Comparison between Phacoemulsification and Laser Assisted Cataract Surgery

Essay

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SUMMARY

In 1967 Charles Kelman introduced the technique that uses ultrasonic waves to emulsify the nucleus of the eye's lens to remove the cataracts without a large incision. It has helped 100 million people nation-wide.

Phacoemulsification uses an ultrasonically driven tip to fragment the nucleus of the cataract and to emulsify these fragments. The technique also uses a surgeon-controlled automated aspiration system to remove the cortical material through a small needle introduced through a very small incision. Phacoemulsification results in a lower incidence of wound related complications, faster healing, and more rapid visual rehabilitation than procedures that require larger incisions. This technique also creates a relatively closed system during both phacoemulsification and aspiration, thereby controlling anterior chamber depth and providing safeguards against positive vitreous pressure and choroidal hemorrhage.

Phacoemulsification complications include posterior capsule tear, zonular dehiscence, iris trauma, hyphaema, vitrous loss, nucleus loss, and bullous keratopathy. Incision problems include short corneal tunnel, wound burn, and wound leak. The ultrasound power necessary for phacoemulsification in routine cataract surgery induces an endothelial cell density loss of 6.3% to 12.8%.Therefore; decreasing ultrasound energy has become a

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CHAPTER ONE

PHYSICS OF ULTRASOUND ENERGY

Phacoemulsification represents a complex interplay of various forms of energy with lens material. The forms of energy used to break up the cataract include (1) a jackhammer effect created as the needle physically impacts the nucleus, (2) an acoustic wave traveling in front of the advancing needle, and (3) cavitational energy, in which microbubbles are stripped out of solution.The fluid wave and microbubbles move away from the phaco tip in conical fashion with annular spread from the direction of the bevel of the needle. The mechanics of phacoemulsification depend on the relationships among ultrasonic energy, anterior chamber irrigation, flow rate, and vacuum extraction of lens material.[1]

The core of the phaco handpiece is a transducer that converts electric energy into mechanical movement of the phaco tip. This is possible due to the piezoelectric effect, whereby some crystals exhibit properties that produce electricity in response to applied mechanical stress. The piezoelectric effect is a reversible process, in that materials exhibiting the direct piezoelectric effect also exhibit the reverse piezoelectric effect the internal generation of a mechanical force (deformation) resulting from an applied electrical field. Applying a high-frequency current induces these crystals to oscillate at a particular frequency. The oscillation is transmitted to the phaco tip via an ultrasonic horn, which also acts as an amplifier, and thus longitudinal backward and forward movement of the phaco needle (stroke) is achieved. This is the traditional longitudinal form of phacoemulsification. Some of the energy applied is dissipated into heat. The frequency at which a material naturally vibrates is called its *resonant frequency*, or the optimal frequency required to obtain the maximum mechanical amplitude and to reduce heat production. The characteristics of stroke are length and frequency. Longitudinal phaco needle movement can reach a maximum of 100 to 120 μm, and the working frequency ranges from 28 to 45 kHz. The stroke frequency is defined by the manufacturer and cannot be modulated by the surgeon. Stroke length can vary linearly with application of the footpedal. Some argue that longer stroke length may generate more heat and corneal damage.[2]

Components of phacoemulsification equipment:

The key components of phacoemulsification equipment are as follows:

- A hand piece containing piezoelectric crystals, and irrigation and aspiration channels.
- Titanium tip attached to the hand piece.
- Pump system.
- Control systems and software for the pump and ultrasound generator.
- Foot pedal.[3]

Phacoemulsification most likely operates by a combination of mechanisms, including direct action of the vibrating tip against tissue and indirect cavitational effects.

Mechanical cutting

This occurs because of the jackhammer effect of the vibrating tip and relies upon direct contact between tip and nucleus. The high acceleration of the tip (up to 50 000 m/s) causes disruption of frictional bonds within the lens material, but because of the direct action of the tip energy it may push the nuclear material away from the tip.[3]

Cavitation

This occurs just ahead of the tip of the phaco probe and results in an area of high temperature and high pressure, causing liquefaction of the nucleus. It occurs because of the development of compression waves caused by the ultrasound that produce microbubbles; these ultimately implode upon themselves, with subsequent release of energy. This energy is dispersed as a high pressure and high temperature wavefront (up to 75 000 psi and 13 000°C, respectively). The determinants of the amount of cavitation are the tip shape, tip mass, and frequency of vibration (lower frequencies are best). Therefore, reducing the internal diameter will increase the mass of the tip for the same overall diameter and therefore increase cavitation for harder nuclei. A side effect of this component of phacoemulsification is the development of free radicals; these may cause endothelial damage. but they may be also absorbed by irrigating solutions that contain free radical scavengers, for example glutathione.[3]

