The fluidics &physics of Phacoemulsification

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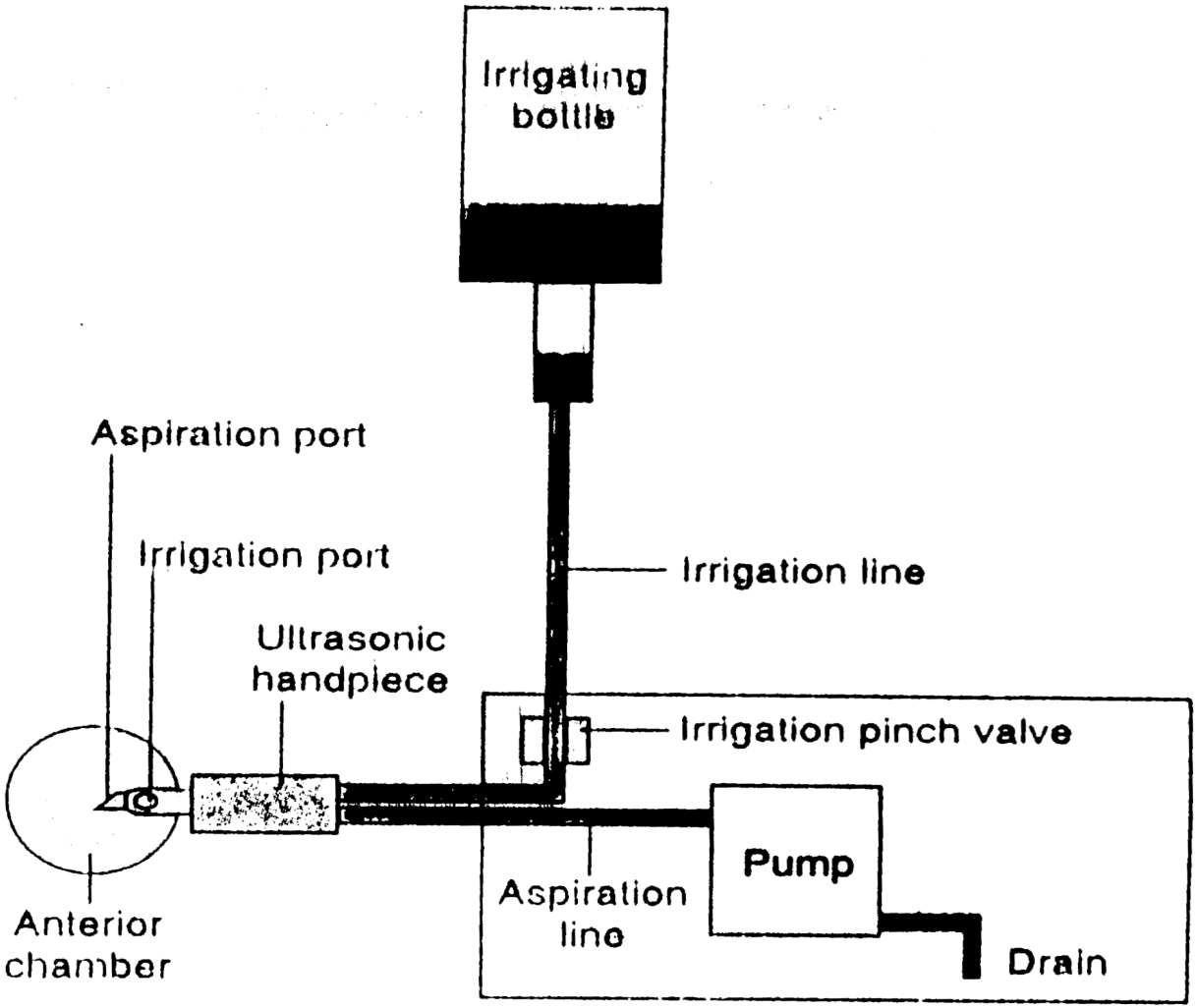
Basic facts

- Phacoemulsification (phaco) is composed of two basic elements : First, ultrasound, Second, a fluidic circuit
- Ultrasound power, which is produced most often by a piezoelectric crystal oscillating between approximately 20 000 and 60 000 times a second for most machines.
- Circuit is supplied by an elevated irrigating bottle which supplies both the fluid volume and pressure to maintain the chamber hydrodynamically and hydrostatically

Basic facts

- Anterior chamber pressure is directly proportional to the height of the bottle
- The fluid circuit is regulated by a pump, which clears the chamber of emulsate and also attract nuclear fragments when the phaco tip is not occluded .
- When a fragment completely occludes the tip, the pump pro holding power, measured in m (vacuum)


Irrigating bottle
Aspiration port
Irrigation port
Irrigation line
Ultrasonic handpiece
Irrigation pinch valve
Pump
Aspiration line
Drain
Anterior chamber

Understanding the logic behind setting the parameters

- ultrasound power
- Vacuum
- flow
- bottle height.

Discussions of flow and vacuum in phaco surgery must begin with a categorization of the various pumps, which are utilized.

