Let’s Talk In Frequencies

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Abstract
Humans as a race tend to restrict their faculties to their perceived areas of expertise or interest. Doctors tend to leave mechanics of phacoprocure to physicists and keep working with improvisation of techniques rather than providing an insight on technology. It is time to revisit the science behind phacoemulsification and stop taking things as they were comprehended decades ago. The frequency range of current phacoemulsification machines is a limiting factor. This article evolves with thought provoking questions supported by encouraging preliminary studies paving the path in a new direction.

Keywords: phacoemulsification, effective phacotime, ultrasonic frequency, viscoelasticity, resonant frequency

Introduction
“If you wish to understand the universe, think of energy, frequency and vibration” Nikola Tesla
Quantum mechanics tells us that everything in this universe is a wave, having a wavelength and frequency at which it resonates. More complex the geometry of an object, more frequencies are required to describe it. This applies to all objects living or non living. The amino acids, fatty acids, pigments, collagen structures all have an intrinsic frequency at which the components resonate. The internal resonant frequency of biological tissues has a wide range due to complex composition. We all know massive oscillatory motion can be imparted to objects on application of resonant frequency waves. This has been exemplified by phenomenon occurring naturally like shattering of wine glass with opera singer’s voice at a particular frequency or falling apart of Tacoma Narrows bridge by a gail storm, as well as experimentally like spectacular electrical phenomenon in Tesla coil. The same, if happens at a molecular or atomic level imparts oscillatory motion to the atoms and causes a phase change. This implies that a solid form becomes more fluid like at a particular frequency.

Phacoemulsification as of Now
Phacoemulsification works on ultrasound based dissolution of lens matter. The piezoelectric crystal imparts a specific frequency vibratory motion to the phaco tip which when interacts with the lens matter in a fluid based environment leads to disintegration and dissolution of the cataractous lens. The ultrasound generating mechanism of the phaco handpiece causes the tip attached to it to vibrate rapidly back and forth. Tip excursion or stroke length is defined as the distance the tip displaces in the longitudinal direction at maximum power. Stroke length varies for different machines and normally ranges from 1.5-3.75 milli-inches. All phaco machines permit the user to alter phaco power and this is usually indicated as a percentage. The frequency of a given handpiece is usually indicated in kilohertz (KHz). The Phacoemulsification needle moves at a frequency of between 35,000 to 45,000 cycles per second (Hz).1 This frequency range is the most efficient for nuclear emulsification. Lower frequencies are less efficient and higher frequencies create excessive heat.

Despite advances in phacoemulsification technology, sight threatening complications related to excessive or inappropriate application of phaco energy still occur.3 Corneal endothelial damage and posterior capsular rupture are two most undesirable complications of cataract surgery. These are related to the amount and time of ultrasonic energy used.3,4 Effective phaco time is time taken to remove cataract if continuous 100% phaco power is used. Lower the effective phaco time, lesser the energy delivered in the eye and thus clearer the cornea with better visual rehabilitation. Surgeons are constantly investigating new techniques to reduce phaco time and power thereby limiting energy expenditure and minimizing trauma during surgery.5

What Have we Failed to Account For?
Phacoemulsification as a procedure was conceptualised and developed by Charles Kelman in 1960s as an ultrasound based emulsification of solid state of matter which can then be aspirated using a fluid based aspiration system. At that time he felt that he was working at the limits of that era’s technology and felt the same would apply in times to come as regards the improvements in the functionality of modern phaco machines.6 The physicists have long debated upon cutting and cavitation effects and their relative roles in phacoemulsification. Stepping up amplitude increased the extent of involvement but also increased the thermal damage. While the engineers worked on reducing thermal damage and increasing efficiency they introduced pulse mode and micropulse mode not realizing that they were actually also working on frequency modulation. This is not only due to the fact that we have forgotten the basic principle behind phacoemulsification but also because the knowledge and technology since the time of development of this technique has faced some limitations.

Concept Of Resonant Frequency
Like all solids the human cataractous lens will have its own
internal resonant frequency. Applying same frequency during phacoemulsification would lead to disintegration of intermolecular bonds and make it easily aspirable. Increasing hardness of cataract is associated with change in chemical and physical properties and should logically require a change in frequency of ultrasound. However different machines, though within the range of 22-50 KHz, use the same frequency ultrasound (inherent to machine) for all grades of cataract and hence end up with higher effective phaco time in hard cataract. The concept of internal resonant frequency if applied can revolutionize the present day phacoemulsification but there is a catch.

The catch:
• We do not know the exact resonant frequencies of cataractous lens
• Presently higher frequency use may be associated with greater heat generation due to piezoelectric effect used to generate oscillations, causing wider area of involvement

The solution:
• Studies to identify resonant frequency of various grades of cataract
• Non thermal high frequency generation -use better modalities of oscillation generation like optoacoustic to get focused effect at high frequencies with no heat production

Striving To Find A Solution
Focus 1: The resonant frequency of a solid matter can be assessed either by studying either the optical properties or physical properties with relevant apparatus OR by subjecting samples to a range of frequencies and analysing the effects.