Tip technology and generation of power:

Phacoemulsification tips are made of a titanium alloy and are hollow in the centre. There are a number of different designs with varying degrees of angle of the bevel, curvature of the tip, and internal dimensions. The standard tip is straight, with a 0, 15, 30, or 45° bevel at the end. At its point of attachment to the phaco hand piece there may either be a squared nut or a tapered/smooth end that fits flush with the hand piece. The advantage of this latter design is that turbulent flow over the junction is avoided, and so air bubbles are less likely to come out of solution and enter the eye during surgery. Tips with 45° or 60° angulation are said to be useful for sculpting harder nuclei, but with a large angle the aperture is greater and occlusion is harder to achieve. In contrast, 0° tips occlude very easily and may be useful in chopping techniques where sculpting is minimal. Most surgeons would use a 30–45° bevel. Angled or Kelman tips present a larger frontal area to the nucleus, and therefore there is greater cavitation. They have a curved tip that also allows internal cavitation in the bend to prevent internal occlusion with lens matter. Reducing the internal diameter but maintaining the external dimensions increases the mass of the tip and hence increases cavitation. The “cobra” or flare tip is straight but there is an internal narrowing that causes greater internal cavitation and reduces the risk of blockage. These tips are useful in high vacuum systems in which comparatively large pieces of lens nucleus can become impacted into the tip. If internal occlusion occurs then there may be rapid variations in vacuum pressure, with “fluttering” of the anterior chamber. Ultrasonic vibration is developed in the hand piece by two mechanisms: magnetostrictive or piezoelectric crystals. In the former an electric current is applied to a copper coil to produce the vibration in the crystal. There is a large amount of heat produced and this system is inefficient. In the piezoelectric system power is applied to ceramic crystals to produce the mechanical output. The power is usually limited to 70% of maximum and, as previously mentioned, this is controlled by the foot pedal either in an all or none manner (panel control) or linearly up to the preset maximum (surgeon control). It is usual to be able to record the amount of energy applied. This may simply be the time (t) for which ultrasound was activated, the average power during this period (a), or the full power equivalent time (t × a). It is then possible to calculate the total energy input to the eye (in Joules). The application of phaco power to the tip can be continuous, burst, or pulsed. The latter is particularly useful toward the end of the procedure with small remaining fragments. In the pulsed modality, power (%) is delivered under linear (surgeon) control but there are a fixed series of ultrasound pulses with a predetermined interval and length. For example, a two pulse per second setting generates a 250 ms pulse of ultrasound followed by a 250 ms pause followed by a 250 ms pulse of ultrasound, and so on. This contrasts with burst mode, in which the power (%) is fixed (panel control) and the length of pulse is predetermined (typically 200 ms), but the interval between each pulse is under linear control and decreases as the foot pedal is depressed until continuous power is reached. Burst mode is ideally suited to embedding the tip into the lens during chopping techniques because there is reduced cavitation around the tip. This ensures a tight fit around the phaco probe and firmly stabilises the lens.[3]

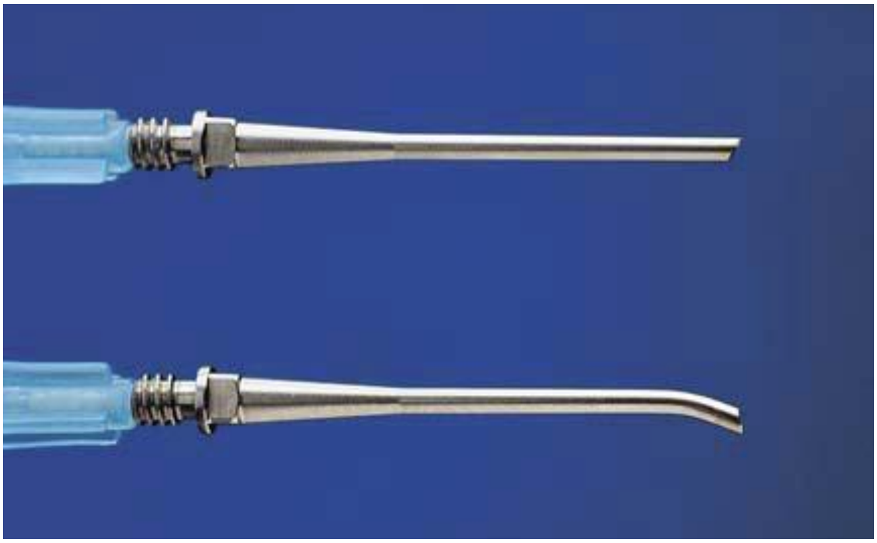

Fig. (1): Kelman and straight phaco tips.[3]

