of various frequencies and amplitudes are constantly being generated within our universe. Sound waves by definition are acoustic waves of a frequency audible to the human ear. When the frequency reaches above the human audible range, the waves are called "ultrasonic." Ultrasonic waves have been used for such medical purposes as diagnostic examination (ultrasonography), tooth scaling, and physiotherapy.[1,3] There are also many industrial uses for ultrasound, such as in sonar (Fig. 1-1), cleaning, welding, and soldering.

It was the Curie brothers who first discovered the phenomenon known as piezoelectricity. When quartz crystals are subjected to mechanical strain, they generate an electrical charge. The reverse effect is produced when a piezoelectric crystal is stimulated by an alternating electrical current. The crystal then vibrates, and can be used as a source of ultrasonic waves (Fig. 1-2). It is interesting to note that the crystal will vibrate at its own "natural" frequency.

A medium such as a gas, a liquid, or a solid is necessary for the transmission of acoustic waves, including those of ultrasonic frequency. However, the transfer of ultrasonic energy from a vibrating transducer is more efficient into a liquid or a solid or living tissue than into air.

At ultrasonic frequencies the wave length is shorter than in the audible range. If the wave length is reduced sufficiently, the propagation of the waves can be treated geometrically. That is, like light waves, ultrasonic waves form a beam that can be refracted by a prism or a lens and also at interfaces between media. In this way it is possible to focus or concentrate sound energy and obtain intense energy density locally. High energy densities can also be obtained by using a horn.[8,9,72]

Ultrasound of a high frequency can induce great stress with only a small amplitude of displacement within a solid vibrating body. The force exerted on the vibrating body by the acceleration obtained can be as great as 72,000 times the force of gravity (72,000 g's). If a solid piece of material, for example, is made to vibrate at approximately 30,000 times per second (30 kilohertz) and the amplitude is only 20 μ (0.02 mm) (that is, the peak-to-peak amplitude is 40 μ [0.04 mm]), and this vibrating solid is placed against a cataractous lens, the acceleration produced exerts a force 72,000 times that of gravity and thereby causes an effective *fragmentation* of the lens material.

The complete mechanism of fragmentation is not clear. The hammering effect of the end of the probe is quite possibly a major contributor, but some other factors may play roles in the total process.

This chapter was prepared with the help of Dr. Edward Murry, Chicago, Illinois, and Dr. Robert Finch, Professor and Chairman, Department of Mechanical Engineering, University of Houston.

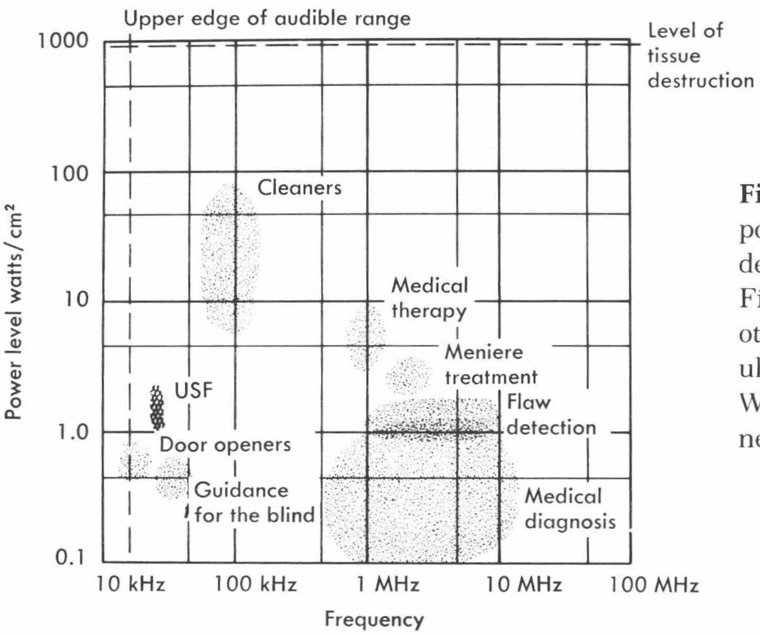

Fig. 1-1. Frequency range and power levels of various ultrasonic devices. (After Bronson, N. B., Fisher, Y. L., Pickering, N. C., and others: Ophthalmic contact B-scan ultrasonography for the clinician, Westport, Conn., 1976, Intercontinental Publications, Inc.)