The two basic types of Pump in Phaco

The flow pump.
The peristaltic pump is the most commonly employed in current Phaco machines

The vacuum pump.
The Venturi pump is the most commonly employed in current vitrectomy machines

Parameters

In the flow pumps:

- **Flow rate**, also known as aspiration flow rate, is measured in milliliters per minute and is directly proportional to time rotational speed of the pump head, measured in revolutions per minute. In simple non medical words: it is the speed of work (turn over) inside the eye.

The irrigation bottle's drip, reflects the activity in the anterior chamber.

Flow rate decreases with increasing tip occlusion (i.e. decreased effective aspiration port surface area) until flow ceases completely with complete tip occlu

Parameters

In the flow pumps:

- **Rise time**, it's the amount of time required to reach a given vacuum preset, assuming complete tip occlusion, is defined as rise time.

Rise time is inversely proportional to the rotational speed of the pump head. When the flow rate is cut in half (from 40 to 20 ml/mm), the rise time is doubled (from 1 to 2 s).

A longer rise time gives the surgeon more time to react in cases of inadvertent incarceration of iris, capsule, or other unwanted material.

Parameters

In the vacuum pumps:

- **No Rise time**, No occlusion is required to reach a given vacuum preset, thus vacuum is present all the time.

Some pumps allow the surgeon to set a time delay for full commanded vacuum build-up, any subsequent engagement of material will be exposed to a typically rapid vacuum pump rise time.

Alternatively, direct linear control of vacuum is another solution, the surgeon can approach material with safer lower vacuum levels and increase them when needed..


I'm not done
yet...

Ultrasound

- One theory explains the acoustic breakdown of lenticular material as a result of sonic wave propagation through the fluid medium.
- Another theory concerns the micro cavitation bubbles produced at the distal phaco tip; the implosion of these bubbles produces brief instances of intense heat and pressure which are thought to emulsify adjacent lens material.
- Another potential mechanism of action is via the tip's axial oscillations through its stroke length; this resultant jackhammer effect is thought to mechanically break down lens material.

Phaco tips

- One basic design parameter is the distal bevel angle, which is most commonly 0, 15, 30 and 45 degree.
- The sharper 45 angle is thought to carve dense nuclei more efficiently, to the extent that the jackhammer mechanism of action is valid, whereas the 0 tip would be more efficient to the extent that the micro cavitation theory is valid (the 0 tip has more frontal surface area perpendicular to the axis of oscillation, thereby producing more cavitation bubbles).
- Also we have the straight tip and the Kelmann or bent tip

Sculpting

- In case of increased resistive load caused by the increased tip engagement, the surgeon must compensate by either:

1. increasing the phaco power or
2. decreasing the linear speed of sculpting.

Either solution is satisfactory, as long as the interrelationship among the above variables is respected so as to facilitate the needle carving through the nucleus instead of pushing it and stressing the zonules or capsule.

Parameters

Adjusting the Parameters

Phaco 1 stage:

- A low vacuum is adequate for sculpting. Although 0 mm-Hg is advocated by some surgeons, a slightly higher level of 15-30 mm-Hg still provides significant safety
- Once the nucleus is debulked or grooved, it then needs manipulation such as rotation or cracking. These maneuvers should be performed in pedal position 1, so that the chamber will be pressurized without any pump action, which might inadvertently aspirate unwanted material

Adjusting the Parameters

Phaco 2 stage

- Once the nucleus is debulked or cracked into fragments, machine parameters need to adapt to the needs of emulsifying these fragments. Ultrasound power requirements are lower at this stage relative to sculpting, because of the increased efficiency of Phaco-aspiration with complete or almost complete tip occlusion
- 26-ml/min-flow rate and 200-mmHg vacuums are reasonable baseline values for beginners, these parameters should ideally be linearly titrated intraoperative to a given ultrasound level and nuclear density.
- However, higher vacuum levels of 250-400 mmHg can be used advantageously to grip and manipulate the nucleus.
- The smaller the tip's bore width, the higher the vacuum can be raised.

Surge

- Surge, occurs when an occluded fragment is held by high vacuum and is then abruptly aspirated (i.e. with a burst of ultrasound); fluid tends to rush into the tip to equilibrate the built-up vacuum in the aspiration line, with potentially, consequent collapse of the anterior chamber.
- Fluidic circuits are engineered with minimal compliance, which will still allow adequate ergonomic manipulation of the tubing as well as functioning of the pump mechanism
- Small-bore aspiration line tubing, similar to that of the Micro Flow needle, provides increased fluidic resistance, which obtunds surge.
- Some Surgical Designs machine incorporates a second, higher irrigating bottle, or a pumped bottle, whose fluidic circuit is engaged upon detection of a surge.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Take home messages

- Modern phaco machines offer unprecedented levels of control and safety.
- In order to fully explore these values, a good understanding of the principles by which the machines operate is essential; in particular, the surgeon must appropriately adjust flow rate, vacuum, ultrasound power and bottle height as necessary for a given patient and for a given stage in the operation.
- This attention, coupled with meticulous technique designed to optimize the machine's performance, will result in the safest, most efficient ph surgery.




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Thank you

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