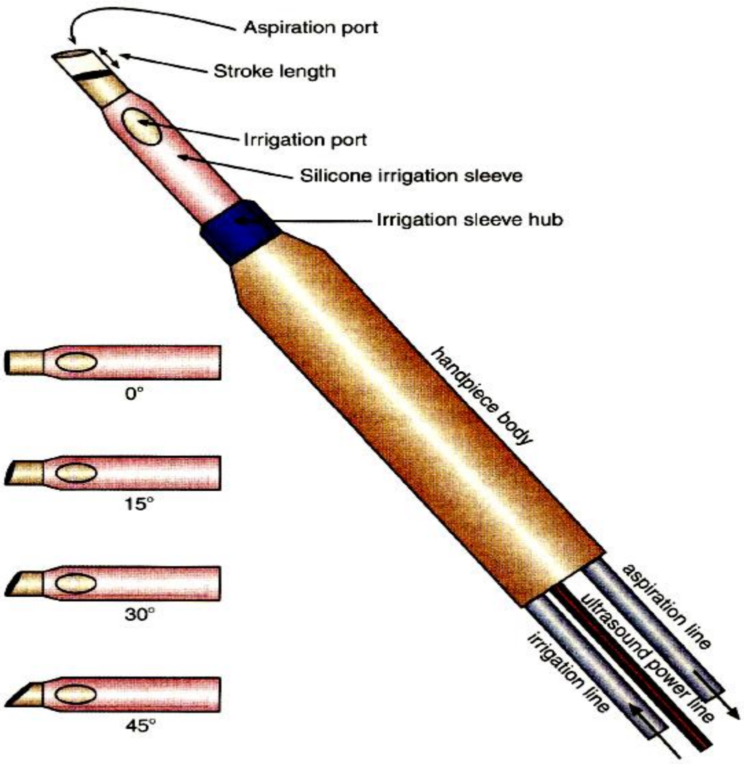

Fig. (2): Parts of phaco handpiece, smaller drawings depict the different tip bevels available.[4]

PHACOEMULSIFICATION: SURGICAL TECHNIQUES

A-Incision planning and construction:

Phacoemulsification is a significant advance in cataract surgery that reduces postoperative inflammation, with early wound stability, resulting in minimal postoperative astigmatism and rapid visual rehabilitation. Most of these advantages are directly attributable to the sutureless small incision. Accordingly, incision construction is a key component of modern cataract surgery. In each of the steps of phacoemulsification, the success of a subsequent step is dependent on that preceding it.[5]

In 1967 Kelman demonstrated that phacoemulsification might allow surgical incisions to be as small as 2–3 mm in width. However,the subsequent widespread introduction and acceptance of intraocular lenses (IOLs) constructed of rigid polymethylmethacrylate necessitated an incision width of approximately 7 mm. The advantage of a small phacoemulsification incision, with low levels of induced astigmatism, was therefore substantially reduced. It has been recognised that if an incision is placed further from the optical axis, then it may be increased in width while remaining astigmatically neutral.[6] The need for a larger incision was therefore partly overcome by the development of posteriorly placed scleral tunnel incisions[7], and innovative astigmatic suture techniques.[8]The advent of lens implants with an optic diameter of around 5 mm allowed these scleral tunnels to be left unsutured, and such incisions have been shown to be extremely strong.[9]The development of foldable lens materials has enabled the initial small phacoemulsification incision to be retained. This has made it possible for a self-sealing incision to be placed more anteriorly, in the clear cornea, without increasing astigmatism or loss of wound stability. Further development in hand piece technology has seen a reduction in phaco tip diameter and hence incision width. Some lenses can be inserted through these incisions that measure less than 3 mm; however, it remains to be seen whether this further reduction in wound size confers a significant refractive advantage.[10]

Incision choice:

The principal decision facing a surgeon is whether to perform a scleral tunnel incision (STI) or clear corneal incision (CCI).