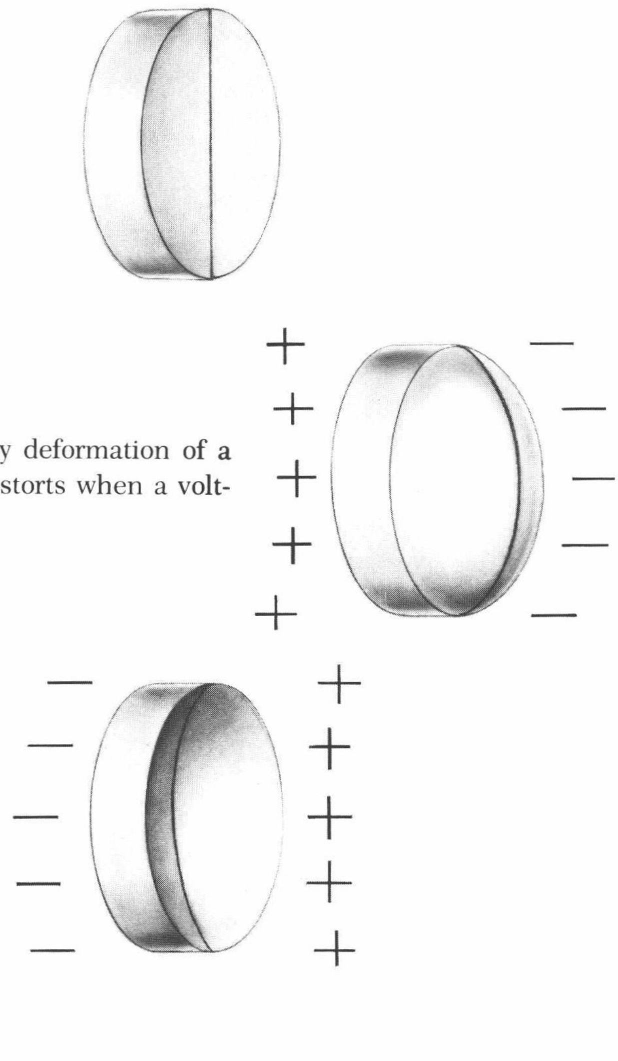

Fig. 1-2. A pulse of ultrasound is created by deformation of a small disc of piezoelectric material, which distorts when a voltage is applied to it.

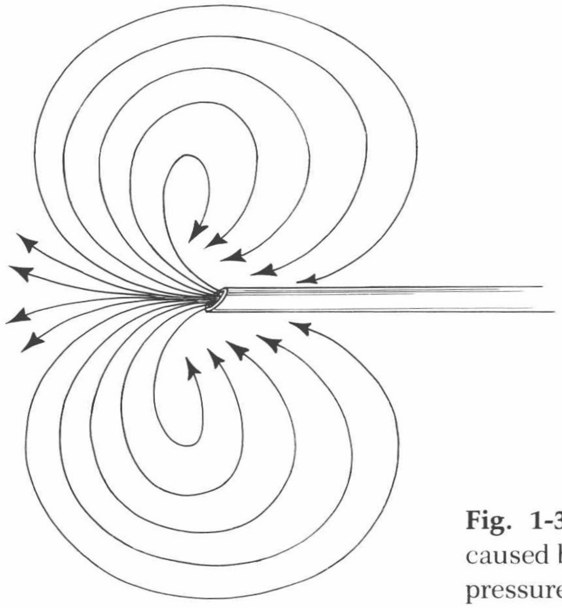

Fig. 1-3. Microstreaming is the production of currents caused by movements of fluid from areas of high ultrasonic pressure to areas of low pressure.