• Materials exhibiting characteristics that are both solid- and fluid-like are categorized as viscoelastic materials. Most of the biological tissues such as tendons and ligaments are viscoelastic materials. Very often the viscoelastic behavior of these materials is evaluated using methods such as stress-relaxation, quasistatic and dynamic tests. With the dynamic test, it is possible to obtain a full spectrum of information about the viscoelastic properties of a material, but the material has to be characterized at each frequency over a wide range of frequencies. Micromechanical characterization of various tissues has been successfully attempted by Nanoindentation using Atomic Force Microscopy.

The authors performed nanoindentation of few explanted nuclei using AFM to get a rough idea of the viscoelastic properties of cataractous nuclei. Though the microindentation studies are very preliminary but the graphs pave a way for developing a viscoelasticity model and identifying sonic resonance properties. It is important to understand that variations in hydration levels of samples can greatly affect values thus necessitating exacting transport and testing conditions. We await more results for drawing inferences.
• The resonant frequencies can also be identified using optical modalities like Raman spectroscopy. CARS is an excellent tool for examining tissues ex vivo without...
the need for labelling tissue components. The label-free approach enables investigation of tissue structures that are intact and not compromised by labelling protocols.

- At present we haven’t cracked the exact resonant frequency but the current phacomachines vary in frequencies from 22 to 50 KHz. Comparing two different extremes of frequencies for phacoemulsification can give some idea about the more favourable frequency out of the existing options. Unfortunately the unique parameters of individual machines make them essentially incomparable.

However Geuder Megatron allows simultaneous attachment of two different frequency handpieces keeping all the other settings identical thereby allowing to bring out differences on varying the frequency of phacoemulsification.

We conducted a pilot study in 2014 based on analysis of Effective phacofume time (EPT) in cases operated using Geuder Megatron. A total of 12 cases of immature senile cataract were selected and an informed consent was taken. All cases were operated using Megatron S4(Gueder,Heidelberg, Germany) at 400 mm Hg vacuum and 40% power at coolflask mode in Venturi setting. Three cases were operated using 27.5 KHz and three cases of similar grade were operated using 42 KHz. EPT was compared between the two groups. For the next six cases EPT required to emulsify each half of the nucleus with 27.5 KHz versus 42 KHz frequency at same settings of power and vacuum were compared. As the mode of surgery differed in first 6 and next 6 cases they were analyzed separately.

In first six cases the two groups were matched for LOCS III grade of cataract 6.13 +/- 0.7 (27.5 KHz group) and 5.96 +/- 0.95 (42 KHz group) p = 0.82. The effective phaco time was 5.0 (27.5 KHz group) and 3.9 (42 KHz group). In next six cases the effective phaco time in seconds was 3.14 +/- 1.24 (using 27.5 KHz) and 1.26 +/- 0.71 (using 42 KHz). This was significantly higher in 27.5 KHz group (p=0.012) The results of this study suggested that probably the ultrasound frequency at which the phaconeedle vibrates increases or decreases its cutting efficiency depending upon resonant frequency of the matter it is emulsifying. It provides an impetus to study the extreme ranges as a part of a randomised controlled trial.

Focus 2: Nonthermal frequency generation

The current phacoemulsification utilizes piezoelectric crystal based generation of ultrasound. This leads to heat production at higher frequencies resulting in a wide area of focus of the waves that is likely to leave an effect on all the ocular tissues within a certain distance from the tip.

One of the promising modalities is the optoacoustic high frequency ultrasound generation. Hyounget al demonstrated a new optical approach to generate high-frequency (>15 MHz) and high-amplitude focused ultrasound, which can be used for non-invasive ultrasound therapy. A nano-composite film of carbon nanotubes (CNTs) and elastomeric polymer is formed on concave lenses, and used as an efficient optoacoustic source due to the high optical absorption of the CNTs and rapid heat transfer to the polymer upon excitation by pulsed laser irradiation. The CNT-coated lenses can generate unprecedented optoacoustic pressures of >50 MPa in peak positive on a tight focal spot of 75 mm in lateral and 400 mm in axial width. This pressure amplitude is remarkably high in this frequency regime, producing pronounced shock effects and non-thermal pulsed cavitation at the focal zone. Their study demonstrated that the optoacoustic lens can be used for micro-scale ultrasonic fragmentation of solid materials and a single-cell surgery in terms of removing the cells from substrates and neighboring cells.

Conclusion

Working with existing limitations a randomised controlled trial to compare the effective phaco time and endothelial cell losses using different frequencies in same machine with identical parameters for phacoemulsification can give some idea about selective role of different frequencies.

As the ultimate goal we recommend redefining the optimal frequency for phacoemulsification to match internal resonant frequency of lens matter to achieve targeted emulsification using non thermal ultrasound generation

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