If a solid vibrator as described previously is placed in a liquid medium, intense ultrasound above a certain threshold value produces *cavitation,* a complex phenomenon (depending basically on rupturing of the liquid) that occurs at the end of a vibrating solid rod or bar. These cavities can be filled with gas or the vapor of the medium or with a gas absorbed in the medium. After their production, these cavities grow and finally *implode* with great violence. Destruction of the cavities creates strong shock waves and thus generates very high temperatures and pressures for brief instants. This energy can, for example, erode or fragment the metal of a ship's propeller, destroy concrete raceways in dams, and create new chemical compounds. Such energy is used in ultrasonic cleaners, welders, and medical devices. Thus, cavitation could be a major factor in ophthalmic operations.

A third phenomenon that occurs is *microstreaming,* or production of currents in a fluid (Fig. 1-3). This phenomenon, added to high-velocity longitudinal vibration and cavitation, could circulate the fragmented tissue, thereby aiding aspiration. (See U.S. Patent 3,990,452-Murry.)

Displacement, velocity, and acceleration

Consider a transducer whose surface vibrates with displacement η given by:

$$\eta = \eta_0 \sin\omega t \qquad (1)$$

where η_0 is the displacement amplitude, ω is the angular frequency, and t is time. Angular frequency is given by:

$$\omega = 2\pi f \qquad (2)$$

where f is the frequency. The velocity of the transducer surface is then v, given by:

$$v = \eta_0 \omega \cos \omega t = v_0 \cos \omega t \qquad (3)$$

The velocity amplitude is given by:

$$v_0 = \eta_0 \omega = 2\pi \eta_0 f \quad \textbf{(4)}$$

The acceleration of the transducer surface is than a, given by:

$$a = -\eta_0 \omega^2 \sin \omega t = -a_0 \sin \omega t \quad \textbf{(5)}$$

The acceleration amplitude is calculated with the equation:

$$a_0 = \eta_0 \omega^2 = 4\pi^2 \eta_0 f^2 \quad \textbf{(6)}$$

The peak-to-peak displacement and the frequency of vibration of an ophthalmic ultrasonic probe can be measured using a variable-frequency stroboscope and a microscope. Suppose, as a typical example, that the peak-to-peak displacement is found to be 40 μ (0.04 mm). Then:

$$\eta_0 = 0.04/2 = 0.02 \text{ mm}$$

If the frequency is found to be 30 kHz (that is, 30,000 vibrations per second), from equation 2:

$$\omega = 2\pi \times 30{,}000 = 1.88 \times 10^5 \text{ Hz}$$

From equation 4, the velocity amplitude can be calculated as follows:

$$v_0 = 3.76 \text{ m/sec}$$

And from equation 6, the acceleration amplitude can be calculated as follows:

$$\begin{aligned} a_0 &= 7.1 \times 10^8 \text{ mm/sec}^2 \\ &= 7.1 \times 10^5 \text{ m/sec}^2 \\ &= 7.2 \times 10^4 \text{ g's} \end{aligned}$$

In other words, the maximum force of acceleration is 72,000 times the acceleration due to gravity!

If the displacement amplitude were increased to 0.1 mm, at the same frequency, the velocity and acceleration amplitudes would both be increased by factors of five.

Power and intensity

Consider a point source radiating acoustic energy in an unbounded fluid medium. The energy radiated per unit time is known as the "power" of the source, and the appropriate unit is the watt. The "intensity" of the acoustic radiation field is the amount of energy crossing the unit area in the unit time. The power, W, and the intensity, I, at a distance r from a point source are related thus:

$$I = W/4\pi r^2 \quad \textbf{(7)}$$

In other words, the intensity falls off with the inverse square of distance from the source. Intensity is measured in watts/cm² or watts/m².

A sound source acts like a point source, radiating its power uniformly in all di-